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

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Restoring Forest Spatial Pattern**

**Implementation Guide**

**Version 3.3 - October 2016**



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Version 3.3 - October 2016

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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. Since its release in 2013, ICO has undergone a lot of development and improvement. In the third version of the guide we have included these important advancements:

- Reference data from 4 regions is now available to assist in developing targets for clump sizes.
- We developed an Android app to make marking and implementation easier.
- Innovative implementation approaches developed by a number of silviculturists.
- We developed a desktop application to use with monitoring data to assess spatial pattern.

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). Finally, the ICO method is still evolving, and this document will be updated again. Comments and feedback are welcome!

This guide is organized into stand-alone chapters. Managers should read and use chapters as they find useful to their own needs.

## **Acknowledgements**

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**The ICO Android APP, desktop monitoring application, user’s guides, and other ICO documents can be downloaded at:**

<https://www.dropbox.com/sh/4pb5qpbni32dpwt/AACATRPixTM4cBJ28yNJsYYa?dl=0>

**Contents**

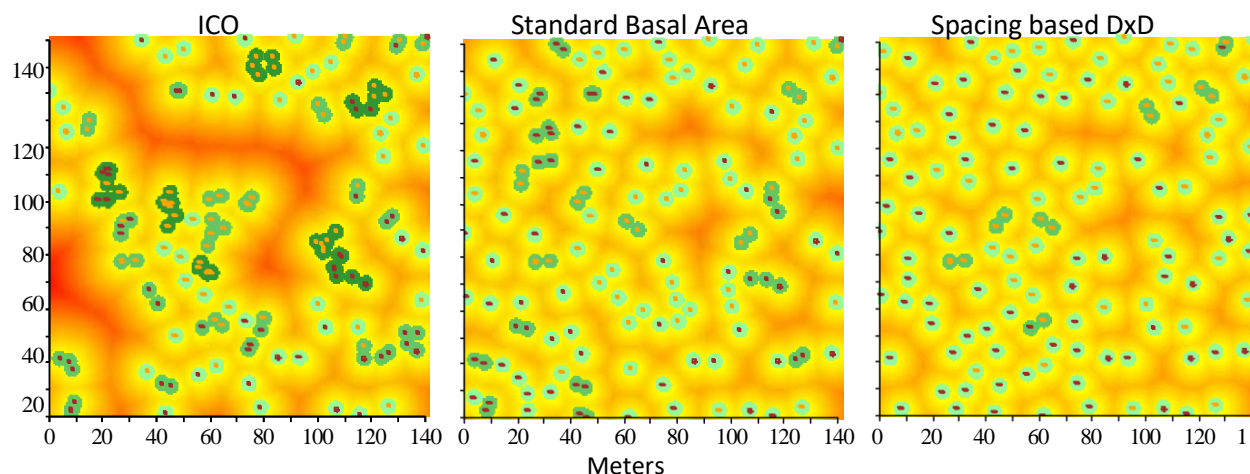
- I. Introduction ..... 5
- II. Assessing Whether the ICO Approach is Appropriate for Your Stand ..... 7
- III. Prescription and Marking Guide Development..... 8
  - 1. Identify skips and other special treatment areas ..... 8
  - 2. Consider the need for openings..... 8
  - 3. Determine the stand average density target: ..... 11
  - 4. Determine the appropriate distance to define clumps ..... 11
  - 5. Obtain targets for clump proportions ..... 12
  - 6. Select target clump proportions for your stand ..... 14
  - 7. Generate clump targets for the whole unit ..... 15
  - 8. Combine clump and opening targets with leave tree criteria into marking guidelines ..... 16
- IV. Implementation..... 17
  - 1. Layout and marking..... 17
  - 2. Tracking during marking ..... 19
  - 3. Cruising & Designation by Prescription (DxP) ..... 21
- V. Monitoring using a “QuickMap ” ..... 23
  - 1. Determine the inter-tree distance to define clumps ..... 23
  - 2. Determine lower diameter cutoff for sampling ..... 24
  - 3. Define sampling area within stand..... 24
  - 4. Identify and record clump information ..... 25
  - 5. GPS centerpoint of clump..... 26
  - 6. Analysis ..... 27
- VI. Obtaining Reference Stem Maps and Quantifying Pattern..... 28
  - 1. Identifying appropriate sources of reference spatial data..... 29
  - 2. Site selection criteria for new reference stem maps ..... 30
  - 3. Installing stem map plots to acquire new spatial reference data ..... 31
  - 4. Quantifying within-stand patterns: individual trees and the clump size distribution ..... 33
  - 5. Quantifying within-stand patterns: targets for large openings ..... 37
- VII. Links to Companion Tools and Documents ..... 38
- VIII. References..... 39
- Appendix 1: Visual ICO Guide: From the Fremont-Winema National Forest (Andrew Spencer)..... 42
- ..... 42

## 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. Variable spatial patterns affect a variety of functions such as fire behavior, understory plant diversity, tree regeneration, insect spread, nutrient cycling, and snow retention (Larson and Churchill 2013). 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 (Allen et al. 2002, North et al. 2009, Stephens et al. 2010, Franklin and Johnson 2012, Reynolds et al. 2013, Hessburg et al 2015, Stine et al. 2014). In addition, there is increasing recognition that strict basal area or spacing-based prescriptions do not achieve this goal (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 wide variation in basal area as individual trees and tree clumps are readily visualized. Another major difference between ICO prescriptions and spacing or basal area prescription approaches is that there is not a per acre average density to shoot for on every acre. Instead, the goal is to retain a specified number of individual trees and clumps across the entire unit. This provides flexibility to vary density and clumping across a unit and tailor it to site conditions.

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). In this guide, we provide summary reference data for dry forests from four regions within Oregon and Washington. Regional reference datasets exist for many other areas in the interior western US (Larson and Churchill 2012). Obtaining the necessary reference data to implement the ICO method is covered in detail in section VI. Reference stem maps from a particular project area are not mandatory to implement the method, however. If reference data does not exist for your area and is not feasible to collect, professional judgment can be used to set spatial targets based on data from other regions and site conditions.

The ICO approach has been implemented on a number of public and private ownerships and the method is fully operational. Many sales have been marked, sold, and cut, and more are currently in the pipeline. 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, Hessburg et al. 2015). This guide is organized into stand-alone chapters. Managers and stakeholders can read chapters as they work through different phases of a project.



## **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. Similarly, 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. 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:

#### **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).

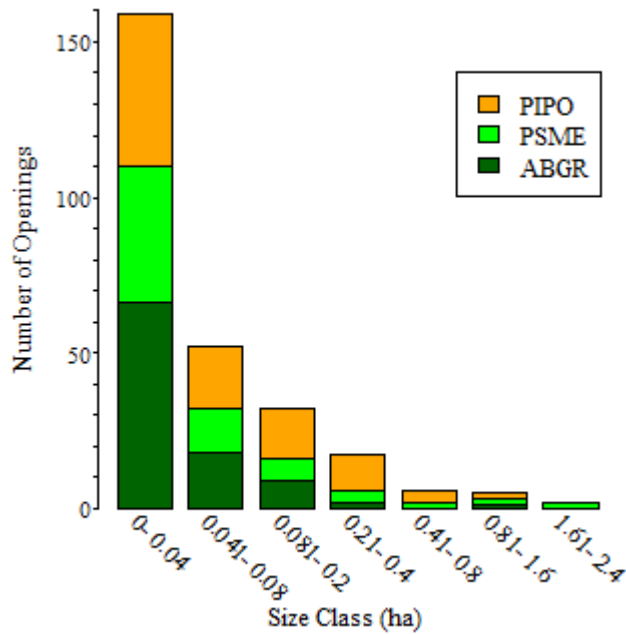
In general, larger special treatment areas located on distinct biophysical microsites (e.g. riparian buffers) should be considered separate from the general thinning area and not count towards clump totals for stands. Smaller special treatment areas that are widely distributed in the stand can be integrated 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, smaller areas of aspen release).

#### **2. Consider the need for openings**

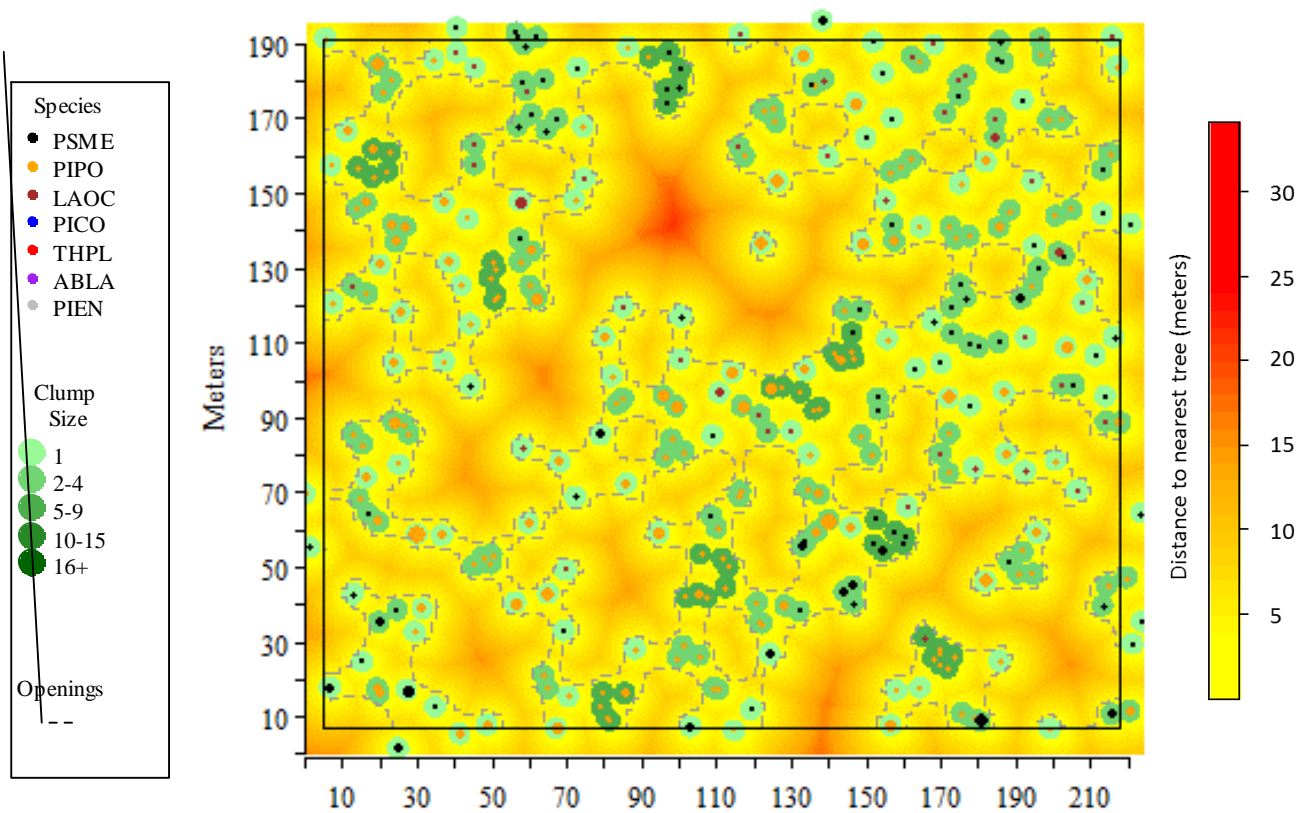
Openings are a critical component of the structure, pattern, and function of dry forests. Unlike high canopy cover forests where gaps are readily identifiable, however, openings in low density dry forests are very difficult to delineate and quantify. The number and size of openings in historical dry forests is directly related to density (trees per acre) and the degree of clumping (Churchill 2013). On all but

the lowest density (<30 TPA) historical plots we have reconstructed, almost all openings are less than 1/2 acre in size with some up to 1 acre (Churchill et al. in press). Most openings are small (< 1/10th ac), and opening size distributions exponentially decrease (Fig. 3). On plots with less than about 30 TPA, openings often fuse together into larger openings (2-5+ acres) (Fig 4). However, openings in dry forests are sinuous and amorphous in shape (Fig. 1 & 4) and are rarely circular gaps. Thus thinking about opening size in terms of width and linear distance is easier to implement than area. Even the densest historical plots have some openings that are 60' across. The largest openings found are generally 165' across. Through trial and error, we have developed the following methodology to deal with the opening aspect of ICO:

- Small to medium sized openings (<1/2 acre): As long as marking crews are comfortable leaving areas without leave trees and are instructed to occasionally walk for 50- 80' without retaining a leave tree, specific targets for small and medium openings are not necessary. We have found that these sizes of openings will be created in the course of achieving a particular density and clumping level, and that the resulting openings are within the range of reference conditions.
- Large openings (>1/2 acre): In general, we have found that specific instructions and targets are needed to achieve larger openings in treatments. Targets for the number and size of large openings should be based on concrete functional objectives (e.g. habitat, forest health issues, regeneration needs), and are most appropriate for low density treatments (<~30 TPA). Ideally, silviculturists or other specialists can identify locations for marking crews. Linear, sinuous openings can be laid out prior to general marking with a flag line. Marking crews can then be instructed to space off of the flag line for a certain width (e.g. remove most trees within 30-80' of the flag line). Landings will result in large openings as well.
- Locating openings: Topography, soils, current vegetation conditions, insect or pathogen issues, and an ecological understanding of the site should guide the location of openings as much as possible, especially for larger openings. Clear guidelines for crews and field training is needed to ensure that openings are put in the most favorable locations to achieve the desired objectives. Prescribed fire can also create and expand openings if burn conditions allow for mortality of small to large sized trees.



**Figure 3:** Number of large openings by size class and potential vegetation series for 14 historical reference plots on the Malheur National Forest (Churchill et al. in press). The total area of the plots is 142 acres.



**Figure 4:** An example of openings from a reconstructed 10-acre plot from the Colville National Forest on a warm-dry Douglas-fir site. The historical TPA is estimated to be 32. The largest opening is 2.7 acres in size.

**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 conditions, and management objectives. Expected mortality from prescribed fire should be factored in. Stand average targets can come from historical reference stands, plant association based stocking guides, 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 accounted in setting 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:  $TPA = BA / ((QMD)^2 * 0.005454)$ .

		Basal Area (ft <sup>2</sup> /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 dry forests dominated by ponderosa pine and Douglas-fir. 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. 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' typically still allows for some clumping and formation of contiguous patches of canopy over time. Finally, in denser, moist forests a smaller clump distance based on criterial other than crown interlock may be more appropriate.



**Figure 5:** Photos of four 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+ trees) 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 or 5 bins (Fig 5): 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 difficulty leaving the upper end of the size range (e.g. an 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 ideally be grouped into different levels of clumping (low, medium, high) (Table 2) to facilitate translation to marking guidelines. 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 60% of the trees in moderate to large clumps, and as few as 13% as individuals. These proportions will vary based on the clump distance (inter-tree distance) being used. At longer inter-tree distances, more trees are in clumps.

**Table 2** Summary of clump proportions from 4 historical reference datasets. Values are the percent of trees in each clump size. The datasets include 10 plots in the Eastern Cascades of Washington, 12 plots on the western half of the Colville National Forest in North-Central Washington, 14 plots on the Malheur National Forest in North Central Oregon, and 12 plots on Winema National Forest in South-Central Oregon. Plots range from 7 to 12 acres in size and were reconstructed to pre-fire suppression conditions (1890 or 1880). Plots represent a range of site conditions from dry ponderosa pine plant associations to dry Douglas-fir, grand fir, white fir, and sub-alpine fir associations. Contact the authors for more detailed information for each area.

Clumping Level	Clump Distance	Clump (Bin) Size (# of trees)					TPA
		1	2-4	5-9	10-15	16-20+	
<b>Eastern Washington Cascades</b>							
High	20' – 6m	0.22	0.38	0.24	0.10	0.06	40-60+
Mod	20' – 6m	0.30	0.42	0.11	0.17		25-40
Low	20' – 6m	0.45	0.43	0.12			15-25
<b>Western Colville National Forest</b>							
High	20' – 6m	0.13	0.27	0.28	0.13	0.19	40-60+
Mod	20' – 6m	0.21	0.35	0.32	0.09	0.04	25-40
Low	20' – 6m	0.38	0.44	0.14	0.04		15-25
<b>Malheur National Forest</b>							
High	20' – 6m	0.15	0.25	0.25	0.1	0.25	40-60+
Mod	20' – 6m	0.2	0.35	0.35	0.08	0.02	25-40
Low	20' – 6m	0.35	0.45	0.15	0.05		15-25
<b>Winema National Forest</b>							
High	20' – 6m	0.2	0.3	0.2	0.15	0.15	40-60+
Mod	20' – 6m	0.25	0.35	0.2	0.1	0.1	25-40
Low	20' – 6m	0.3	0.35	0.25	0.1		15-25

## 6. Select target clump proportions for your stand

To set targets for individual stands, each stand must be matched with a clumping level from an appropriate set of reference stands. For example, using Table 2, select a low, moderate or high clumping target for a stand. To set targets for individual stands, consider the following:

- Align clumping levels with your target density. Historically, low density stands (20-40 TPA) had low or moderate clump levels while higher density stands had moderate to high levels. Site factors such as productivity, plant association, soils, forest health considerations, and anticipated climate change should be factored into the target density, which will then influence the clumping target you select.

- Assess clumping levels of old trees and suitable young trees: The clump targets should accommodate retaining existing old trees (Fig. 6). If there are not enough younger trees in clumps that meet the desired leave tree criteria, prescribing high clumping levels can result in retention of excessive numbers of trees with poor vigor. Some inferior trees often need to be retained to make up larger clumps, however.



**Figure 6:** High density and clumping of old trees in on the Fremont-Winema National Forest.

- Factor in prescribed fire. Some clumps can be intentionally killed with prescribed fire to create snag patches and openings.
- Factor in wildlife habitat requirements and visual considerations. Larger clumps can provide cover for different species and break up sighting distances.
- Factor in no-cut buffers or larger skips (~0.5+ acres) that will be retained within the unit or on unit edges. These dense leave areas will provide many of the functions of large or very large clumps. However, keep in mind that the historical clumping levels are from 7-12 acre plots, indicating that clumps were distributed across stands and not packed into riparian areas or other microsites.
- Vary pattern among units. Prescribing different clumping levels for units across a larger project area will avoid creating a similar fine scale pattern across large areas. Treatments that only achieve one end of the historical envelope (e.g. the more uniform end) will not create the larger scale variability associated with historical forests.



### 7. Generate clump targets for the whole unit

Using your target TPA and selected target clump proportions, follow the steps below to generate clump targets for the treatment unit (See table 3 for an example). An Excel based prescription worksheet is available to assist with this step (see section VII for links). The ICO app also performs these calculations.

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 by 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.
3. Multiply the clump per acre targets by the total stand acreage to get clump targets for the whole unit (row 4 by 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 exist in the future and hedge against higher anticipated rates of mortality in large clumps vs. individual trees. As clumps self-thin over time, they will progressively move down in clump size.

It is important to recognize that the goal of ICO prescriptions is to retain a specified number of individual trees and clumps across the entire unit, not on every acre. This provides flexibility to vary density and clumping across a unit and tailor marking to site conditions. Some areas on shallow soils for example may be quite open, while denser patches are retained in more productive areas. Incorporating guidelines that encourage crews to integrate topographic and soil conditions into locations for openings and moderate to large clumps will help crews tailor marking to site conditions.

**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. Combine clump and opening targets with leave tree criteria into marking guidelines

ICO prescriptions follow the same principles for leave tree selection as typical dry forest restoration or fuel reduction prescriptions. This includes retaining old, pre-settlement trees, favoring fire tolerant species, retaining larger trees, selecting vigorous trees with healthy crowns, and retaining some green wildlife trees (Box 1). The only difference in ICO prescriptions is that a few smaller diameter, lower vigor trees often need to be retained to form larger clumps. These often become snags over time. Diameter based criteria from uneven-aged management approaches can also be incorporated (e.g. BDq method).

### **Box 1: Sample Marking Guidelines from ICO method**

#### **Density & Pattern:**

- Leave an average of 40 TPA over the 20-ac unit. Ignore all trees <5" DBH. Across unit retain:
  - ➔ 200 individual trees. These are trees with no neighbors within 20'.
  - ➔ 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).
- Preferentially leave large & super clumps in swales and on north facing side of riparian area, where good leave tree candidates exist. Some clumps can be left close together.
- To create small openings (<1/2 acre) occasionally walk for 40-80' without retaining a leave tree in coordination with other crew members. Select locations with poor vigor 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 some vigorous trees
- Favor ponderosa pine
- Thin from below removing mostly trees <21" with poor crowns (<35% live crown ratio). Retain occasional mid and small trees as individuals (>45 LCR) or to make up clumps.
- Retain 2-5 live wildlife trees per acre: trees with forks, broken tops, or large platforms.

#### **Skips and Openings within 20-acre General Thin Area:**

- Create 2 large openings: These should be ~0.75 – 1 acre and wavy. Focus on expanding existing root rot pockets. Retain old trees within opening and 1-2 larger young trees.
- 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.
- Snags/Down wood skips: Protect snags > 20 inches with a no-cut buffer (~30' radius).
- Visual and Regeneration skips: Leave 4-5 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)**

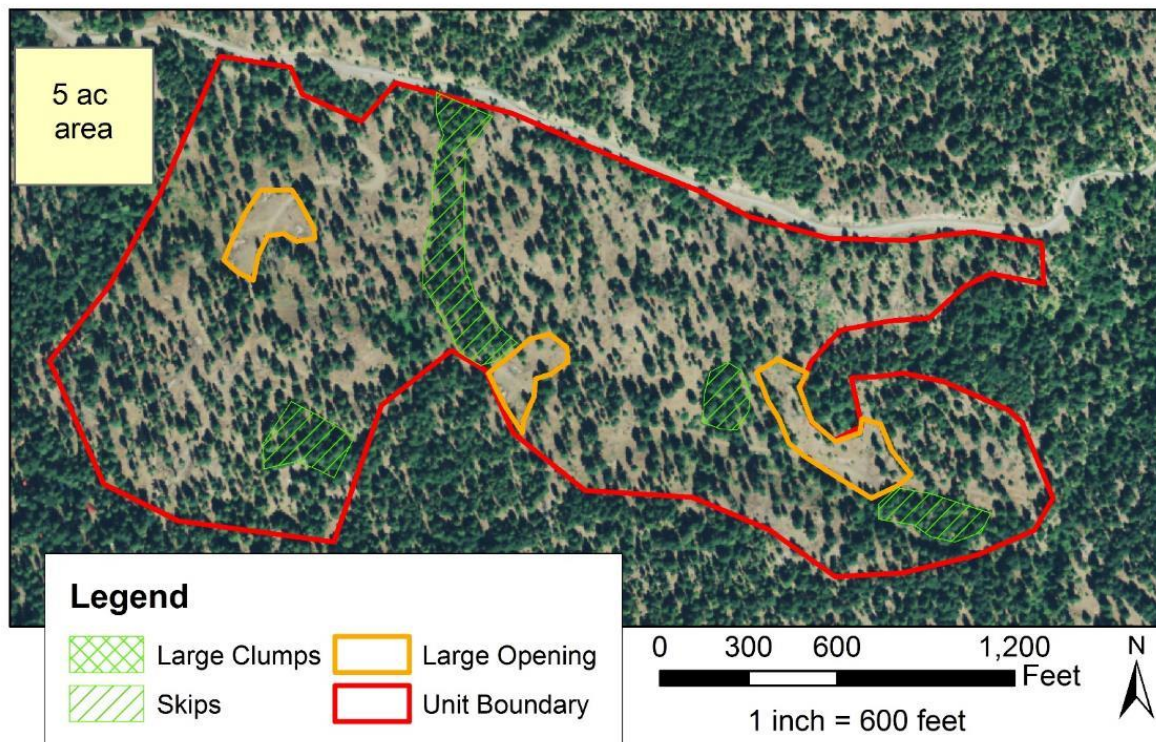
- Riparian buffers: Layout 50' no-cut buffers on streams and seeps in unit. Use wavy boundaries to work with topography and include some multistory, complex patches. These buffers are not part of the 20-acre unit and do not count towards clump targets

## **IV. Implementation**

We have found that marking crews can learn and implement ICO marking effectively within 2-4 days, especially if training is provided. Once markers adjust to conceptualizing forest structure in terms of individuals and clumps, they often find it to be an intuitive method. ICO has been done by contract marking crews and with Designation by Prescription (DxP). Also, some silviculturists and layout personnel have developed hybrid approaches that use basal area targets along with clump targets. Below we address three key aspects of implementation:

### **1. Layout and marking**

We recommend laying out larger special treatment areas (skips and large openings), especially those with unique, biologically important features, prior to the general marking (Fig. 7). 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 National Forest 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 soil factors and disturbance processes.



**Figure 7:** Example of skips and large openings that were laid out prior to general marking.

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 unit, or sections of the unit. It is critical that markers work with existing stand conditions, topographic and soil factors, 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. Trees per acre and basal area can vary widely across a unit. The goal is not to get the exact number of clumps on every acre, but to ensure that a clump/opening pattern is created.

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

- Where high numbers of old trees exist, the clump targets are often met with the old trees.
- 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.
- Consider what you have already marked and what sizes of clumps are deficient or in excess.
- Look ahead to see what opportunities for clumps of different sizes exist.
- 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.
- 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.
- 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.
- Intentionally leave small openings (<~1/3<sup>rd</sup> 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. The crew gets real time feedback on how they are progressing towards clump targets as well as overall density targets. For stands over 20-30 acres, we recommended breaking the stand into 30-60 acre sub-units for marking so that marking crews can track their clump totals within a reasonable amount of area.

There are several methods that crews have developed for tracking:

- A single person tracks clump retention: 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 will inform whether basal area targets are being met. An experienced marker can tally and mark at the same time.
- Each person in the crew carries a clicker and is responsible for tracking one of the clump size bins. For example, when a crew member yells out “moderate clump”, the person responsible for moderate clumps does a click. The crew periodically checks on each clump size relative to how much of the unit they have covered.
- Each person in the marking crew carries 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.
- 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 used in conjunction with clump tracking. Check plots can help markers adjust their “eye” as to different density and clump targets.



**Figure 8:** Marking out clumps and real time tallying of clump totals. Note that in this case, a 4 tree clump is being thinned to a 2 tree clump. The 4 tree clump could have been left, or just the tree on the right retained to create an individual. Cut tree marking is being used with 3P cruising.

- ICO-Mark tablet-based app: To assist with ICO marking, we have developed an Android app (**Box 2**) to use with tablets and GPS in the field. The app allows users to enter density and clumping targets, easily track progress, and export results to a csv or shapefile. It also has mapping functionality that displays unit boundaries, skips & gaps, clump locations, user location, and “tracks”. Instructions for the app are in the users guide that accompanies the app. See section VII (page 38) for link to download.

### Box 2: ICO-Mark Tablet App for tracking clumps during marking

**ICO-Mark** is a tablet- and phone-based application (app) developed for forest managers and forestry field crews to spatially monitor and map forest structure. ICO Mark relies on the Individuals-Clumps-Openings approach to characterizing dry forest spatial patterning, where forests are composed of varying proportions and sizes of individual trees, clumps of trees, and treeless openings. ICO Mark allows users to track individual trees and clumps for both marking pre-harvest, and for monitoring conditions post-harvest. See page 38 for a link to download.



*Example of an active tally sheet in ICO-Mark App*

Saving screenshot...

← Tally

1		4		27		6		# trees DBH	
1	23.0	4	26.0	27	9	24.0	6	12	30.0
1	36.0	2	35.0	28	5	11.0	7	12	23.0
1	26.0	2	32.0	29	9	24.0	8	10	14.0
1	32.0	2	15.0	30	6	20.0	9	13	17.0
1	29.0	2	38.0	31	8	14.0	10	10	13.0
1	12.0	4	17.0	32	5	31.0	11	10	14.0
1	29.0	3	22.0	33	9	18.0	12	10	14.0
1	34.0	2	30.0	34	5	16.0	13	14	17.0
1		2-4		5-9		10-14		15-30+	
#	228 / 465	#	117 / 140	#	34 / 43	#	13 / 19	#	3 / 10
%	0.25 / 0.2	%	0.31 / 0.3	%	0.23 / 0.2	%	0.16 / 0.15	%	0.06 / 0.15

Tracking is also real time implementation monitoring, especially if the app is used. Crews will know how they did relative to the density and clumping targets 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 builds trust in the ability of the agency to implement restoration prescriptions.

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. In addition to the APP, sample tracking paper datasheets are available; see section VI. Once crews are familiar with the ICO method, we have found that marking ICO treatments takes the same amount of time as standard basal area marking. Markers generally appreciate the quantitative targets for pattern.

Finally, it is critical to remember to work with the site and the forest and to not 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, however, bias for or against clumping may exist in the crew.

### 3. Cruising & Designation by Prescription (DxP)

Most ICO sales have been marked, cruised, and sold using standard contracting mechanisms. For cut tree marking, 3P 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, leave tree marking and standard variable radius plot cruising post marking can also work well and offers easier tracking during marking. Due to the higher variability, more plots are generally necessary.

As the need to treat more acres with fewer implementation staff has grown, ICO prescriptions have been done using a DxP approach. ICO prescription with the full range of clump targets can be used. Another approach has been to use a basal area or trees per acre target for average density and then specify targets for medium and large clumps only, as well as large openings. By emphasizing species and tree condition in leave tree criteria over strict spacing, small clumps generally result without a specific target; hence the need to only specify medium and large clumps. Andrew Spencer from the Fremont-Winema National Forest created an excellent visual guide for an ICO DxP sale. An example is provided in **Appendix 1**.

Contract compliance for DxP can be done through standard TPA or basal area compliance plots for density, combined with requiring the contractor to GPS the location of the medium and large clumps, and large openings. A smart phone or higher grade GPS can be used for GPSing clumps. The sale administrator can then spot check the locations of clumps and large openings with their own tablet or phone based mapping app (e.g. Avenza PDF maps). Alternatively, the contractor can use the Android ICO Mark app for tracking and then provide the sale administrator with the output (coordinates of all clumps), which can then be spot checked. A DxP ICO prescription could also be implemented by an experienced machine operator, particularly in a young, simplified stand. Similar contract compliance mechanisms could be used.

A DxP approach requires a cruise prior to marking of the stand by the purchaser. This can be done in two 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 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 clumps across plots.



## **V. Monitoring using a “QuickMap ”**

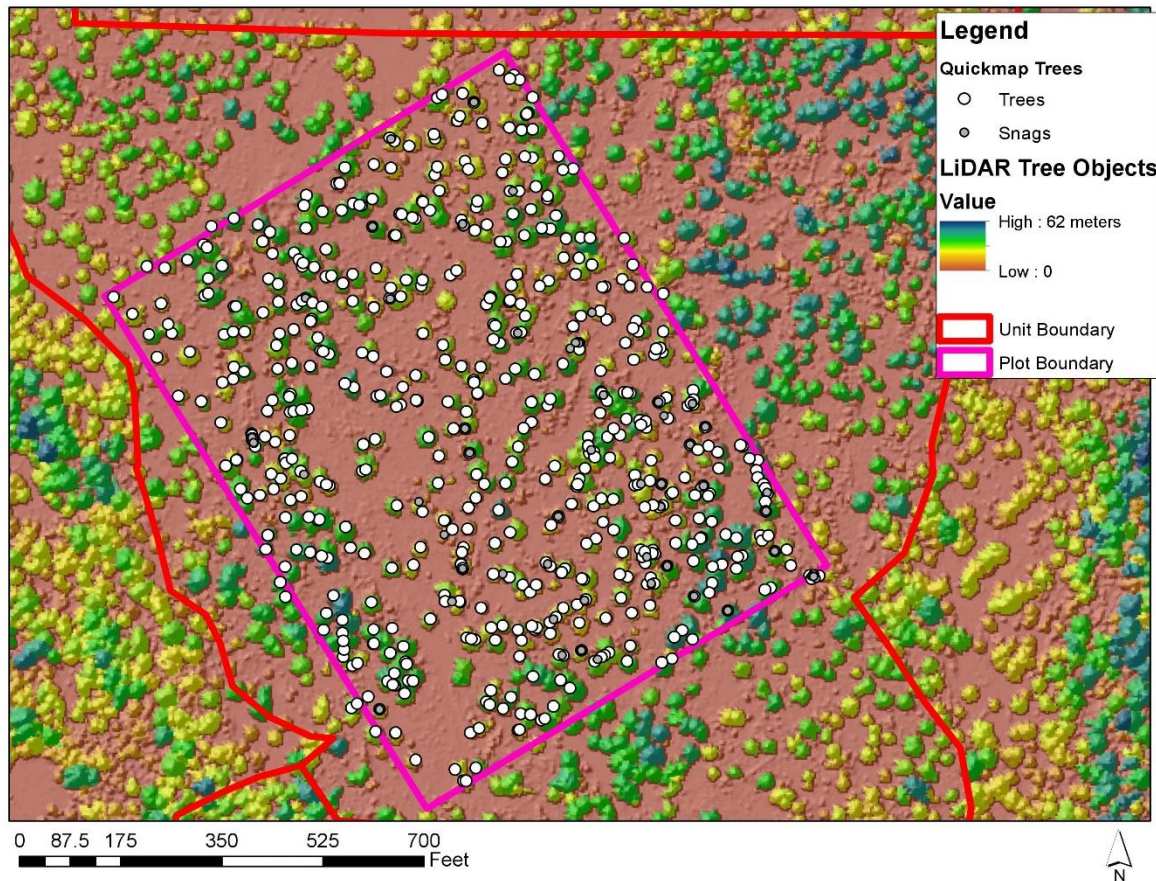
The ICO approach can be used to quantify and monitor the patterns and structural changes created by any treatment, whether the ICO method or another approach was used to develop the prescription. Spatial and structural metrics generated from the monitoring data can be used to objectively determine whether 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). 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 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. We recommend monitoring of cut stands vs. stands that are marked but not cut due to increased GPS accuracy and efficiency. We have tested the accuracy of QuickMapping and found that it produces comparable spatial pattern metrics to a full stem map (Fig. 9, 10). Additionally, methods are being developed to combine QuickMapping with LiDAR to quantify spatial pattern of treatments over large areas. Contact the authors for more information. Below we lay out field methods for QuickMapping as well as the analysis steps.

**The Android ICO Mark app can also be used for QuickMap Monitoring.** Instructions for using the app for monitoring are provided in a users guide that accompanies the app. If you do not have access to an Android tablet and external Bluetooth GPS, contact the authors. We may be able to lend you one.

### **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.



**Figure 9:** Example of QuickMap GPSed clump locations over a LiDAR canopy surface model. QuickMapping is a fast and effective way to quantify spatial patterns. LiDAR has the potential to quantify spatial pattern of treatments over large areas.

### 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 multiples of two 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 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 the ICO app or another 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. We recommend using “virtual boundaries” to avoid the need to flag plot boundaries.



Figure 10: 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. The ICO app is set up to record clump information. Links to paper datasheets are also available in section VII. For each individual tree and 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 trees outside the plot (buffer trees) in the notes column.
- d. Diameter & Species: One of three approaches can be taken, 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 with 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.

**For clumps only record:**

- e. Clump shape: circle, line, oval, or snake. For snake, be sure to GPS a line feature (see below).
- f. 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.
- g. Length of minor axis for ovals only. This axis is perpendicular to the major axis.

**5. GPS centerpoint of clump**

The ICO app is set up to automatically record the coordinates of each clump center while clump information is being entered. However, clump information from #4 above can be recorded separately from GPS coordinates if a high accuracy GPS is desired, or if part of the crew is recording clump information separately from the GPS person.

For clumps larger than 5-8 trees, especially those with an irregular shape that does not conform to a line, circle, or oval, **we recommend using the snake shape and then GPSing a line feature.** The ICO Mark app has this functionality. The line should include the major "corners" of the clump and does not need to be "closed."

The following practices for GPSing are suggested.

- Use a GPS unit that has a precision level less than 2m. Some recreational grade GPS units can achieve this level in open forest conditions, particularly those that connect with the GLONASS satellites. If QuickMapping an untreated or dense unit, we recommend using a high grade GPS unit that allows for differential correction.
- 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.

## 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 analyses below. A desktop program, “ICO Analyze” has been developed to perform these analyses. Instructions for this program are provided in a users guide that accompanies the program. See section VII (page 38) for a link to download it.

- 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.
- c. Create a figure of the monitoring plot (e.g. Fig. 9). This is perhaps the 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

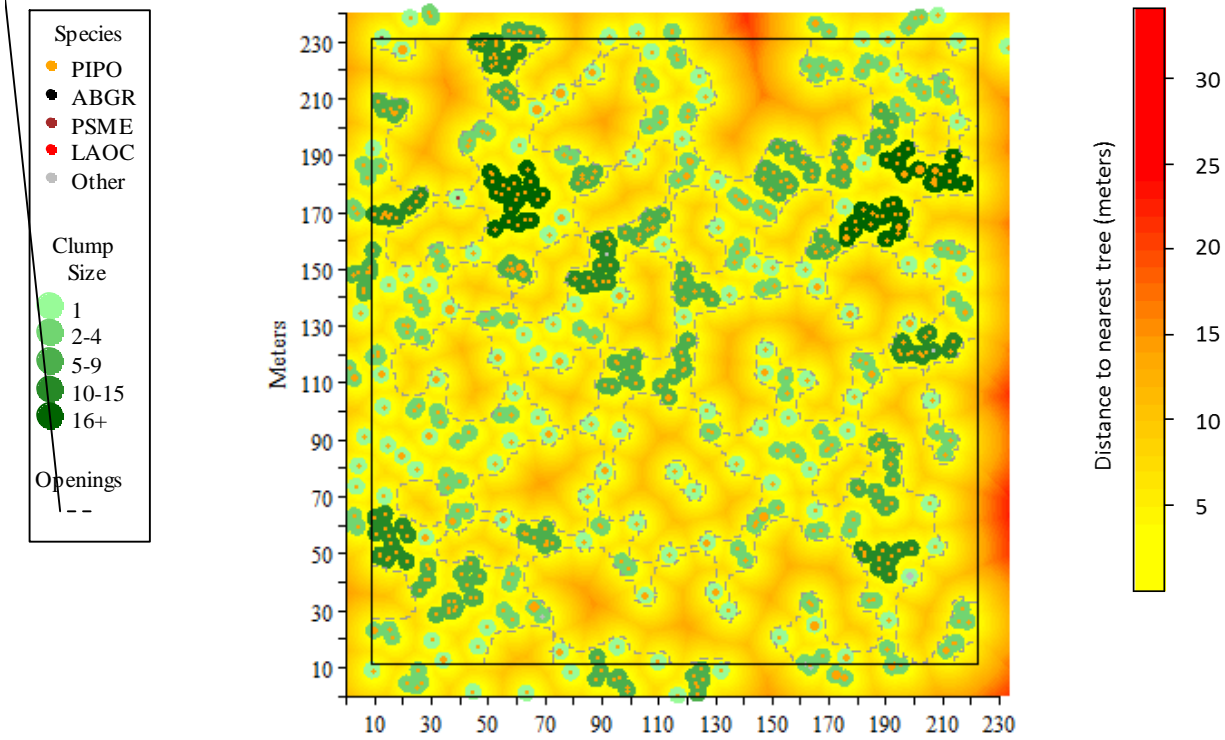
## **VI. Obtaining Reference Stem Maps and Quantifying Pattern**

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. 11). 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 exist (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 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 is 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, unharvested 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 QuickMaps) to obtain new reference data, as well as the procedures to analyze and summarize data (from either new or existing stem maps) in a way that can be used in ICO prescription development.

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 11:** Stem map of historical conditions from an 11-acre plot on the Malheur National Forest.

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 returns, 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 or 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 frequent historical fire regime.
- 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 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.

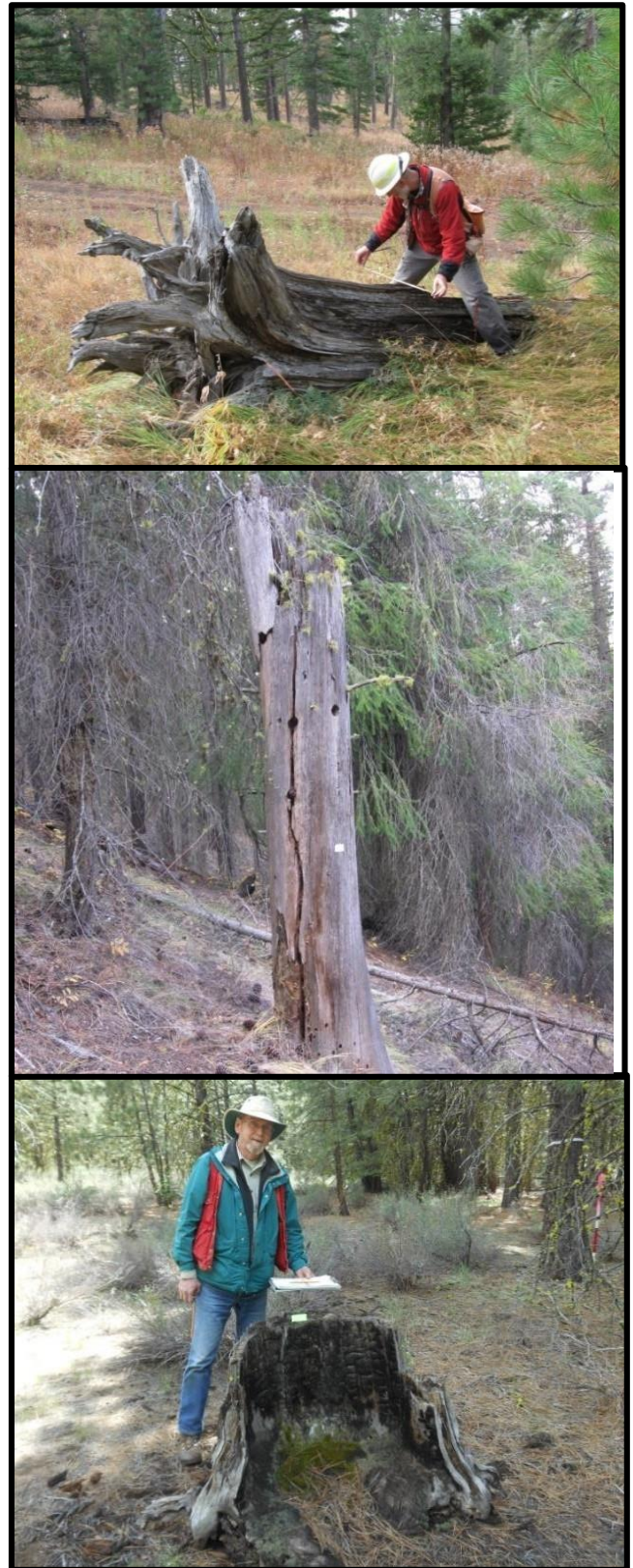
Installing a stem map is a relatively straightforward surveying exercise. It can be done with tapes and compasses, with laser range finders and an electronic compass, high precision GPS and laser rangefinder/angle encoder, or with formal surveying instruments such as a total station. High precision equipment 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 12:** Survey equipment used in stem mapping.

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.

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).



**Figure 13:** Working with dead wood in stem map plots.

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 task 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  $\frac{1}{2}$  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 11 is shown in table 4. Instructions for implementing the Plotkin algorithm in ArcGIS are presented in Box 3. 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 clumps for the purpose 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 2). Low clumping are stands with a high proportion of individual trees (~40%) and few large clumps, while high clumping stands have fewer individual trees and more trees in clumps.

**Box 3.** 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 inter-tree 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 inter-tree 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 inter-tree 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”. Prescriptions that leave significant proportions of trees in clumps will automatically create a certain amount of small and medium sized openings (< ~1/3<sup>rd</sup> 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 grid 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. (in press). Methods for delineating openings are also discussed in Churchill et al. (in press).

## **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](mailto:derek@stewardshipforestry.com)

All documents and tools are accessible at:

<https://www.dropbox.com/sh/4pb5qpbni32dpwt/AACATRPixTM4clBJ28yNJsYYa?dl=0>

Currently, the following items are available for download:

- The most recent version of the ICO Managers Guide.
- The apk file to install the ICO Andriod APP on a tablet. The users guide is also here.
- The setup and reference files for the desktop analyzer program. This program analyzes results from QuickMapping. The users guide is also here.
- A prescription worksheet excel file to help develop ICO prescriptions
- Marking and monitoring datasheets in an excel file
- PDFs for a number of useful field info sheets (e.g. old tree identification)
- A pdf of the Franklin et al. 2013 Dry Forest Restoration Handbook, plus other key background science papers.



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**Appendix 1: Visual ICO Guide:** From the Fremont-Winema National Forest (Andrew Spencer)

**Individuals, Clumps and Openings Guide for Commercial Harvest**

<p><b>General Objective:</b> Structurally complex Ponderosa Pine forests resulting in the following:</p> <ul style="list-style-type: none"> <li>-Historical, variable spatial arrangements</li> <li>-Reduced fuel loads/high severity fires</li> <li>-Improved mule deer and bald eagle habitat</li> <li>-Enhanced and restored aspen stands</li> <li>-More large trees while retaining and protecting Mature Trees</li> </ul>	<p><b>Residual Density Targets and Structure</b></p> <p><u>Thin From Below:</u> remove suppressed, intermediate and some co-dominate trees, leaving the desired stocking level of larger, dominant and co-dominant healthy trees.</p> <p><u>Desired Stocking:</u> 30-50 TPA over 9" DBH The target is 60-70 ft<sup>2</sup>/ac but 50-80 ft<sup>2</sup>/ac may be acceptable: 22" DBH trees at 80ft<sup>2</sup> would be around 30 TPA; 14"DBH trees at 50ft<sup>2</sup> would be around 50 TPA.</p>	<p><b>Species Preferences</b></p> <ol style="list-style-type: none"> <li>1. Incense Cedar (IC)</li> <li>2. Douglas Fir (DF)</li> <li>3. Sugar Pine (SP)</li> <li>4. Ponderosa Pine (PP)</li> </ol> <p>Remove Lodgepole Pine (LP) and White Fir (WF) under 21"DBH</p>	<p><b>Definitions</b></p> <p><u>Mature Tree:</u> appears 150+ years old <u>Large Tree:</u> Over 20.9" DBH/27" DSH <u>DSH:</u> stump diameter 4" above ground on uphill side of the tree <u>Healthy Tree:</u> fuller crown, darker foliage, and free of broken/forked tops, mistletoe or insect damage <u>Aspen Patch:</u> 5+ live, healthy stems at least 8' tall within a 15' radius</p>
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<p><b>Individual</b> Single Tree - 20'+ away from others</p>	<p><b>Small Clump</b> 2 -4 Trees within 20' of each other</p>	<p><b>Medium Clump</b> 5 - 9 Trees within 20' of each other</p>	<p><b>Large Clump</b> 10-15 Trees within 20' of each other</p>
<p>Created by releasing large or mature trees where available, or desirable young trees where they are not.</p> <p><u>Avoid leaving smaller diameter trees near (within about 35') large and/or mature trees in order to achieve spatial targets.</u></p> <p>≈20-40% of the trees should be individuals (≈12/acre)</p>	<p>Created by releasing existing large and/or mature trees where available, or using desirable young trees where they are not. Look for trees of similar sizes and ages to build clumps.</p> <p>≈30-60% of the trees should be in small clumps (≈ 17 trees/acre), or about six small clumps/ac</p>	<p>Mature and/or large diameter trees may exist in this clump category when available, and often with younger, desirable trees.</p> <p><u>Small diameter and undesirable trees should be removed to release trees in medium clumps</u></p> <p>≈10-30% of the trees should be in medium clumps (≈7 trees/acre), this is about one medium clump/ac</p>	<p>Mature and/or large diameter trees may exist in this clump category when available, often in combination with healthy young trees in close proximity. <i>These will be leave tree marked.</i></p> <p><u>Do not skid through, or remove smaller trees from within 10' of large clumps</u></p> <p>≈5-15% of the trees should be in large clumps (≈4 trees/acre), or about one large clump every three acres</p>
