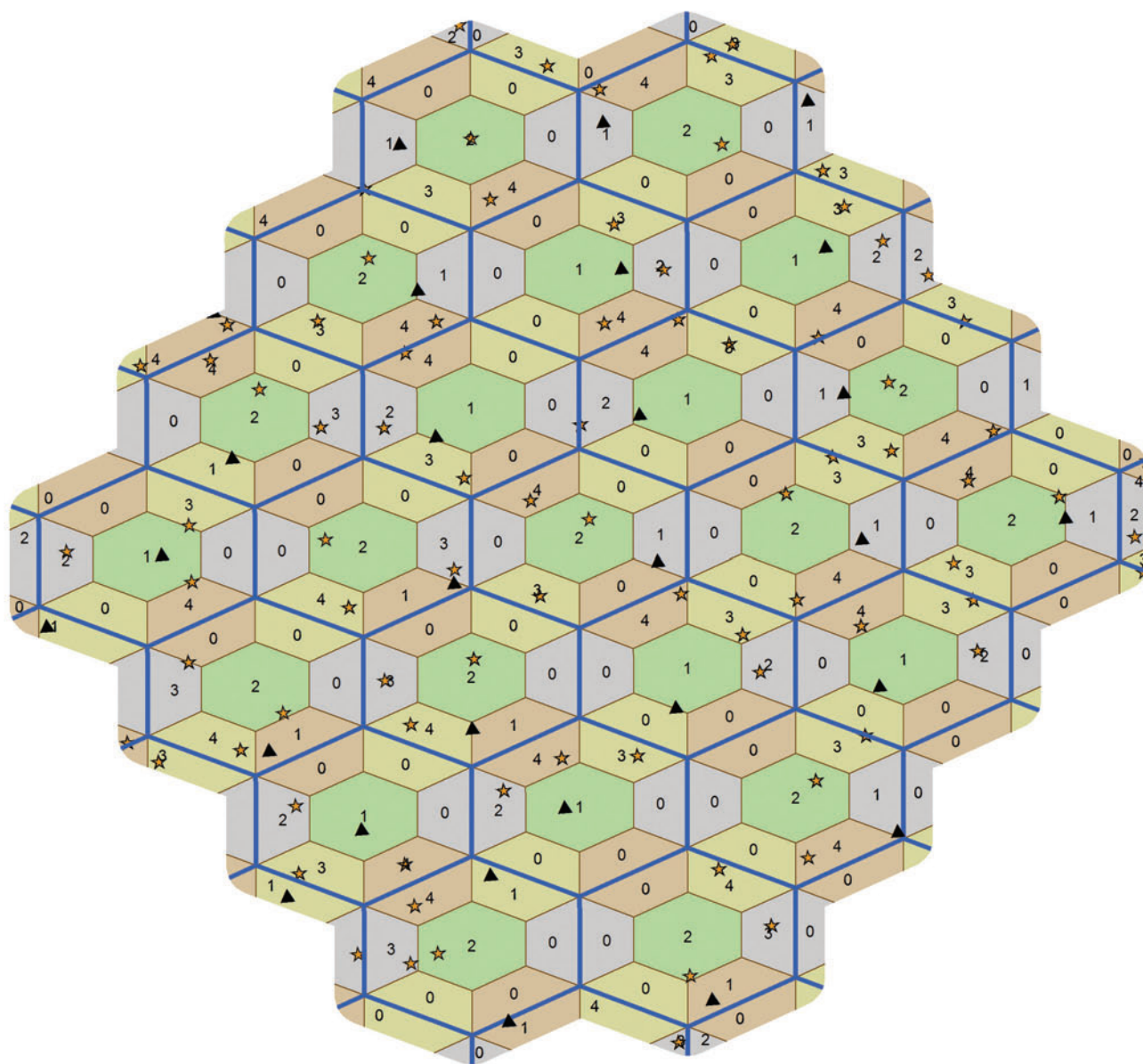


National FIA Plot Intensification Procedure Report

Jock A. Blackard and Paul L. Patterson



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Abstract

The Forest Inventory and Analysis (FIA) program of the U.S. Forest Service (USFS) measures a spatially distributed base grid of forest inventory plots across the United States. The sampling intensity of plots may be increased in some regions when warranted by specific inventory objectives. Several intensification methods have been developed within FIA and USFS National Forest Systems regions; however, a national standard routine for plot intensification does not exist. This report examines eight candidate intensification methods by a developed set of evaluation criteria, and based on those results proposes that FIA adopt the GRID method as its national plot intensification procedure. It is also suggested that the current version of the GRID method be updated by converting it to an ESRI ArcGIS add-in tool.

Keywords: sample intensification, forest inventory, plot intensification, Forest Inventory and Analysis

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About the cover: The cover graphic illustrates FIA's sampling frame (blue hexagon) subdivided into smaller hexagons or sub-regions using the GRID method. Sub-regions are color-shaded to represent a 4x intensification level within each sampling frame. Existing FIA plots are shown as black triangles, randomly placed intensified plots are gold stars, and the labels identify the corresponding intensity number for each intensified plot. Those sub-regions that will not receive a new intensified plot are assigned the number 0. Cover artwork by Jock A. Blackard.

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We also thank John Coulston and Joe McCollum for providing valuable support, documentation, and various examples for the GRID method. John Coulston also provided many R script examples and background information on the Clark & Evans and Ripley's K statistics. Joe McCollum provided additional insights on the results obtained from these statistics, as well as produced several figures for various intensification methods.

For assistance with the remaining intensification methods examined by the task team, much gratitude to Kirk Evans; a GIS Analyst at Tetra Tech and contractor for the USFS Region 5 Remote Sensing Laboratory. Kirk ran the R5 method for USFS Region 5 intensification tasks, and detailed this methodology and shared its documentation with the task team. Also, thanks to Andy Lister who provided many examples, documentation, and an AML script for the NIMAC or SFC method. The RIPL program, written by J.D. Zeiler, was developed primarily to support a mid-level inventory system for USFS Region 1. Much thanks to J.D. for his patience and assistance in the initial setup of the RIPL program and his insight and analysis of the RIPL method. The Python4x method, developed by Tom Thompson, has been used for various intensification tasks for the PNW-FIA region. At the request of the task team, Tom updated his original program to allow an option of conducting either a 2x or a 4x intensification. We appreciate his efforts, analysis, and valuable insight of the Python4x method. The R4 intensification method, proposed by Larry DeBlander, is used for USFS Region 4 intensification projects. Much thanks to Larry for sharing his knowledge of FIA sampling designs (past and present), along with his assistance in testing this method.

While we have tried to thank all that helped, please forgive us if we have omitted anyone who assisted in this effort.

Executive Summary

This report addresses the need for the U.S. Forest Service (USFS) Forest Inventory and Analysis (FIA) program to adopt plot intensification methodologies that meet a set of desired criteria. A variety of methodologies exist within FIA and National Forest Systems regions for constructing plot intensifications, but there seems to be no consensus on a national procedure for intensifying plot locations.

The primary objectives of this proposal were to 1) identify various intensification methods currently being implemented by FIA or utilized by other USFS National Forest Systems regions; 2) develop a set of characteristics and assumptions used to evaluate these methods, which are separated into two groups: a *critical* group in which an intensification method was not considered further unless it met each criterion, and a *non-critical* group which contains desirable traits but a missing criteria would not eliminate that method; 3) examine each intensification method using these characteristics and assumptions; and 4) recommend a potential national FIA plot intensification procedure that would adequately address the needs for all FIA regions.

After examining eight plot intensification methods, the core members of the task team (Appendix A) recommend a national FIA plot intensification procedure that includes adopting the GRID method to create sub-regions for each FIA Phase 2 (P2) hexagon, and then randomly assign new plots within those sub-regions that do not contain an existing FIA base plot. We also suggest that the current version of the GRID method be updated and incorporated in an ESRI ArcGIS add-in tool. An FIA analyst would be able to execute the GRID method for intensification projects within the confines of ArcMap, which would remove the need to import/export files from other programs.

We show that for a 4x intensification of the Bighorn National Forest in Wyoming, assigning panels and subpanels to intensified plots using a procedure derived from the traditional method of creating a 10-year panel system from a 5-year panel leads to an east-west banding of plots. We recommend an alternative approach to assigning panel and subpanel values for intensified plots as detailed in the Methods section.

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Introduction

In the late 1990s, the United States Forest Service (USFS) Forest Inventory and Analysis (FIA) program began using a national set of hexagons (approximately 6000 acres each) to spatially distribute the placement of their Phase 2 (P2) plots. These hexagons (P2 hexagons or P2 hexes in this report) were based on the existing Forest Health Monitoring (FHM) hexagon network. This FHM national sampling frame was previously derived by performing a spatial offset of the EMAP (U.S. Environmental Protection Agency's Environmental and Assessment Program) hexagon network (Reams and others 2005b).

The same methodology that was used to create the national FIA P2 grid of plots can also be used to develop more intensive hexagons in specific geographic areas if needed (Coulston and others 2009). This methodology, however, involves the use of C programs and ArcInfo (ESRI 2001) AML (ARC Macro Language) programs that were written in the 1990s. The user is typically required to download additional software (CYGWIN for example, www.cygwin.com) to run a compiled C program executable file. Additional time may also be required to become familiar with the various parameter settings for this program to work correctly. Nonetheless, the programs are already written and have been implemented numerous times for such tasks.

As computing and GIS software has made advances over the past few decades, so has the number of scripts made available to members of the GIS community. These scripts can generate hexagons or other polygon features across a defined geographic area and are accessible on various websites, such as ESRI's GIS support forums (<http://support.esri.com/en/>). A GIS user can simply download a script (such as Jenness 2009), install it in ArcMap (ESRI 2009) and generate hexagons based on user-specified parameters in a more user-friendly wizard-style environment. This enables hexagons of various sizes to be created relatively quickly for any geographic area.

Other intensification routines are also used within FIA; each method has merit and benefits in creating intensified plots locations. However, the potential for a standard national routine for plot intensification that incorporates various FIA needs should be investigated.

An invitation was issued to all FIA regions and National Forest System (NFS) regions soliciting intensification methods, and a core group was formed to evaluate these various methods. In addition to the core group, there was a group of consulting members who were asked for advice. The members of the core group and consulting members are listed in Appendix A.

Once the core group was established, a list of factors for evaluating plot intensification procedures was rated by each member of the team. These factors and results of the survey are shown in Appendix B.

The Bighorn National Forest (BNF) located in north-central Wyoming was selected as a case study to conduct an evaluation of the intensification methods. The study area contains 303 P2 hexagons that extend across the BNF boundary (figure 1). Actual FIA plot locations were used in these evaluations, which allowed an appraisal of the implementation of these intensification schemes. A set of characteristics and assumptions, which are properties each intensification method should exhibit, were developed by the core team.

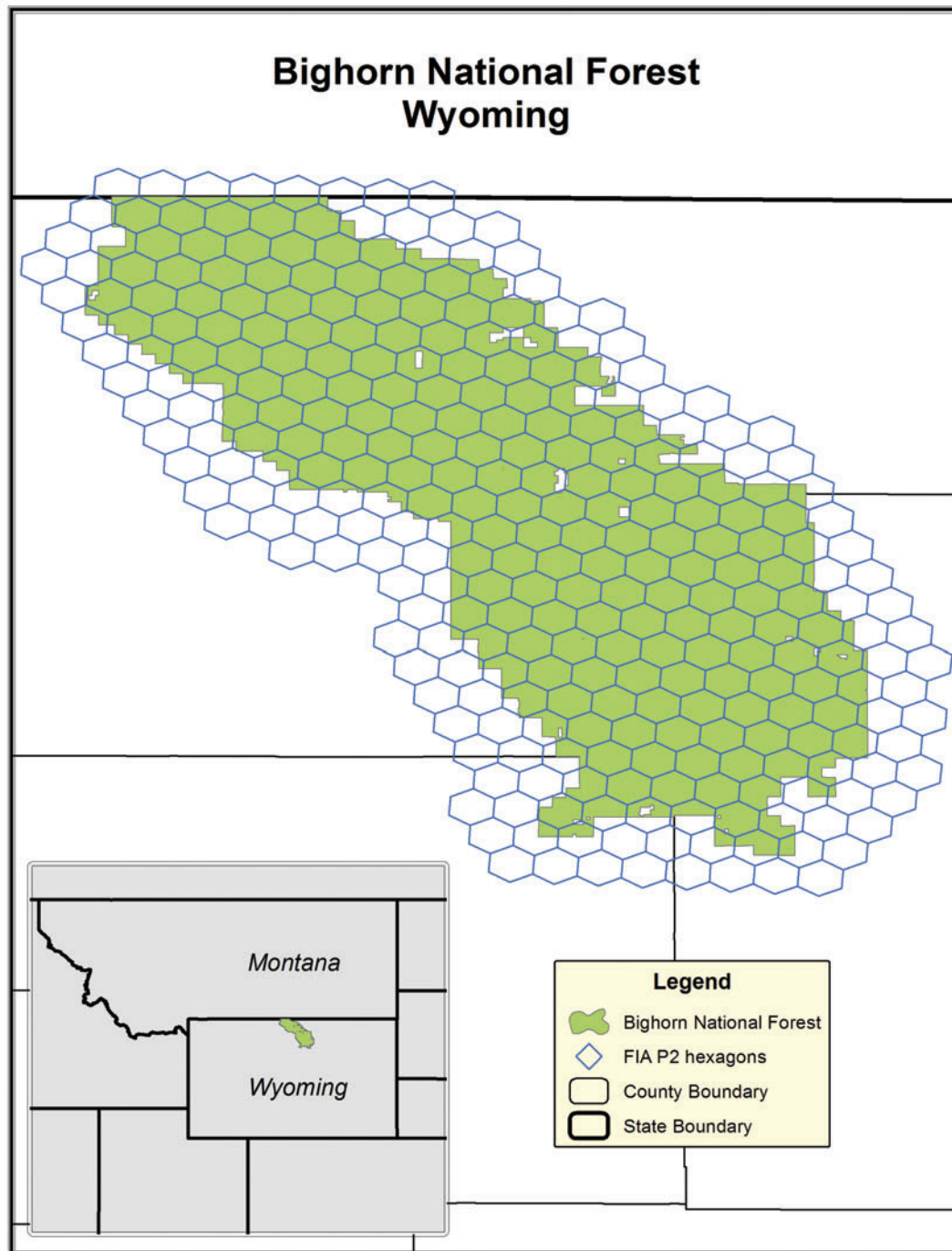


Figure 1—The Bighorn National Forest, primarily located in north-central Wyoming, is the study area. Note that with a buffer zone, 303 P2 hexagons extend across the forest boundary.

While some plot intensification tasks may require a relatively large number of intensified plots to be established for a given project (experimental forests, special projects, etc.), the core group focused their efforts primarily on those requirements needed for more commonly used FIA intensification tasks (state or forest intensifications, etc.); where 7x was considered a reasonable upper limit. The core group selected a 4x level of intensification for the case study, which is defined as an existing FIA base plot plus three new intensified FIA plots within a given P2 hexagon. This level of intensification generally encompasses what is requested from FIA for their statewide intensification tasks (2x to 4x levels), and is typically the intensification level that is selected once budgetary constraints are examined.

While the focus of the core team was specific to FIA needs, the intensification methodology and results presented in this report would likely assist in various plot intensification efforts outside the FIA program. Many land management agencies typically have some type of sampling routine in place that provides “ground-truth” data in support of their efforts to summarize or model natural resource assets across their land holdings. The topics presented in this report should also benefit those agencies that utilize some type of hexagonal sampling program.

The purpose of this report is to:

- describe the intensification schemes that were compared,
- discuss basic attributes that are common to each intensification scheme,
- develop statistical measures used to objectively evaluate the intensification schemes and report results,
- state decision rules and technical characteristics used to evaluate the intensification schemes and report results, and
- recommend an intensification method for FIA to implement.

Methods

The core team members evaluated eight candidate intensification schemes during this effort:

1. **GRID method** (USFS SRS-FIA; C program and ArcInfo AML)
2. **R5 method** (USFS Region 5; python script)
3. **NIMAC or Space Filling Curves (SFC) method** (USFS NIMAC; ArcInfo AML)
4. **RIPL method** (USFS Region 1; ESRI ArcGIS add-in tool)
5. **Python4x method** (USFS PNW-FIA; python script)

6. **Repeating Shapes method** (ESRI download, ArcGIS tool)
7. **R4 method** (USFS Region 4; utilizing existing B-grid plots)
8. **Simple Random Sample method** (used for comparison purposes)

Rather than provide descriptions of these schemes, a discussion of basic attributes that—for this study at least—any intensification scheme should satisfy will be presented, followed by the statistical measures and technical considerations used to evaluate these methods. Afterwards, a description for each of the eight candidate intensification schemes is given.

The characteristics and assumptions used to evaluate these schemes may be separated into two groups: a *critical* group in which a candidate scheme will not be considered further unless it meets each criterion; and a *non-critical* group which contains desirable traits but a missing criteria would not eliminate a scheme.

Critical Group

One critical assumption is that an intensification scheme must accommodate the existing FIA grid; that is, the intensification method must not drop any base grid plots. In addition, the existing FIA paneling system and re-measurement cycle must be preserved. Additional plots may make use of the existing FIA paneling system but cannot change it.

Another assumption is that intensification is performed within each P2 hex primarily to maintain the one-to-one relationship between the unique plot identifier and the P2 hex identifier in the FIA database. One implication to using the P2 hex boundary as the basis for intensification is that the number of intensified plots may be reduced after “clipping” the P2 hex area by the boundary of an intensification region (or study area). This is done to assure each plot location has an equal probability of selection. The result is that the number of intensified plots is random and a function of the number of partial hexes found within the boundary of the study area. If the intensification boundary is geographically coincident with the P2 hex boundary, then the number of plots (base and intensified) will equal the intensification number times the number of P2 hexes in the intensification region.

The intensified plots should also be established in a random manner, within a design that encourages spatial balance among plots compared to using simple random sampling within a P2 hex. Spatial balance is commonly enhanced by utilizing “sub-hex” polygons that are fully circumscribed within each P2 hex.

Also, all areas of a P2 hex outside of the sub-hex polygon that contains the base plot have an equal probability of being selected for the location of an intensified plot; no constraints are imposed for some minimum distance between plots or their corresponding hex boundaries.

A related assumption is FIA plot identification numbers are P2 hex centric, such that the plot identification number is based on the P2 hex from which that plot is located; it is critical that each intensified plot is identified by the P2 hex where its plot center is positioned.

Non-Critical Group

For our considerations, plots were deemed “inside” of an intensification region boundary (or study area) if their plot centers fell within that boundary. Thus, the entire FIA plot was used as a unit of measure, rather than an individual subplot location. So-called “partial plots,” or the data utilized from individual subplots within an area of interest, were not considered in this study. As a result, an FIA plot may be determined to be within the study area boundary, but still have one or more of its subplots outside the study area. Alternatively, it is also possible that an FIA plot is found to be outside the study area boundary, but still have a subplot location within the study area that would not be included. Overall, the potential bias generated from these types of situations is acceptable.

We acknowledge that some study areas may contain a patchy network of areas (such as National Forest lands) that may be under-sampled by using an entire FIA plot as a unit of measure. Alternative units of measure may include other parts of an FIA plot, such as a subplot that is totally contained within the intensification area may be measured. If needed, these alternative units of measure may be used by an analyst on a case-by-case basis with any of the potential intensification methods described in this document. The study area boundary was initially buffered by some sufficient distance (typically by two P2 hexes; figure 1), so that any possible “border” effect would not influence the placement of these newly intensified plots. This “unit of measure” modification will not change the geospatial properties of the resulting intensified plots, and it was these properties on which we based our decision of intensification method to recommend.

The current FIA sample of plots was constructed in the 1990s using the procedure documented by Reams and others (2005b). For additional technical details, see Brand and others (2000), McCollum (2001), McCollum and Cochran (2005), and McCollum and others (2008). In this procedure, if there were one or more “historical” FIA plots within a P2 hex, then one was randomly selected as the base plot for that specific hex. Otherwise, a random point was chosen within the P2 hex as the new FIA base plot. The construction of the historical plot locations differed among FIA regions; some were established along equal intervals while others used a random component. An idealized version of the FIA sample locations may be described as a tessellation of the area, with a random plot location within each section of the tessellation (Reams and others 2005b).

Statistical Characteristics

An intensification scheme should preserve the spatial distribution characteristics of the FIA base grid. Since the current FIA base grid was created in the late 1990s from previously existing FIA grids (Reams and others 2005b), the spatial distribution of FIA base plots varies from region to region; hence, a statistical measure is needed to evaluate its spatial properties. Based on the discussion presented in Perry and others (2006), the first-order Clark and Evans (CE) statistic and the second-order Ripley's K (K) statistic were selected as statistical tools to provide an evaluation of each intensification method. The CE and K values were calculated for three sets of plots: the base FIA plots, the intensified plots, and the combined set of base FIA plots and intensified plots. The CE and K values for the intensified plots and the combined set of base and intensified plots should be similar to the CE and K values for the FIA base grid. The CE statistic is a nearest neighbor based estimate that provides a basic measure of clustering or ordering of point patterns, and is derived by calculating the mean distance of each location to its nearest neighbor. The K statistic is a distance based estimator and is typically compared to the theoretical K value for a completely random point pattern. These calculations were produced using the CE and K packages in R statistical software (The R Foundation for Statistical Computing 2012).

First-order properties typically focus on the mean number of events per unit area, while second-order properties are related to its variance (Perry and others 2006). These statistics were selected to analyze the resulting spatial point patterns of intensified plots locations for our study, since they are widely used and accepted in spatial ecology literature (Perry and others 2006). The selection of FIA base plot locations within a P2 hex can differ between various FIA regions so both statistics were used as complementary measures to compare how closely the intensified plot indices mirrored those from the original FIA base plot indices.

While both statistics are commonly used, there are also limitations to using Clark and Evans and Ripley's K statistics. Perry and others (2006) describe how first-order tests (for example, CE) are capable of accurately describing patterns at shorter distances, but are generally not able to characterize patterns at distances further than local interactions. They also indicate that for second-order tests (for example, Ripley's K); values of the statistic for some given distance may be strongly influenced by its values at shorter distances. In summary, Clark and Evans is highly scale dependent, while Ripley's K is influenced by a cumulative effect from shorter distances.

For the Clark and Evans statistic, ArcMap version 9.3.1 (ESRI, Inc. 2009) was used to create point shapefiles from the various intensification methods, and R version 2.15.0 (The R Foundation for Statistical Computing 2012) to calculate their corresponding CE values. As a point of reference, a completely random point distribution has a CE value of 1.0, while a maximum aggregation distribution (clumping) has a CE value of 0.0, and a maximum spacing (uniform) distribution has a CE value of 2.1491 (Clark and Evans 1954). Appendix C contains the R script template used to calculate the CE value.

For comparison against the CE values calculated for the various intensification methods, the distribution of CE values were also found by performing simulations using 4000 iterations, to determine the mean and 95% confidence interval values for the following scenarios: (1) 4000 point shapefiles, extending across 303 P2 hexes (spanning the Bighorn NF boundary), containing one random point per P2 hex (303 plots); (2) 4000 point shapefiles, extending across 303 P2 hexes (spanning the Bighorn NF boundary), containing 303 random points with no P2 hex constraints (303 plots); (3) 4000 point shapefiles from (1) above, but with points clipped to the Bighorn NF boundary (approximately 186 plots each); and (4) 4000 point shapefiles from (2) above, but with points clipped to the Bighorn NF boundary (approximately 187 plots each). CE values were calculated for these various simulation scenarios to first obtain the CE values from their theoretical plot placement procedure, and second to test the effect of clipping to the BNF boundary on CE values from these scenarios.

For the Ripley's K statistic, ArcMap version 9.3.1 (ESRI, Inc. 2009) was used to create point shapefiles from the various intensification methods, and R version 2.15.0 (The R Foundation for Statistical Computing 2012) to calculate their corresponding K values. The resulting K values are then displayed in a zero-line horizontal graph within a simulation envelope, which approximates a 95% confidence limit (the R script template used to calculate the K value is provided in Appendix D).

To complement the spatial balance obtained by inventorying one FIA base plot within each P2 hex, FIA also employs a paneling system to achieve a temporal balance of sample plots. A panel represents a given measurement year within one full cycle of plot measurements (for example, a 10-year cycle in this study). As described in Reams and others (2005b), FIA regions typically schedule their annual plot inventories based either on a 5-year (funding for 7-year) or 10-year cycle.

FIA assigns panel values to P2 hexes as described in Brand and others (2000), McCollum (2001), McCollum and Cochran (2005), and McCollum and others (2008). A brief outline of this process is provided since our assignment of panel and subpanel (hereinafter panel.subpanel) values for intensified plots is based on this procedure. Additional details and related discussions on FIA's panel and subpanel approaches can be found in Reams and others (2005a). For a 5-year rotation, the five panels are denoted by 1, 2, 3, 4 and 5; these numbers correspond to each year of the cycle that plots are measured. Figure 2a shows how the P2 hexes were assigned to a five-panel arrangement based on the sequence 1-3-5-2-4, with an offset of three hexagons for each southern-neighboring row of P2 hexes. In figures 2a and 2b, the P2 hexes are shown as the smaller-sized hexes, while the larger single hex represents an FHM hex. Note that for a 5-year cycle, each panel has a corresponding subpanel value of one.

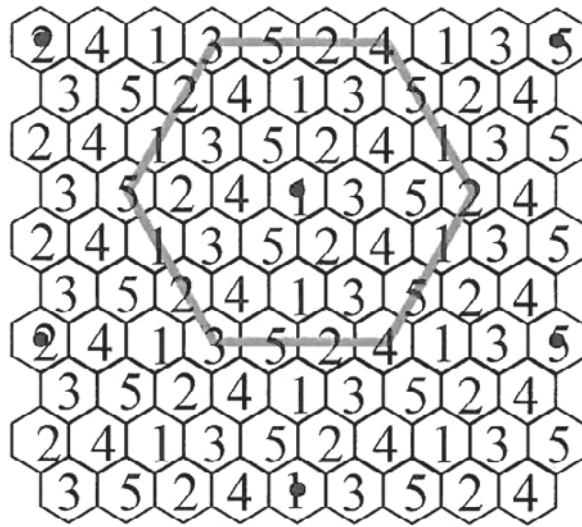


Figure 2a—Assignment of hexagons to one of five panels (shown by number), as shown in Figure 2 of Brand and others (2000).

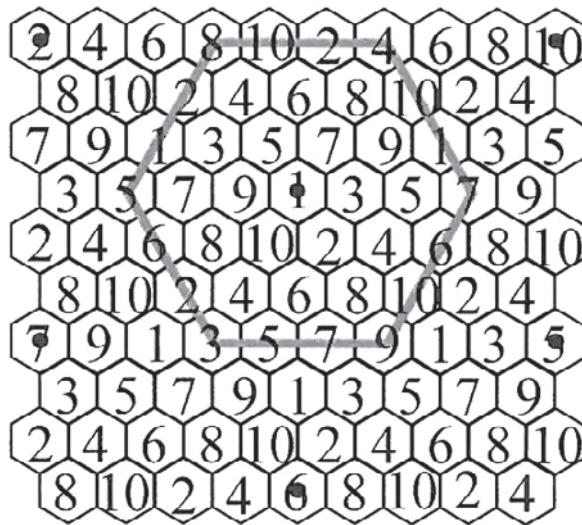


Figure 2b—Assignment of hexagons to a ten-panel arrangement (shown by number), as shown in Figure 3 of Brand and others (2000).

For a 10-year rotation, the five panel example above was doubled by utilizing two subpanel values (1 or 2). The order of panel.subpanel measurement years within a 10-year cycle is given as: 1.1, 2.1, 3.1, 4.1, 5.1, 1.2, 2.2, 3.2, 4.2 and 5.2 (all the subpanel 1 values are measured first). Note that 1.1, 2.1, 3.1, 4.1 and 5.1 are denoted by their panel number (which corresponds to their measurement year), and 1.2, 2.2, 3.2, 4.2 and 5.2 are represented by 6 through 10 (their measurement year). Thus, a measurement year of 10 would be represented as 5.2, while a measurement year of 3 would be listed as 3.1. The assignment of P2 hexes to a panel.subpanel value was derived from the five-panel assignment (figure 2a) and the two panel.subpanel sequences of: 1.2-3.2-5.2-2.1-4.1 and 1.1-3.1-5.1-2.2-4.2. The first sequence is applied to the first two rows of figure 2a, so that the subpanel number was adjoined to the panel number in figure 2a; which transforms the sequence 1-3-5-2-4 in the 5-year cycle to the sequence 6-8-10-2-4 in the 10-year cycle, which is the sequence of the first two rows of figure 2b. The second sequence is applied to the third and fourth rows of figure 2a, transforming 1-3-5-2-4 in the 5-year cycle to 1-3-5-7-9 in the 10-year cycle and producing the rows three and four of figure 2b. This process is then repeated; that is, the sequence 1.2-3.2-5.2-2.1-4.1 is used to transform rows five and six of figure 2a to rows five and six of figure 2b. Notice that the repetition of these sequences across two adjoining rows of P2 hexes leads to bands of P2 hexes that run basically in an east-west direction, as shown in figure 3a for measurement year 1 (or panel.subpanel 1.1) in the 10-year cycle. Note that the odd years are all in one set of bands and even years are in the other set of bands; for this reason we will refer to the bands as odd and even bands. Given the sparseness of the 10-year panels, this “banding” does not have a clumping effect on the distribution of plots (see figure 3a).

As part of the process of assigning panel numbers to intensified plots, an intensity number is assigned to each plot. The intensity numbers run from 1 to the intensification level; for example, in a 4x intensification the intensity numbers are 1, 2, 3, and 4. The intensity numbers are assigned to plots within a given P2 hex so that the base plot has an intensity number 1 and the intensified plots are assigned the remaining numbers.

To assign a panel.subpanel value to each intensified plot within a given P2 hex, two inputs of information were used: (a) the existing base plot’s panel.subpanel value, and (b) the intensified plot’s intensity number, and application of the sequences described in the previous paragraphs (or a variant of those sequences). A natural approach would be to use the base plot’s panel.subpanel value to find a starting place in the Brand sequences (Brand and others 2000), and assign the panel.subpanel for the intensified plots in the P2 hex based on their intensification numbers. For example, assume the base plot of a hex was in panel.subpanel 5.2, and the 1.2-3.2-5.2-2.1-4.1 sequence was used, starting in the 5.2 position. The intensified plot with intensity number 2 would then be assigned to panel.subpanel 2.1, while the intensified plot with intensity number 3 would be assigned to panel.subpanel 4.1, and finally the intensified plot with intensity number 4 would be assigned to panel.subpanel 1.2.

We refer to this method as the Extension of Base Method, or EBM. The problem with this approach is the panel.subpanel assignments for the intensified plots in a P2 hex are in the same band as the base plot, and the slight appearance of odd or even year bands for the base P2 plots (see figure 3a) is accentuated by the higher plot density, as shown in figure 3b.

The drawback to the EBM is that intensified plots are in the same band (spatial arrangement of plots running basically east-west) as their corresponding base plots. To displace some of these intensified plots outside the band of their corresponding base plots, the 1, 3, 5, 2, 4 sequence was used, but then we kept the subpanel number the same as that of the base plot's subpanel number (rather than potentially changing the intensified plot's subpanel number based on the EBM). For example, if the base plot was in panel.subpanel 5.2, then an intensified plot with intensity number 2 would be assigned to panel.subpanel 2.2, while the intensified plot with intensity number 3 would be assigned to panel.subpanel 4.2, and the intensified plot with intensity number 4 would be assigned to panel.subpanel 1.2, which correspond to measurement years 10, 7, 9 and 6 respectively.

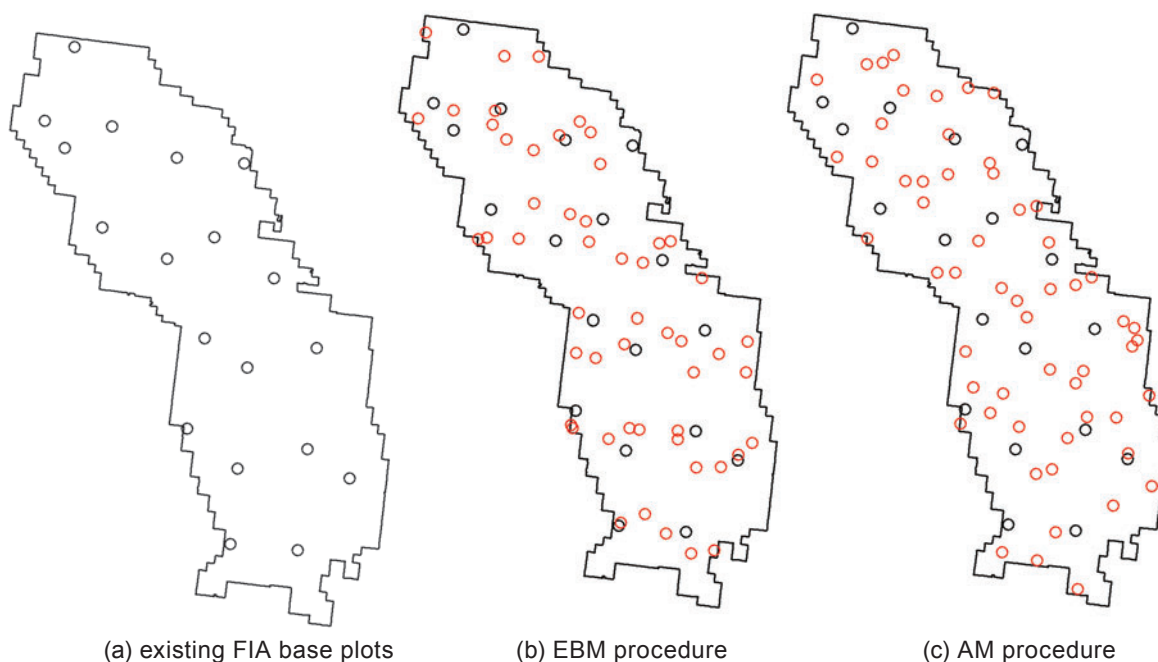


Figure 3—Plot distributions for panel 1 subpanel 1, using the GRID method, clipped to the BNF boundary. Figure 3a shows the existing FIA base plots for panel 1 subpanel 1 within the BNF boundary. Figure 3b displays the EBM panel.subpanel assignment procedure (switching subpanel values) for the intensified plots, while figure 3c shows the distribution of plots when the subpanel value of the intensified plots remains the same as that of the FIA base plot, for a given P2 hex (using the AM procedure). Contrast the amount of east-west banding of intensified plots between the last two figures. Figure 3b has 52 intensified plots, while figure 3c has 57 intensified plots. The black circles represent FIA base plots, red circles are intensified plots and the black line depicts the BNF boundary.

For our case study, the overall effect by using this alternative approach is to move two-thirds of the intensified plots into the “opposite” band (odd or even years) from that of the base plot. We will refer to this method as the Alternative Method (AM). Figure 3c shows the plot distribution for one representative subpanel using AM, while the maps of plot distributions for all panel.subpanel combinations using either EBM or AM are presented in figure 4.

Finally, Clark and Evans values were calculated for the various panel.subpanel combinations of plots created using both paneling methods (EBM and AM) from the GRID method of intensification. In addition, Ripley’s K graphics were produced for the various panel.subpanel combinations of plots from both paneling methods using the GRID method. These were produced as a comparison to the CE and K values obtained using a full set of intensified plots generated from each method.

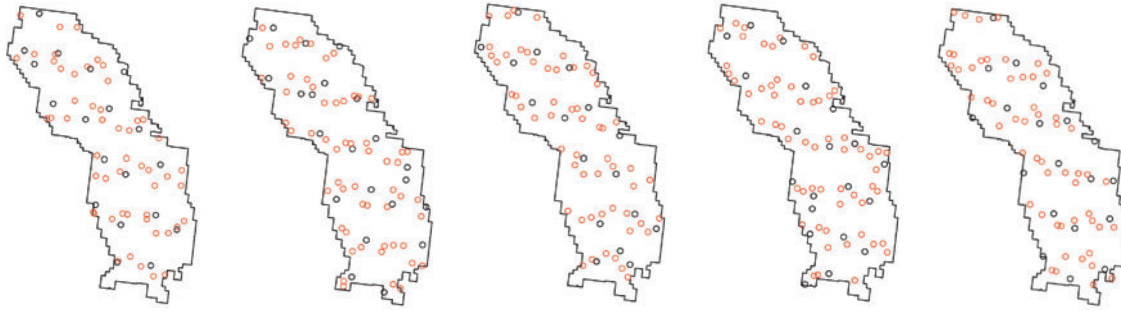
GRID Method

The GRID method has been used by the Southern Research Station FIA (SRS-FIA) region for their intensification projects. This method was initially developed by Denis White for the Environmental Protection Agency (EPA) (White 1989). It allows for the decomposition of hexagons into smaller hexagons by various factors. However, intensification factors of 3x, 4x, and 7x (or multiples thereof) will create smaller “children” hexagons that are spatially “nested” within each larger “parent” hexagon (figure 5).

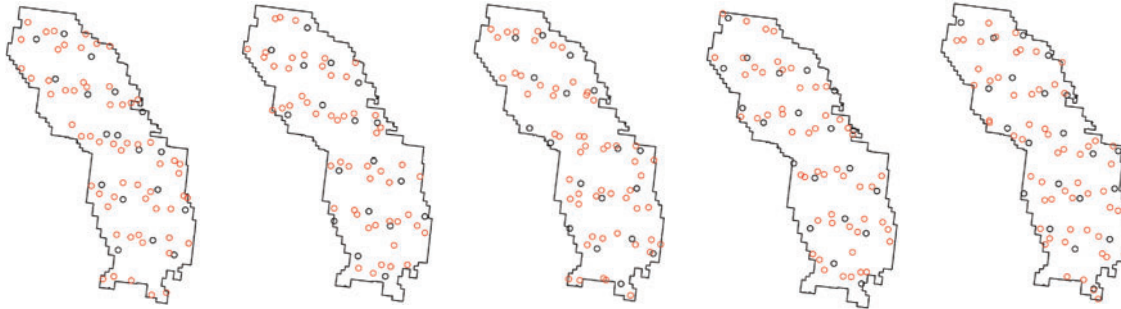
The EPA has not publicly distributed the program to generate these hexagons nor its documentation for several years since Denis White retired. The GRID program is open-source and comes with supporting documentation; however, it requires a C compiler and ArcGIS software. Further details and a downloadable file may be obtained from Denis White’s personal website (<http://people.oregonstate.edu/~whitede/getgrid.htm>) or by contacting the authors.

The GRID program was run against our study area of 303 P2 hexagons (or “parent hexes”) to produce a 4-fold decomposition (“child hexes” or “sub-hexes”), which produced an intensification pattern similar to that displayed in figure 5b. This process involved exporting the P2 hex polygon layer from ArcGIS, running the GRID executable file with user-selected parameters for a given intensification level, then importing the results back into ArcGIS as a new polygon layer. Although this process can be cumbersome, these programs are open-source and have been applied for intensification tasks many times before.

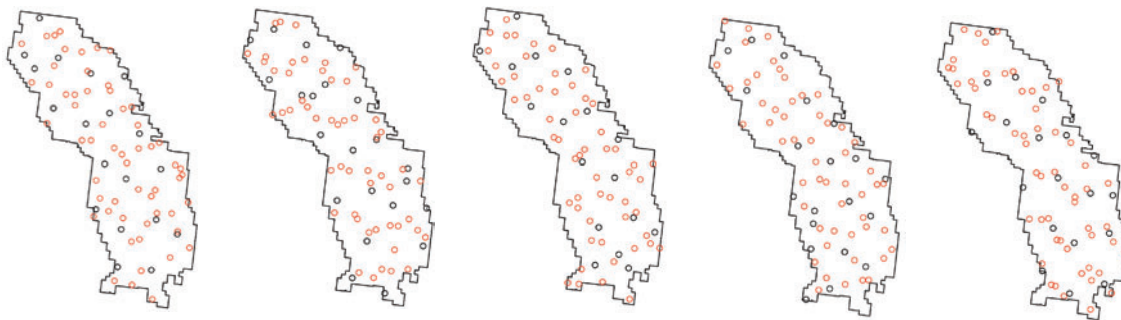
After the resulting intensified hexagons are imported back into ArcGIS, several GIS operations are used to split appropriate sub-hexes into halves, which allow them to be spatially “nested” within their overlying parent P2 hex, as shown in figure 6. One characteristic of the GRID method for a 3x, 4x or 7x intensification (or multiples thereof) is that one sub-hex is always centered within each P2 hex, which tends to deliver one plot that is relatively near the centroid of each P2 hex.



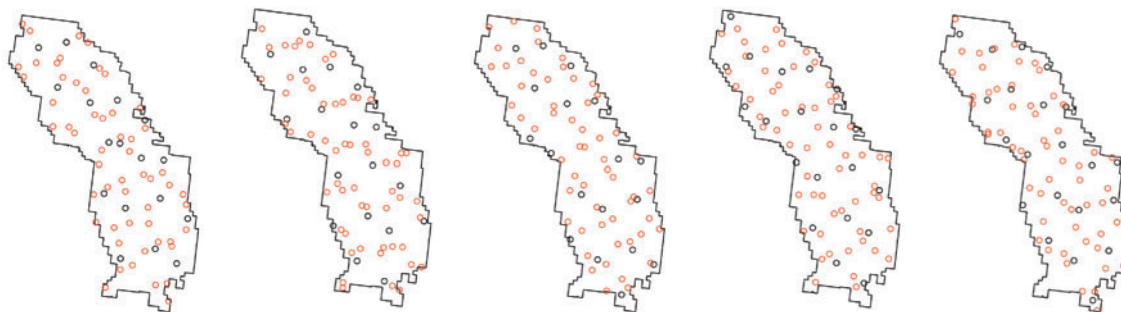
(a) EBM procedure, Panels 1-5 / Subpanel 1



(a) EBM procedure, Panels 1-5 / Subpanel 2



(b) AM procedure, Panels 1-5 / Subpanel 1



(b) AM procedure, Panels 1-5 / Subpanel 2

Figure 4—Plot distributions for different panel.subpanel combinations are shown, using the GRID method and clipped to the BNF boundary. Figure 4a displays the EBM panel.subpanel procedure (switching subpanel values), while figure 4b shows the distribution of plots when the subpanel value of the intensified plots remains the same as that of the FIA base plot, for a given P2 hex (AM procedure). Compare the amount of east-west banding of intensified plots between (a) and (b) for a given panel.subpanel combination. The black circles represent FIA base plots, red circles are intensified plots and the black line depicts the BNF boundary.

This characteristic is desirable since it guarantees one plot near the centroid of each P2 hex, rather than the potential of having several plots clustered near the centroid when using some other sub-hex arrangements. The GRID program also produces a “year” field, which was used to identify the four sub-hexes within a given P2 hex. Using this field, each P2 hex contains four nested sub-hexes of equal area (note year label of 0, 1, 2 or 3 in figure 6).

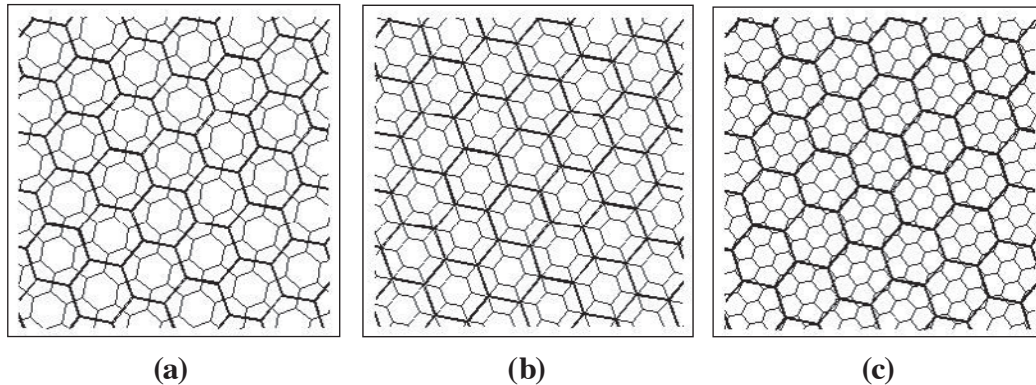


Figure 5—Depiction of (a) a 3x intensification, (b) a 4x intensification, and (c) a 7x intensification using the GRID method (courtesy of Joe McCollum, SRS-FIA).

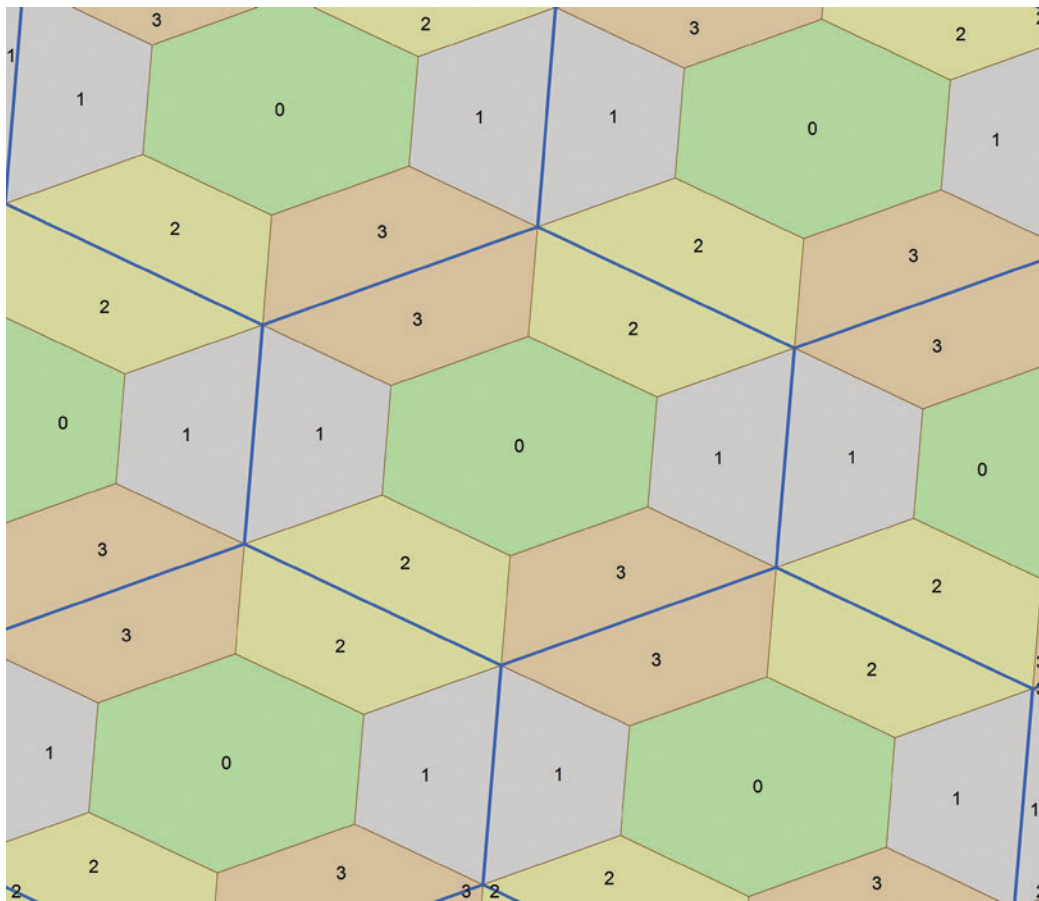


Figure 6—The GRID method produced a 4x intensification pattern of smaller hexes (sub-hexes) within a larger P2 hex. Note the “year” label, produced by the GRID program, was used to identify the 4 sub-hexes within a given P2 hex (shown as blue lines). Using this field, each P2 hex contained 4 nested sub-hexes of equal area (labeled as 0, 1, 2 or 3).

Next, the appropriate pairs of sub-hex halves were selected at random to receive one randomly placed intensified plot within its boundary. An intensity number of 2, 3 or 4 was assigned to each intensified plot, with 1 assigned to the existing base plot location, as shown in figure 7. Note that polygons that will not receive a new intensified plot, based on random selection, were assigned the number 0. This intensity number is used for those situations where only a 2x or 3x intensification is needed; where this number is used to select the appropriate order when intensifying plots. As described above, the intensity number is also used in the paneling process, which is calculated for each intensified plot.

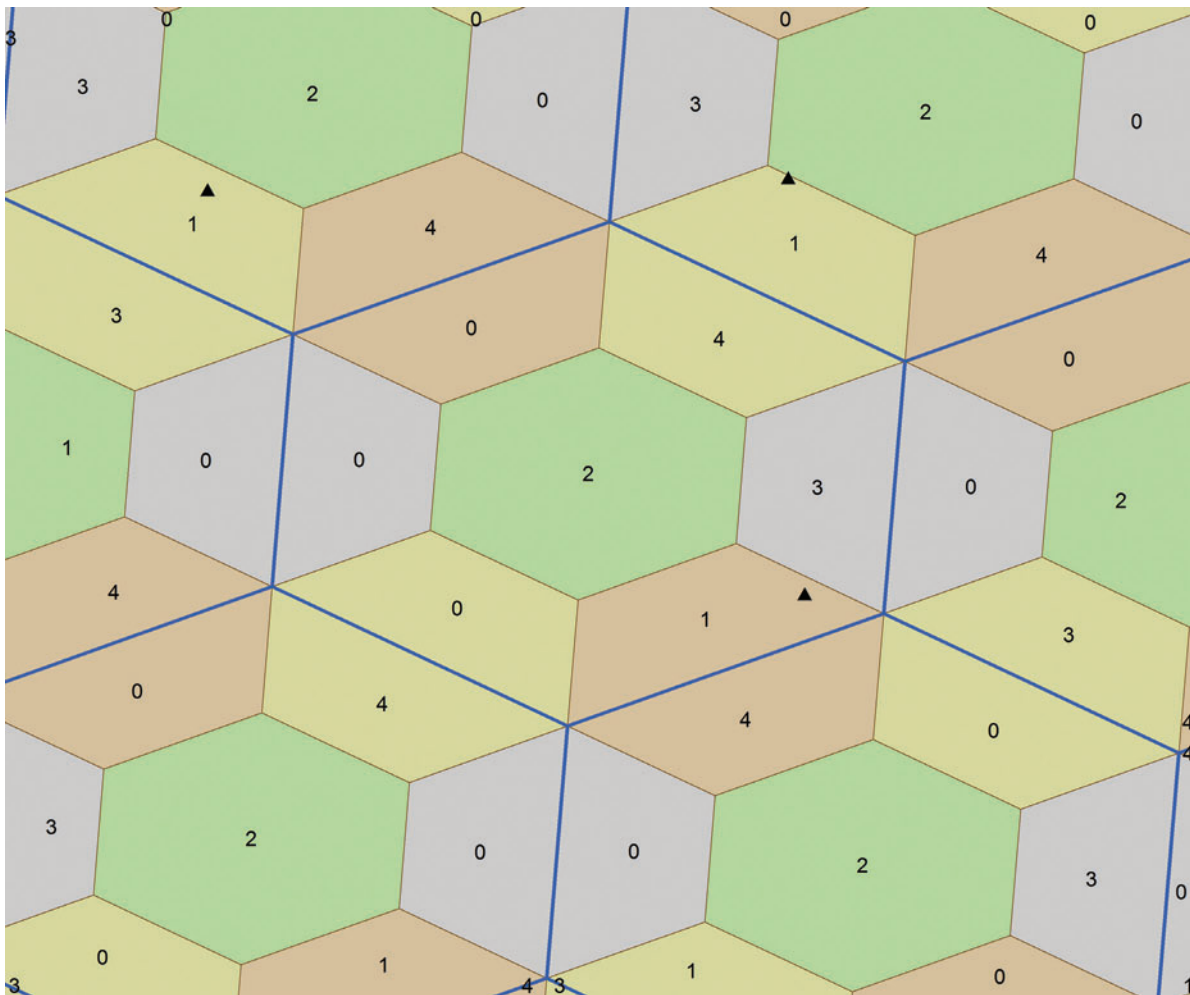


Figure 7—From the GRID method, intensity numbers are calculated, which are used to indicate 2x, 3x, 4x intensification locations for each P2 hex. Note that a label of 1 denotes a polygon that contains an existing plot location, which are shown as black triangles. Consequently, a new intensified plot will be randomly placed within the polygons designated as 2, 3 and 4 within each P2 hexagon. Those polygons that will not receive a new intensified plot are assigned the number 0.

The intensified plots were then clipped to the BNF boundary, based on their plot center location. The resulting intensified plots for a given P2 hex using the GRID method is shown in figure 8.

R5 Method

The R5 method has been used on USFS Region 5 National Forests for intensification tasks. It is similar to the GRID method in that it splits the parent P2 hex into child sub-hexes; however, its primary difference is the placement of those sub-hexes within the P2 hexagon. This intensification method is a 4x intensification, with sub-hexes oriented as shown in figure 9. Note that this method creates three full sub-hexes (grey) and three partial sub-hex (white) areas, which form the 4x portion of the intensification.

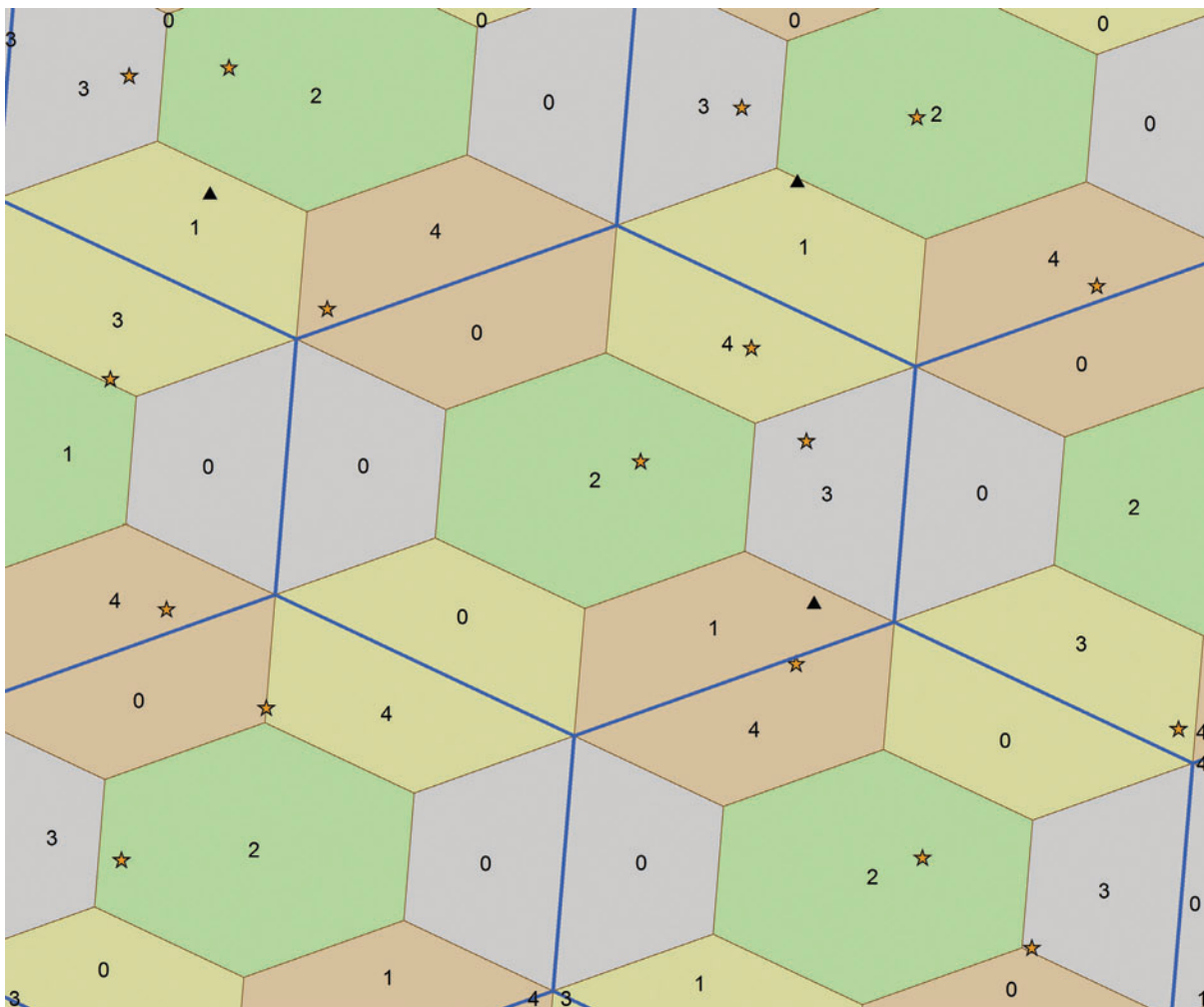


Figure 8—Intensified plots for a given P2 hex are shown using the GRID method. Existing FIA plots are shown as black triangles, randomly placed intensified plots are gold stars, and the labels identify the corresponding intensity number for each intensified plot. Those polygons that will not receive a new intensified plot are assigned the number 0.

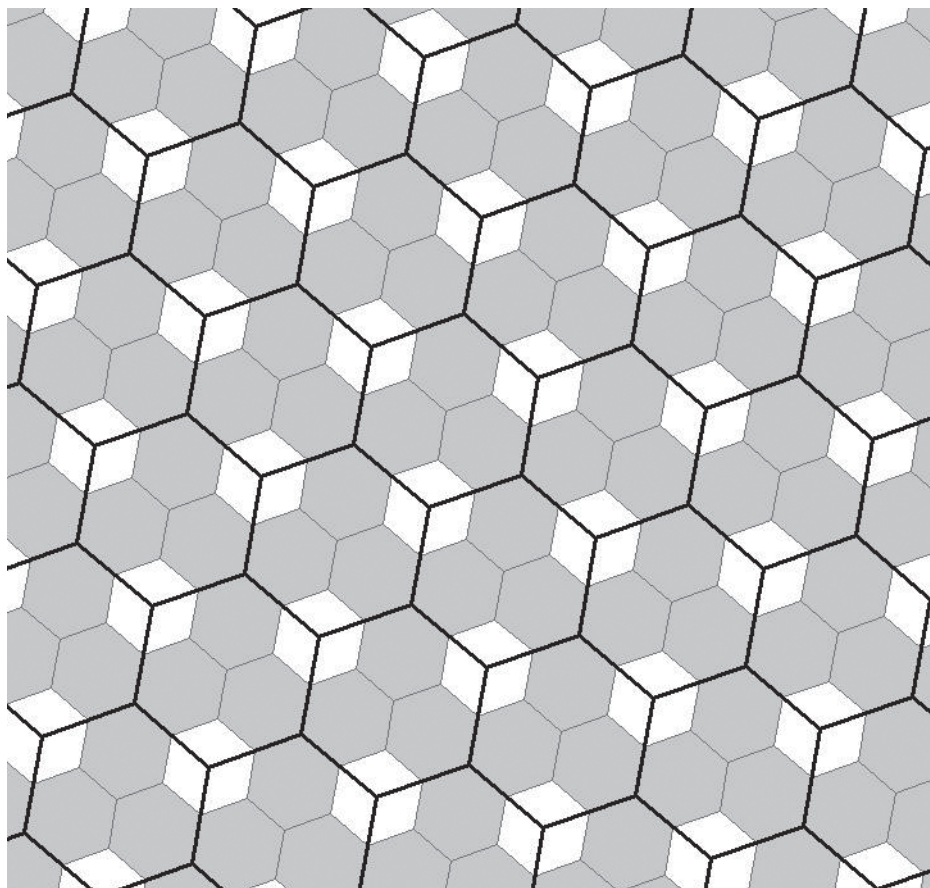


Figure 9—Depiction of a 4x intensification of hexagons using the R5 method (courtesy of Joe McCollum, SRS-FIA).

The python script for this method is relatively self-contained, but must be edited to specify the input and output file geodatabase feature classes, as well as listing the attribute names to be copied over to the child sub-hexes. Other considerations are needed to properly execute this script, such as the geographic location of the study area and projection of the spatial data, which may influence the orientation standard used in the script. After running this script, the user-specified output geodatabase will contain the resulting feature class containing the corresponding sub-hexes. A few GIS operations are needed to “nest” the three partial sub-hexes, along with the three full sub-hexes, within each parent P2 hex. Afterwards, using the same procedures outlined for the GRID method, an intensified plot is randomly placed within each sub-hex area, along with its intensity number and panel.subpanel assignments.

The intensified plots are then clipped to the BNF boundary, based on their plot center location. The resulting intensified plots within a given P2 hex using the R5 method is given in figure 10.

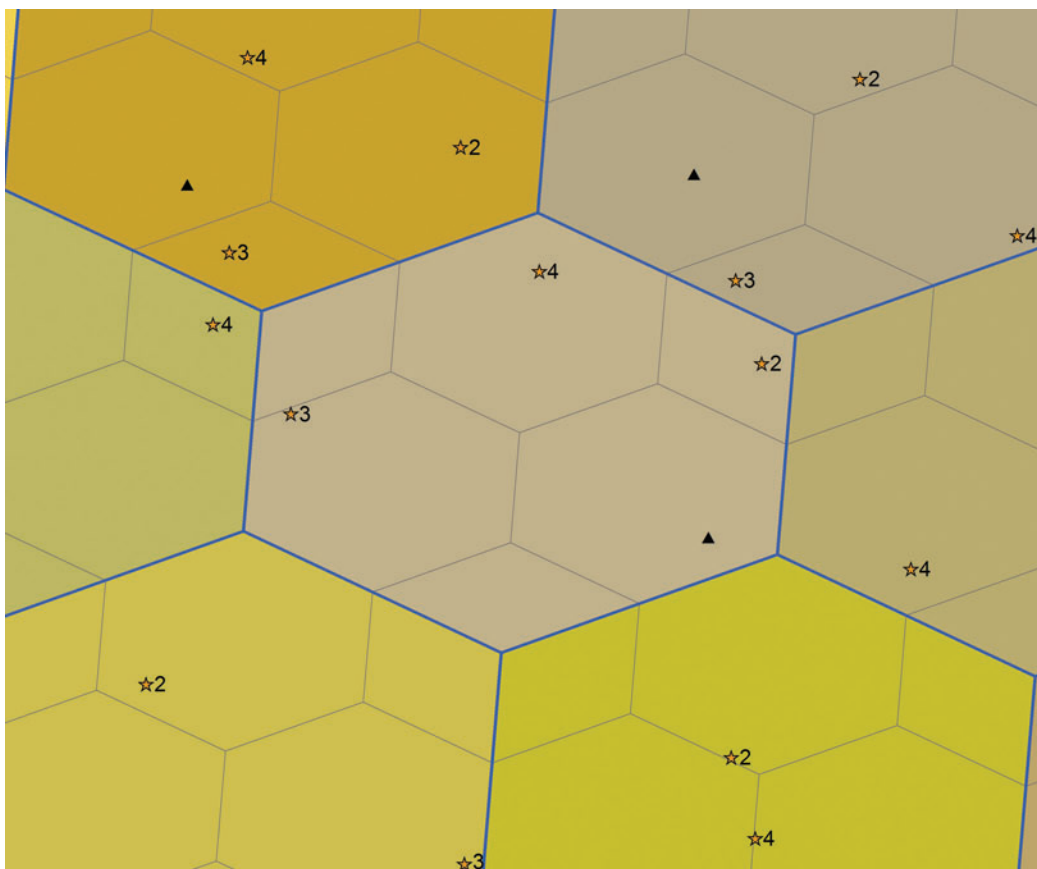


Figure 10—Intensified plots for a given P2 hex using the R5 method. Existing FIA plots are shown as black triangles, randomly placed intensified plots are gold stars, and the labels identify the corresponding intensity number for each intensified plot.

The program for this method was written as a python script by Kirk Evans, GIS Analyst at Tetra Tech, and a contractor for the USFS Region 5 Remote Sensing Laboratory of McClellan, California.

NIMAC or Space-Filling Curves (SFC) Method

The NIMAC or Space-Filling Curves (SFC) method has been advocated by the USFS NIMAC (National Inventory and Monitoring Applications Center) group for various intensification tasks. This method was initiated by Andy Lister of the Northern Research Station FIA (NRS-FIA) (Lister and Scott 2008; contact information in Appendix A). It is similar to the GRID method in that it splits a P2 hex into smaller, nested polygons, and it supports any integer level of intensification. However, one difference between this method and the GRID method is that the smaller polygons can exhibit varied and irregular shapes compared to the hexagon patterns of the GRID or R5 methods. Figure 11 shows how hexagons may be decomposed using the SFC method, with examples of a 2x to 7x intensification.

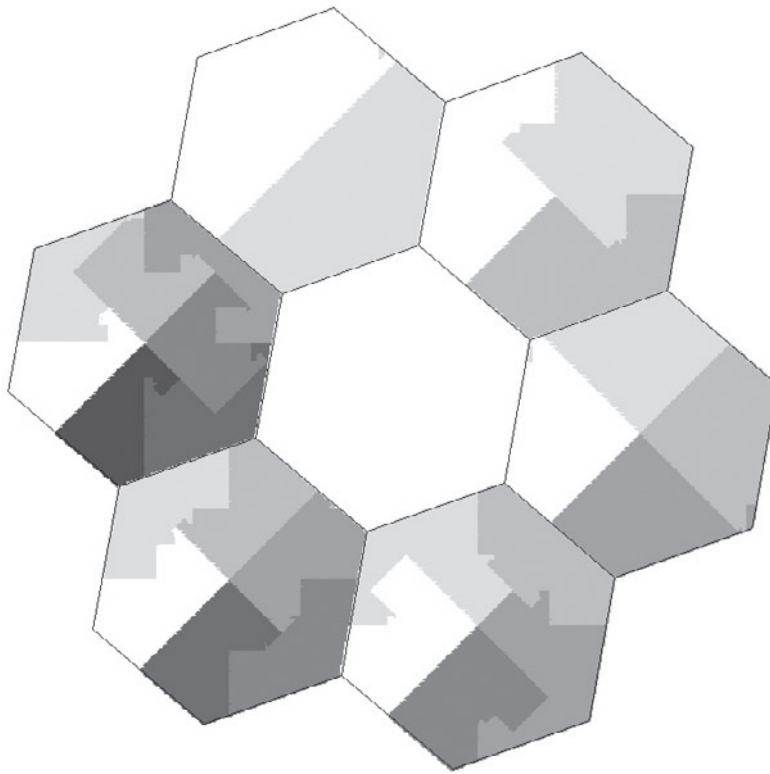


Figure 11—Sample output (2x-7x intensification) using the NIMAC or Space-Filling Curves (SFC) method (courtesy of Joe McCollum, SRS-FIA).

Two versions of this program are available to the user; one is written in AML (Arc Macro Language) by Andy Lister for use with ArcInfo workstation (see Appendix E), while the other is written in python by Deelesh Mandloi for use with ArcMap (Mandloi 2009).

Using the AML version, the user will need to specify the number of clusters, or pieces, needed for every P2 hex (in our case, a 4x intensification was used). Input layers for the AML include the P2 hex layer (303 P2 hexes for our study), which is converted to a 30-meter raster layer. Afterwards, this grid layer is converted to a point layer, using the centroid position for every pixel of the grid layer; this produces a series of points across the study area at 30-meter spacing. The user can then run the AML script, which will create a polygon coverage depicting the equivalent of sub-hexes (clusters, zones or pieces). Then, a series of GIS operations will result in a polygon shapefile with one feature for each cluster. After the clusters are created, the same procedures outlined for the GRID method is used to randomly place intensified plots within each cluster area, along with assignment of its intensity and panel.subpanel numbers.

The intensified plots are then clipped to the BNF boundary, based on their plot center location. The resulting plots within a given P2 hex using the SFC method is presented in figure 12.

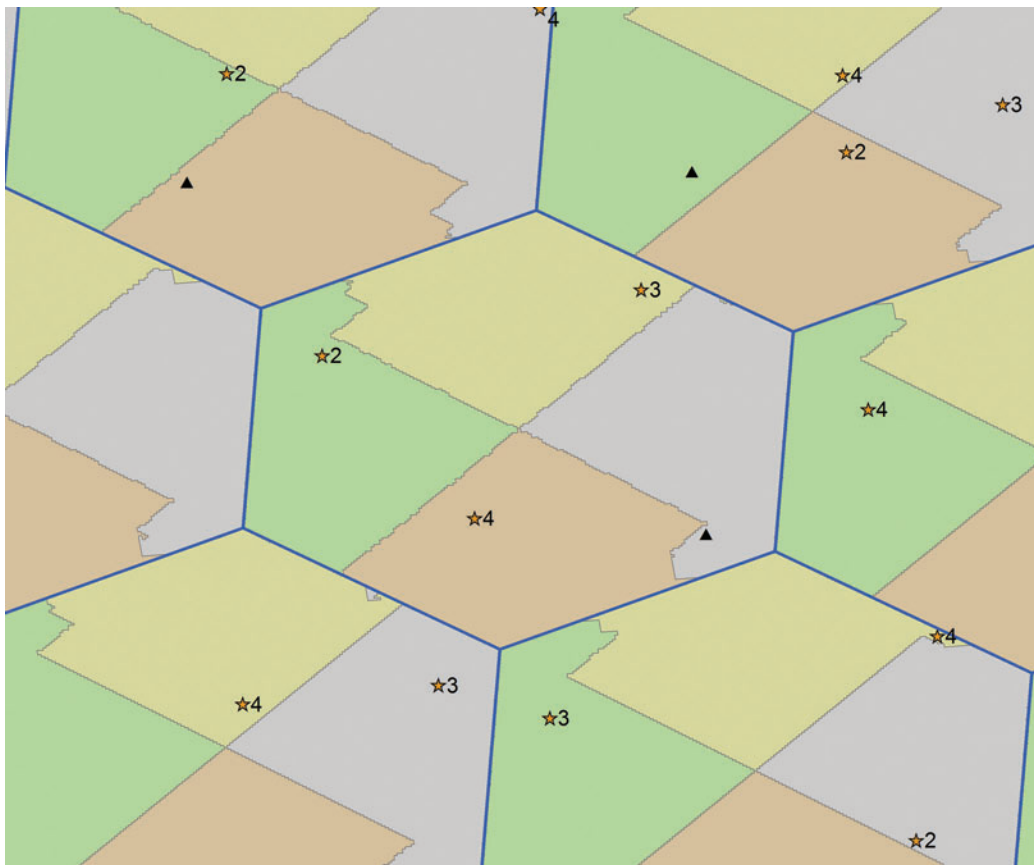


Figure 12—Intensified plots for a given P2 hex using the NIMAC or SFC method. A 4x intensification was generated, with existing FIA plots shown as black triangles, randomly placed intensified plots as gold stars, and the labels identify the corresponding intensity number for each intensified plot.

RIPL Method

The RIPL (Region 1 Intensification Plot Locator) program was written in C# by J.D. Zeiler from USFS Region 1 (contact information in Appendix A), and was developed to support a mid-level inventory system. For USFS Region 1 National Forests, RIPL is used to create intensified plots so additional survey data may be acquired over-and-above that provided by the FIA base grid. RIPL also uses a heuristic that “...maximizes the separation of point distributions while maintaining spatial balance and randomness.” (Zeiler and others 2010). Figure 13 shows a sample output using a 3x intensification, and online documentation from Region 1 is available at: http://fsweb.r1.fs.fed.us/forest/inv/r1_tools/R1_AT.shtml.

As inputs, RIPL requests the level of intensification, the minimum separation between intensifications, the minimum separation between the intensification and its parent plot, and the minimum separation between the intensification and the edge of the study area. Overall, RIPL offers the user a variety of options that it uses as constraints within an optimization (heuristic) problem (Zeiler and others 2010).

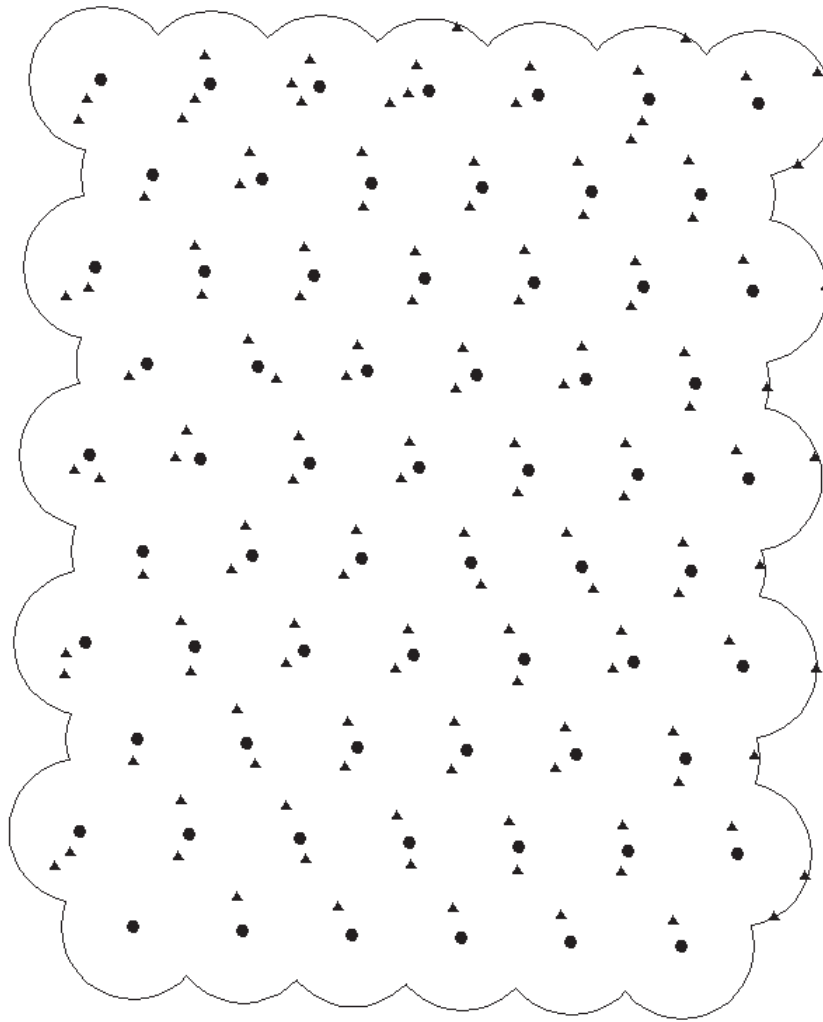


Figure 13—Sample output (3x intensification) using the RIPL method (courtesy of Joe McCollum, SRS-FIA).

As shown in figure 13, RIPL does not specifically produce relatively smaller nested polygons within a P2 hex, as previously discussed intensification methods have done. It will, however, improve spatial balance of intensified plots by utilizing one of the user-defined constraints related to minimum distances between plots.

During our testing of this method, we were unable to access a few required layers since they were only available on R1 SDE servers (RIPL was written specifically as an R1 program). However, it is now available as an ESRI add-in tool that can be used within the USFS CITRIX environment. An additional issue that came up during testing was that a specific number of points could not be constrained within each P2 hex. We were forced to edit the RIPL results so that there were exactly three new intensified plots per P2 hex. After speaking with J.D. Zeiler, it seemed like a relatively easy change for his team to implement, if requested.

In general, the RIPL tool has many desirable qualities, but also a few issues as noted. We remain confident, however, that the RIPL developers are more than capable of making any changes or other customizations needed for this tool.

Following the RIPL procedure, the intensified plots received intensity and panel. subpanel numbers using the same procedures outlined for the GRID method. Then, the intensified plots are clipped to the BNF boundary, based on their plot center location. The resulting intensified plots within a given P2 hex using the RIPL method are shown in figure 14.

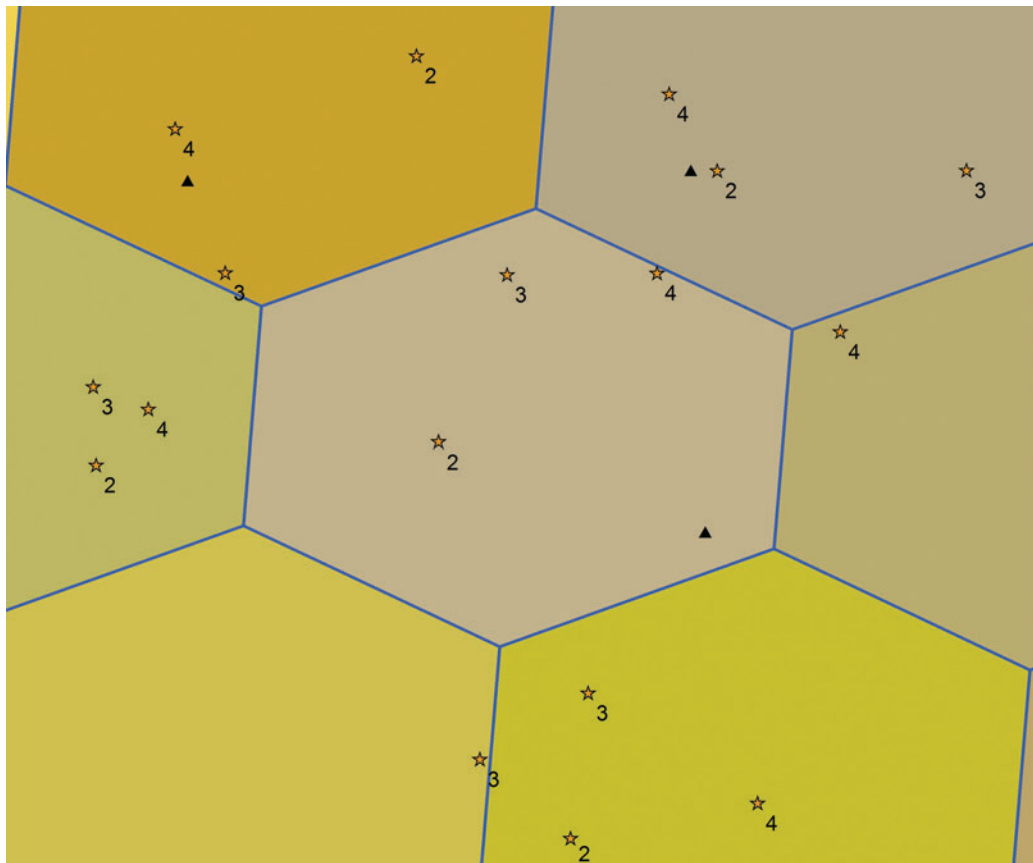


Figure 14—Intensified plots for a given P2 hex using the RIPL method. A 4x intensification was generated, with existing FIA plots shown as black triangles, randomly placed intensified plots as gold stars, and the labels identify the corresponding intensity number for each intensified plot.

Python4x Method

The Python4x method, developed by Tom Thompson (contact information in Appendix A) of the USFS Pacific Northwest Research Station FIA (PNW-FIA), is a python script that generates intensifications at 2x and 4x. Tom has used this script for simple intensifications (primarily 2x) of the FIA base grid in his region.

The Python4x method requires at least python v2.6 software, PYPROJ module and PROJ4 (<http://trac.osgeo.org/proj/>), along with its corresponding environmental variable settings. A CSV file that contains coordinate pairs for the P2 hex center and for existing FIA plots are also needed as input files. The python script is then edited to specify the input and output CSV files, along with the field names that designate the coordinate pairs.

This method does not produce relatively smaller nested polygons within a P2 hex, as with the GRID method. Instead, this method compares the FIA base plot's location to its hex center, and places an intensified point on the opposite side of the hex (for a 2x), at a random distance and somewhat random azimuth. For the 4x, it again compares an FIA base plot's location with its hex center and places points in the other quadrants of the hex (that is, right angles to the 2x bearing). All intensified points are within the same P2 hex as the existing FIA plot, as shown in figure 15. Python4x is an easy script to run and produces intensification results relatively quickly.

Following the Python4x procedure, the intensified plots received intensity and panel.subpanel numbers using the same procedures outlined for the GRID method. Next, the intensified plots are clipped to the BNF boundary, based on their plot center location. The resulting intensified plots within a given P2 hex using the Python4x method are displayed in figure 16.

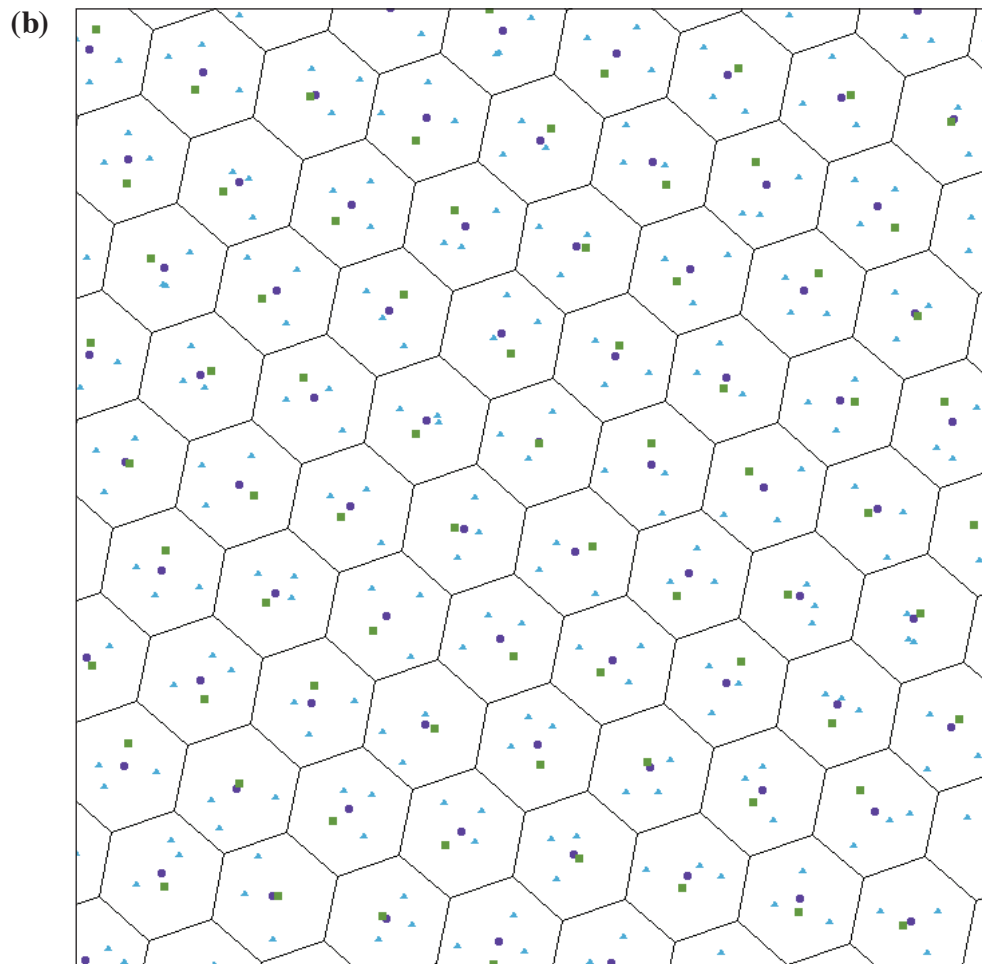
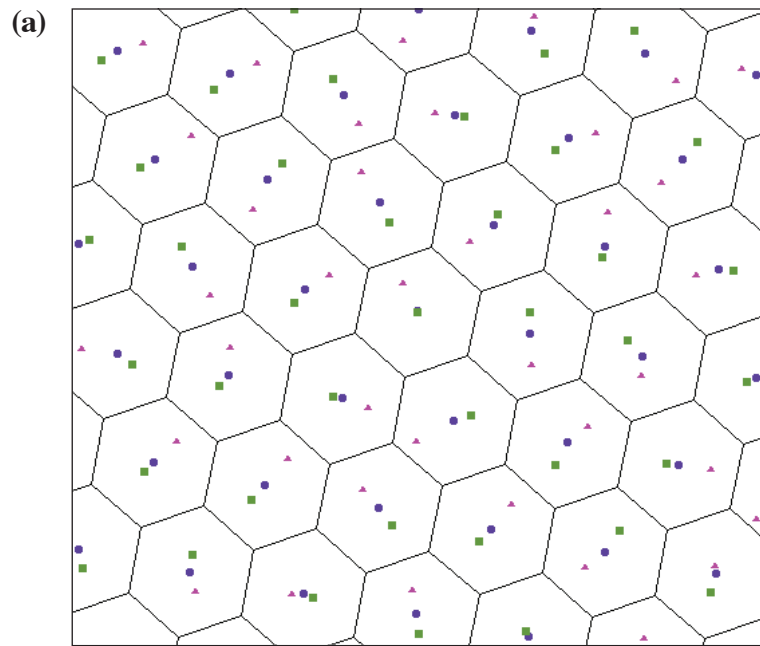


Figure 15—Sample output using the Python4x method, with (a) a 2x intensification and (b) a 4x intensification (courtesy of Joe McCollum, SRS-FIA).

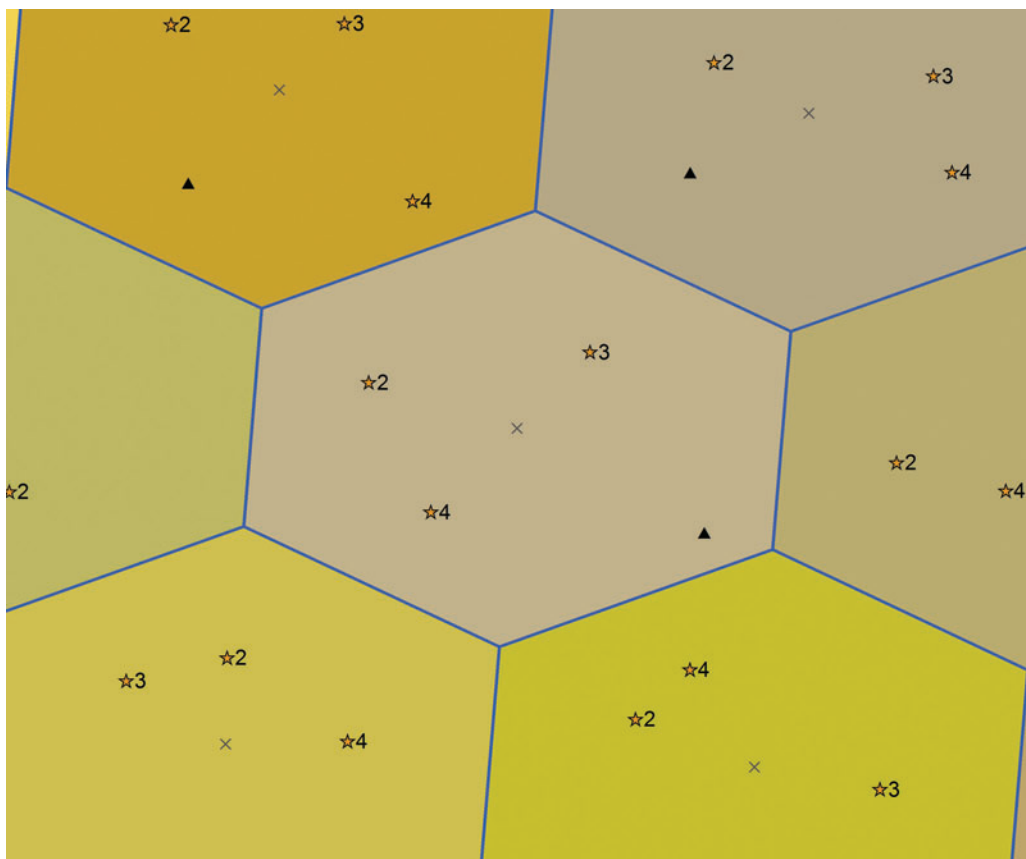


Figure 16—Intensified plots for a given P2 hex using the Python4x method. A 4x intensification was generated, with existing FIA plots shown as black triangles, hex centers are gray x symbols, intensified plots as gold stars, and the labels identify the corresponding intensity number for each intensified plot.

Repeating Shapes Method

The Repeating Shapes (RS) method is a Visual Basic program written by Jeff Jenness of Jenness Enterprises (Jenness 2009), and can be downloaded from the ESRI support page at: <http://arcsripts.esri.com/details.asp?dbid=14695>. It is loaded as a custom tool in ArcMap (ESRI 2009); and with its wizard-type interface, quickly produces hexagons or other types of polygons based on a user-specified area and geographic extent.

However, based on our testing, it does not place intensified hexagons with exact spatial coincidence to the P2 grid, as does the GRID method. There are also situations where two existing FIA plots may be within the same sub-hex, or the centroid of a sub-hex will be in a different P2 hex than that of an existing FIA plot that resides in that sub-hex. Other problematic issues frequently arise due to the overlapping alignment of the sub-hex boundaries in relation to the P2 hex boundaries.

Following the RS procedure, the intensified plots received intensity and panel. subpanel numbers using similar procedures as those outlined for the GRID method. The intensified plots are then clipped to the BNF boundary, based on their plot center location. The resulting intensified plots within a given P2 hex using the RS method are shown in figure 17.

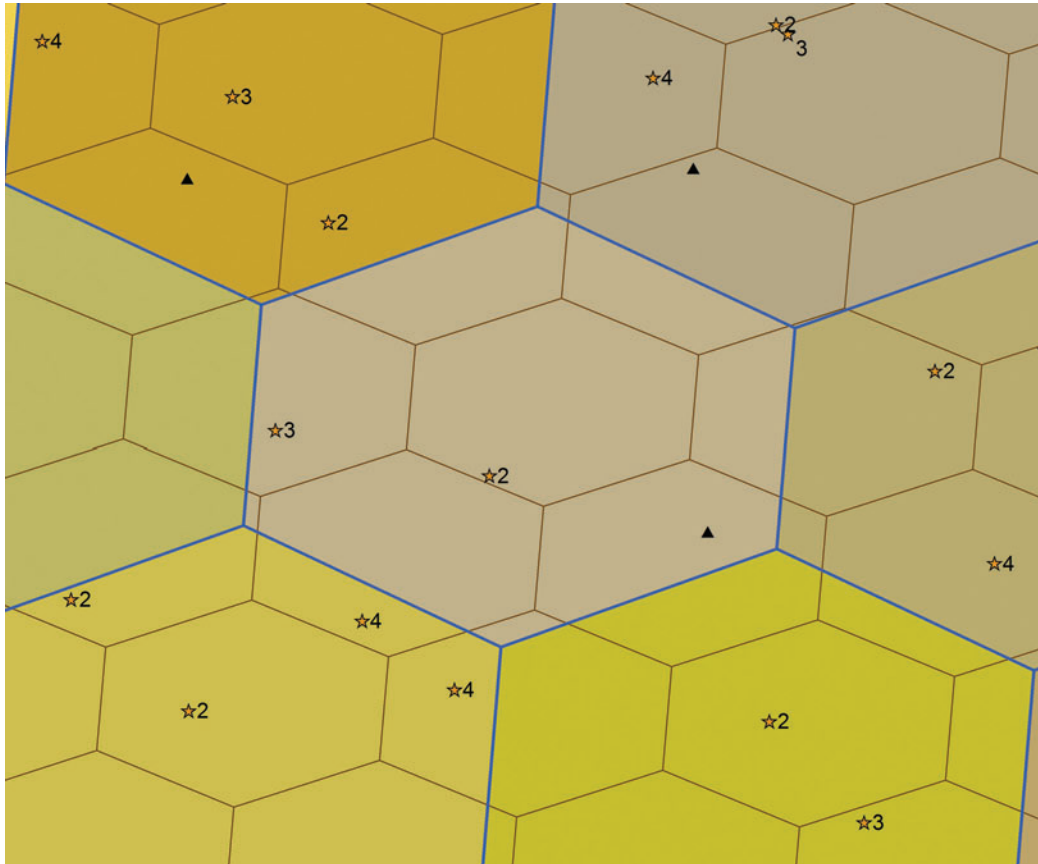


Figure 17—Intensified plots for a given P2 hex using the Repeating Shapes method. A 4x intensification was generated, with existing FIA plots shown as black triangles, randomly placed intensified plots as gold stars, and the labels identify the corresponding intensity number for each intensified plot. Note that the smaller sub-hexes (brown lines) are not spatially aligned with the larger P2 hex (blue lines). There are also situations where two existing FIA plots may be in the same sub-hex. Other problematic issues frequently arise due to the overlapping alignment of the sub-hex boundaries and the P2 hex boundaries.

R4 Method

The R4 method has been used on USFS Region 4 National Forests for intensification tasks by Larry DeBlander, Vegetation Analyst for Region 4 (contact information in Appendix A). This method does not produce relatively smaller nested polygons within a P2 hex, as does the GRID method. Instead, it utilizes historic plots so that previous survey information from those plots may be retained. For Region 4, they attempt to use existing available FIA B-grid plots for their intensification tasks, which are additional FIA plots (not A-grid or base plots) that were established in previous surveys. That way, much of the previous inventory data from B-grid plots are available for further analysis.

Region 4 has many national forests that contain B-grid plots, and plan to utilize those as intensification plots where appropriate. If additional intensification plots are still needed for a specific level of intensification, then randomly placed plots will be added within a given P2 hex after B-grid plots are selected.

FIA B-grid plots were typically established on a grid pattern at roughly 5000 meters spacing between plots. If you can imagine the number 5 as represented on a die; the FIA base plot would be the center dot, while the B-grid plots would be represented by the four surrounding dots. This assumes that the FIA base plot is on a grid pattern as well, which may have been accurate in previous inventory cycles (periodic inventories that preceded the current annual inventory).

For a 4x intensification such as our study, the following decision rules were used when considering B-grid plots. Note that an analyst may need to be involved to determine:

1. If more than three B-grid plots exist per P2 hex, then retain the “best” plots based on:
 - a. the most up-to-date, relevant information to retain for further analysis,
 - b. most recently measured plots,
 - c. closest to the P2 hex centroid,
 - d. other determining factors that may be relevant to future studies.
2. If three or fewer B-grid plots exist per P2 hex, then retain all as intensification plots.
3. If less than three intensified plots still exist per P2 hex, then randomly place additional plot(s) to gain a 4x intensification for each P2 hex.

Following the R4 procedure, the intensified plots received intensity and panel. subpanel numbers using similar procedures as those outlined for the GRID method. Then, the intensified plots are clipped to the BNF boundary, based on their plot center location. The resulting intensified plots within a given P2 hex using the R4 method are shown in figure 18.

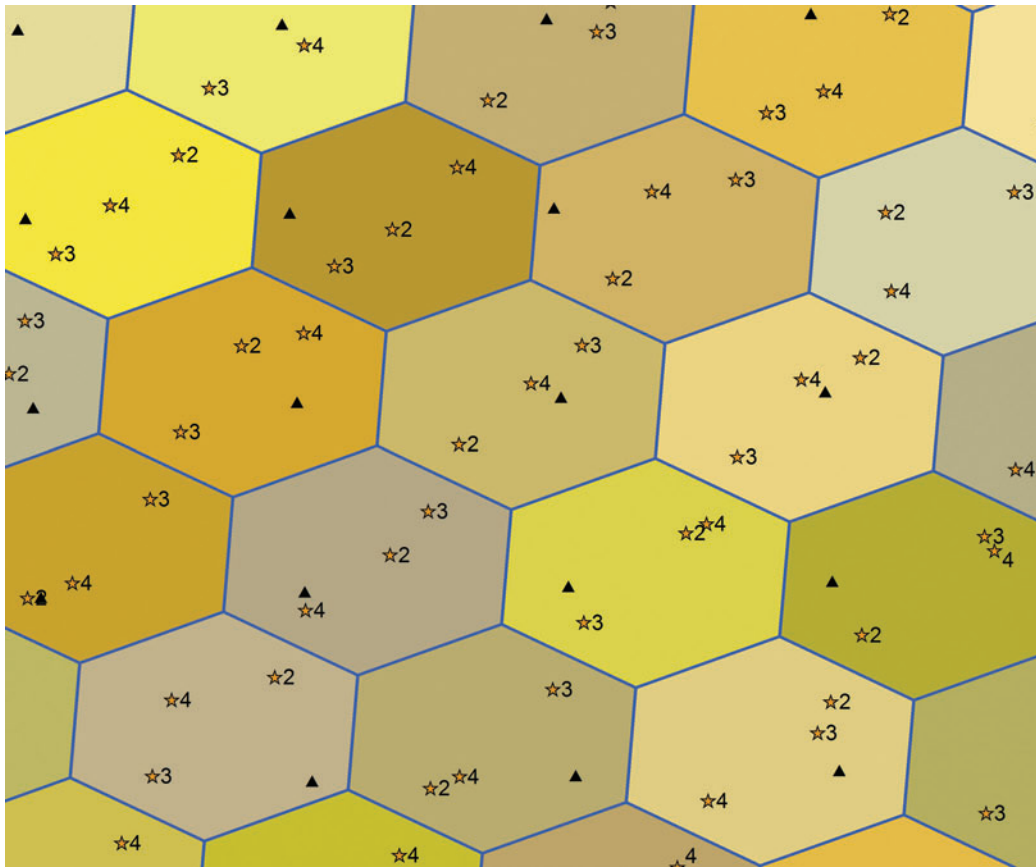


Figure 18—Intensified plots for a given P2 hex using the R4 method. A 4x intensification was generated, with existing FIA plots shown as black triangles, intensified plots as gold stars, and the labels identify the corresponding intensity number for each intensified plot. Note that for this example, there are two B-grid plots for each P2 hex, which are displayed in a somewhat equidistant pattern. The remaining intensified plot for each P2 hex was randomly placed to obtain a 4x intensification.

Simple Random Sample Method

The Simple Random Sample (SRS) method was used primarily as a comparison to the other intensification techniques under consideration. The SRS method does not produce smaller polygons that nest within a given P2 hex, as does the GRID method. Instead, for a 4x intensification, it simply places three randomly located plots within each P2 hex using a simple GIS operation (ESRI ArcGIS Create Random Points tool; ESRI, Inc. 2012). No constraints were placed on minimum distances between plots, etc. when using this method.

Following the SRS process, the intensified plots received intensity and panel. subpanel numbers using similar procedures as those outlined for the GRID method. Next, the intensified plots are clipped to the BNF boundary, based on their plot center location. The resulting intensified plots within a given P2 hex using the SRS method are shown in figure 19.

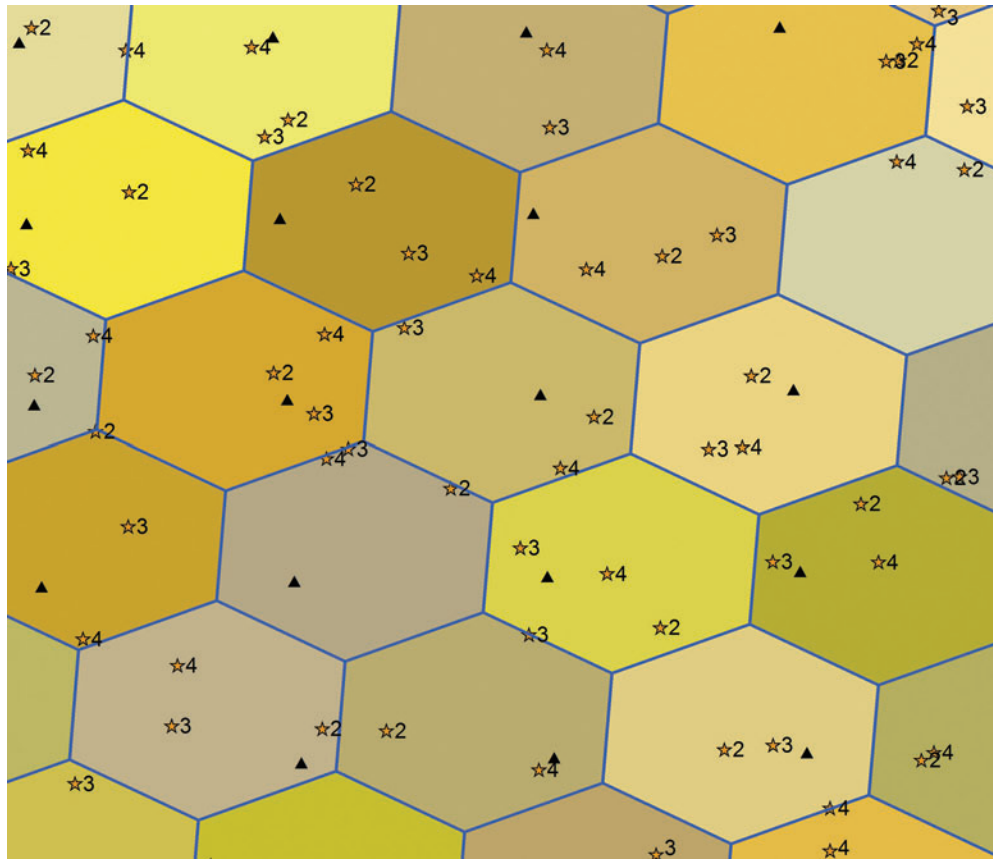


Figure 19—Intensified plots for a given P2 hex using the Simple Random Sample (SRS) method. A 4x intensification was produced by placing three randomly located plots within each P2 hex. Existing FIA plots are shown as black triangles, intensified plots as gold stars, and the labels identify the corresponding intensity number for each intensified plot.

Results

Clark and Evans Statistic

As a comparison for the Clark and Evans (CE) values calculated for the different intensification methods, simulations with 4000 iterations were conducted for various scenarios. The distribution of CE values from the 4000 simulations of a random drawing of one plot location within each of the 303 P2 hexes, after clipping them to the Bighorn NF (BNF) boundary, is shown in figure 20.

Similar simulations with no P2 hex constraint imposed (303 plots randomly placed within the P2 hex boundary) were also conducted. The distribution of CE values from the 4000 simulations of a random drawing of 303 plot locations within the P2 hex boundary, following clipping to the BNF boundary, is provided in figure 21. Note the bell-shaped pattern and mean value obtained from these simulations. The difference in mean values between these two examples is due to the constraint of placing one random plot location within each of the P2 hexes, as opposed to not having this constraint and randomly placing all 303 plot locations within the overall boundary of the 303 P2 hexes.

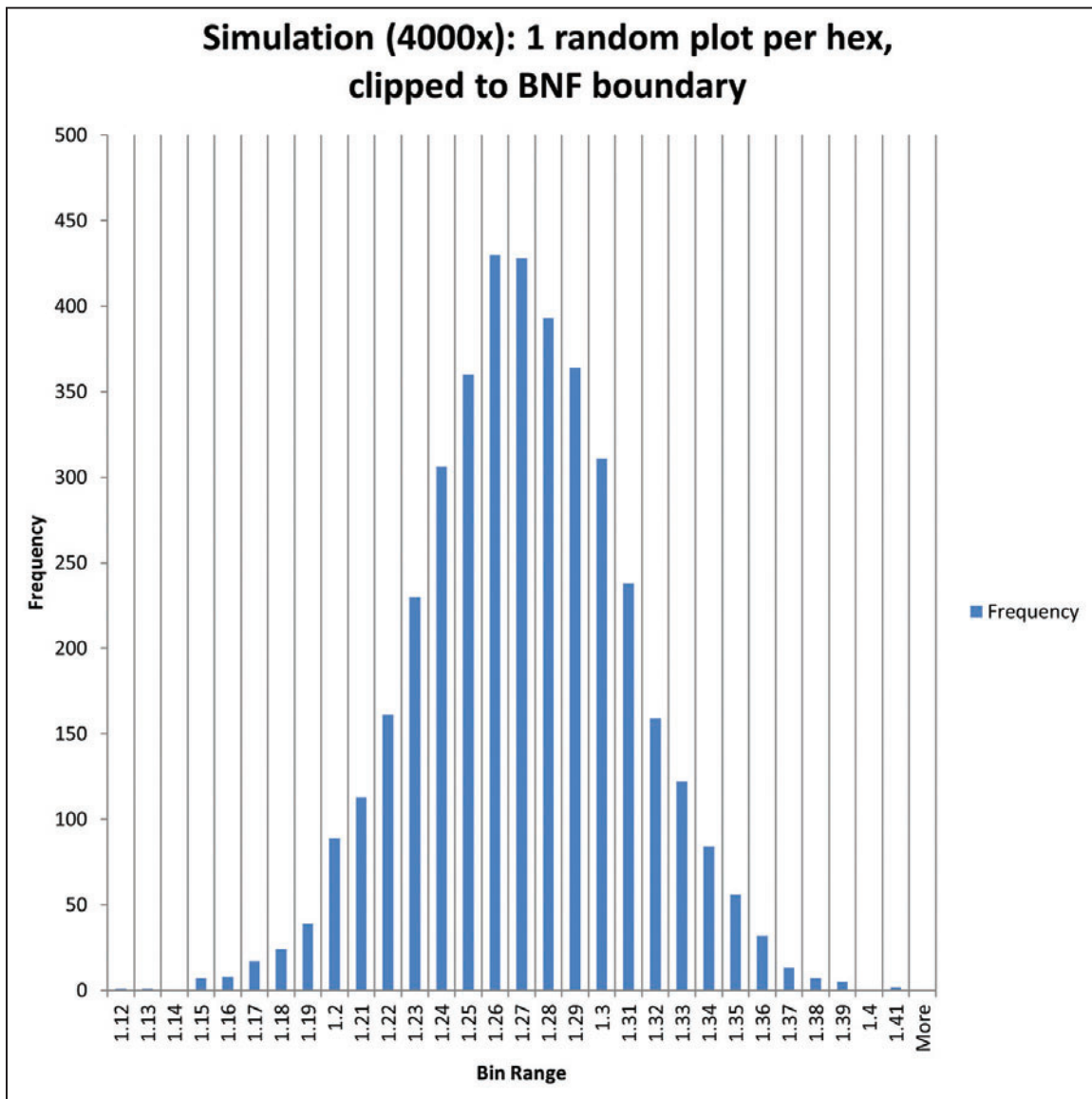


Figure 20—Distribution of Clark & Evans statistic values from 4000 simulation runs of a randomly- placed plot located within each of the 303 P2 hexes, clipped to BNF boundary (~186 plots). The mean of the distribution is: 1.265407, a standard deviation of: 0.03853602, and a standard error of: 0.000609308. The cdf estimate of the CE statistic (which has edge correction) was used, as opposed to the naïve estimate (no edge correction).

The means and other summary statistics obtained from these two simulation runs of CE values are also presented in table 1. Note that the “naïve” estimate provides a CE estimate without an edge correction applied, while the “cdf” estimate is a cumulative distribution function method that has an edge correction. For those simulations with a P2 hex constraint, the mean CE values (cdf estimate) are near 1.26, which tends to imply a more uniform distribution than those simulations with no hex constraint. The mean CE values (cdf estimate) for those simulations without a P2 hex constraint are near 1.0, which indicates a random point distribution, and is what would be expected based on theoretical properties of the CE estimator.

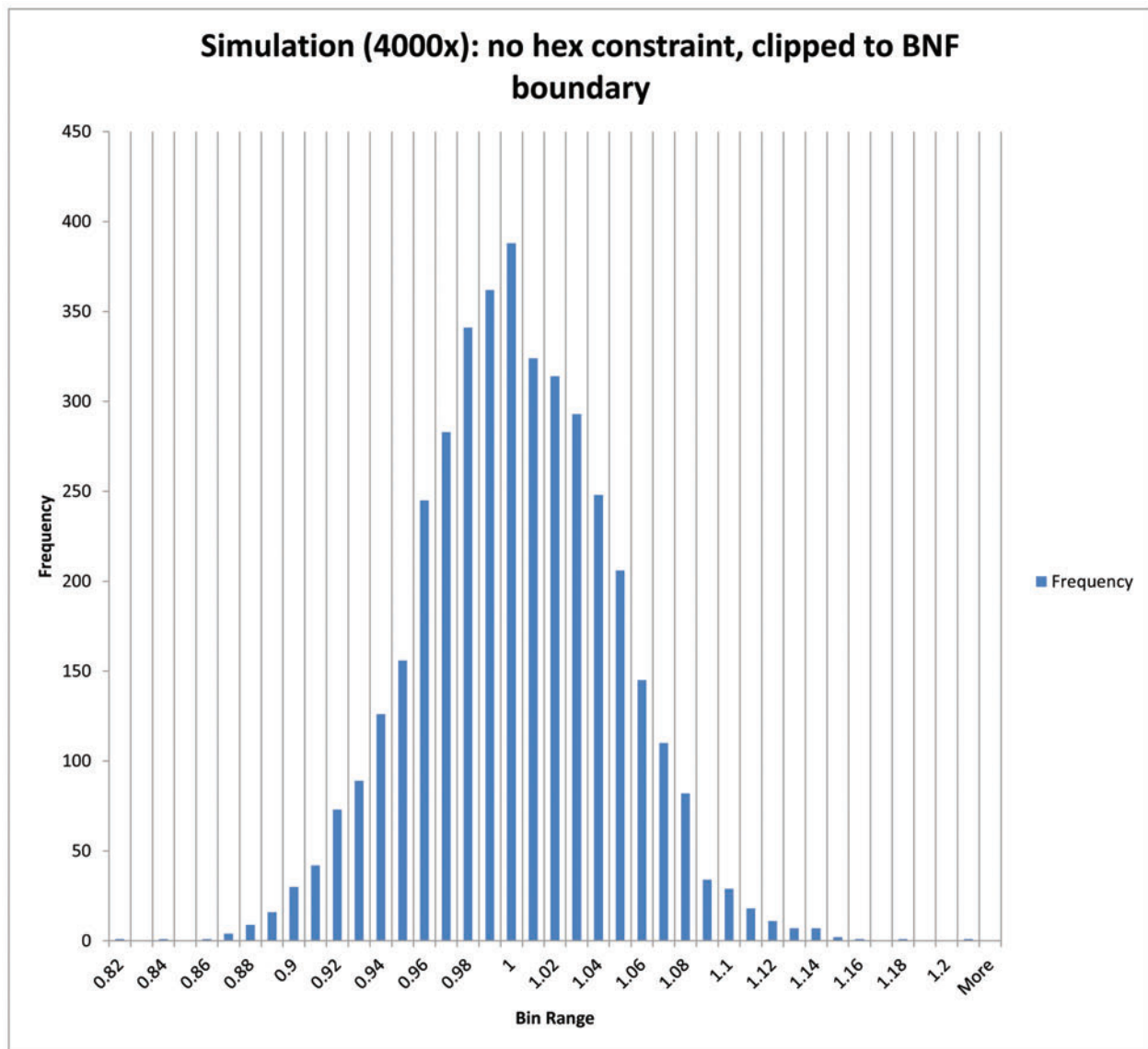


Figure 21—Distribution of Clark & Evans statistic values from 4000 simulation runs of a randomly placed plot not constrained within the P2 hexes, clipped to BNF boundary (~187 plots). The mean of the distribution is: 0.996654, a standard deviation of: 0.04430584, and a standard error of: 0.000700537. The cdf estimate of the CE statistic (which has edge correction) was used, as opposed to the naïve estimate (no edge correction).

For additional comparisons, table 2 lists the CE values obtained from various representative sets of plots, which may provide a reference against those CE values obtained from our candidate intensification methods. Note that when one random plot per P2 hex was produced, the resulting CE value (cdf estimate) is near 1.264, which is similar to the 1.269173 mean value obtained from the 4000x simulation runs listed in table 1. For the 303 random plots with no P2 hex constraint, the CE value (cdf estimate) is near 0.933, which is closer to a more random point distribution value of 1.0 than compared to those distributions created with a P2 hex constraint. For the existing FIA plots on the BNF (from the Annual Field Control table entry), the CE value was 1.696, which implies a more uniform distribution than the randomly placed plots (with or without a hex constraint). For the 303 P2 hex centroids, the CE value was 2.023, which is near the upper limit of 2.14 and suggests a more uniform distribution.

Table 1—Four examples of Clark and Evans (CE) statistic values obtained from 4000 simulation runs. Variations include a randomly placed plot either constrained or not constrained within each P2 hex, and clipped or not clipped to the BNF boundary. Various statistics are presented for each of the variations. Clark and Evans values range from 0 (maximum aggregation) to 2.1491 (maximum spacing). A CE value of 1 indicates a random distribution.

FIA plot examples	Description	Mean CE value				95% Conf. Interval for MEAN (sigma unknown)						Standard Deviation		Standard Error	
		naïve		cdf		lower	naïve	upper	cdf	lower	upper	naïve	cdf	naïve	cdf
303 P2 hexes 1 random plot/hex	SIM: 4000x	1.322872	1.322872	1.269173	1.269173	1.322000	1.322000	1.323744	1.323744	1.268306	1.270040	0.028132	0.027977	0.000445	0.000442
303 P2 hexes no hex constraints	SIM: 4000x	1.029719	1.029719	0.996841	0.996841	1.028741	1.028741	1.030697	1.030697	0.995841	0.997841	0.031550	0.032266	0.000499	0.000510
303 P2 hexes 1 random plot/hex CLIP BNF bdry (~186 plots)	SIM: 4000x	1.315822	1.315822	1.265407	1.265407	1.314693	1.314693	1.316952	1.316952	1.264212	1.266601	0.036437	0.038536	0.000576	0.000609
303 P2 hexes no hex constraints CLIP BNF bdry (~187 plots)	SIM: 4000x	1.048368	1.048368	0.996654	0.996654	1.047048	1.047048	1.049689	1.049689	0.995280	0.998027	0.042595	0.044306	0.000673	0.000701

Table 2—Clark and Evans (CE) statistic values obtained from various sets of plots for comparison purposes. Note that the Annual Field Control table entry represents FIA plots across portions of Wyoming and Montana that overlap the study area (303 P2 hexes around the Bighorn National Forest boundary). Clark and Evans values range from 0 (maximum aggregation) to 2.1491 (maximum spacing). A CE value of 1 indicates a random distribution.

Plot Category	Description	Number of plots	CE value (R)	
			naïve	cdf
Annual Field Control (AFC) table	1 plot per hex, nearest 5000m plot	303	1.710588	1.696813
1 random plot per hex	Bighorn NF case study	303	1.331633	1.264272
303 random plots (no P2 hex constraint)	Bighorn NF case study	303	1.002502	0.933883
1 random plot/hex clipped to BNF boundary	Bighorn NF case study	186	1.298888	1.266688
303 random plots clipped to BNF boundary (no P2 hex constraint)	Bighorn NF case study	187	0.972237	0.912466
P2 hex centroids	centroid of P2 hex	303	2.02662	2.02347

The CE values for the eight intensification methods, *intensified* plots only and *clipped* by the BNF boundary, are shown in table 3. Also, the CE values for the eight intensification methods, *FIA base and intensified* plots combined and *clipped* by the BNF boundary, are shown in table 4. Note that the cdf estimate for a majority of these methods has a CE value that ranges near 1.2; while RIPL, SRS and R4 methods are closer to 1.0.

Table 3—Clark and Evans (CE) statistic values for the eight intensification methods: intensified plots only, all plots clipped within the BNF boundary, and estimates adjusted by the BNF boundary. Clark and Evans statistic values range from 0 (maximum aggregation) to 2.1491 (maximum spacing). A CE value of 1 indicates a random distribution.

Method (4x intensification)	Description	Number of plots	CE value (R)	
			naïve	cdf
RIPL_4x_ex1 (default distance constraints)	no constraint of 3 INT. plots per hex	553	1.278268	1.235146
RIPL_4x_ex2 (zero distance constraints)	no constraint of 3 INT. plots per hex	551	0.9879712	0.954247
RIPL_4x_ex3 (zero distance constraints)	edited RIPL output to have 3 INT. plots per hex	553	0.9985097	0.954535
Simple Random Sampling (SRS)	ArcGIS Create Random Points	559	1.067604	1.030549
GRID	Southern Research Station	560	1.205294	1.18114
R5	R5: python script	549	1.241144	1.206019
Repeating Shapes	ESRI support script	518	1.246039	1.213996
NIMAC (Space-Filling Curves)	Andy Lister's AML	565	1.304317	1.256817
R4	R4: B-grids	560	1.130563	1.107566
Python4x	Tom Thompson's python script	552	1.268993	1.214638

Table 4—Clark and Evans (CE) statistic values for the eight intensification methods when intensified plots are combined with the 303 FIA base grid plots, all plots clipped within the BNF boundary, and estimates adjusted by the BNF boundary. Clark and Evans statistic values range from 0 (maximum aggregation) to 2.1491 (maximum spacing). A CE value of 1 indicates a random distribution.

Combined with MT-WY AFC table plots (n = 192)			
Method (4x intensification)	Number of plots	CE value (R)	
		naïve	cdf
RIPL_4x_ex1	745	1.039565	1.023244
RIPL_4x_ex2	743	0.9821773	0.9539735
RIPL_4x_ex3	745	0.9701635	0.9345374
Simple Random Sampling (SRS)	751	1.048709	1.004608
GRID	752	1.231287	1.199543
R5	741	1.243387	1.209682
Repeating Shapes	710	1.282263	1.251283
NIMAC (Space-Filling Curves)	757	1.289631	1.251443
R4	752	1.073348	1.059302
Python4x	744	1.350058	1.299343

Ripley's K Statistic

As a comparison for the Ripley's K (K) values calculated for the different intensification methods, K values were derived for various sets of plots. Ripley's K values for a randomly placed plot located within each of the 303 P2 hexes, after being clipped to the BNF boundary, is given in figure 22. Note that a statistically significant dispersed (uniform) pattern versus a random distribution exists at relatively shorter distances. Using the ESRI ArcGIS Average Nearest Neighbor script (ESRI, Inc. 2012), the mean distance between these plot locations was found to be 3193 meters, which seems to be where the actual K values line begins to trend upward towards the 95% confidence bands of a random distribution. That inflection point in the actual K values line is consistent with gaining several new neighbors at that distance, which would typically move the trend line from a relatively dispersed pattern toward a more clustered pattern. As the distance increases and additional neighbors are obtained, the actual K values line eventually moves into the 95% confidence band. The abrupt changes in slope of the actual K values line may be affected by a relatively sudden increase in neighbors at a certain distance, or possibly an edge effect influence where points would not have a full complement of neighbors.

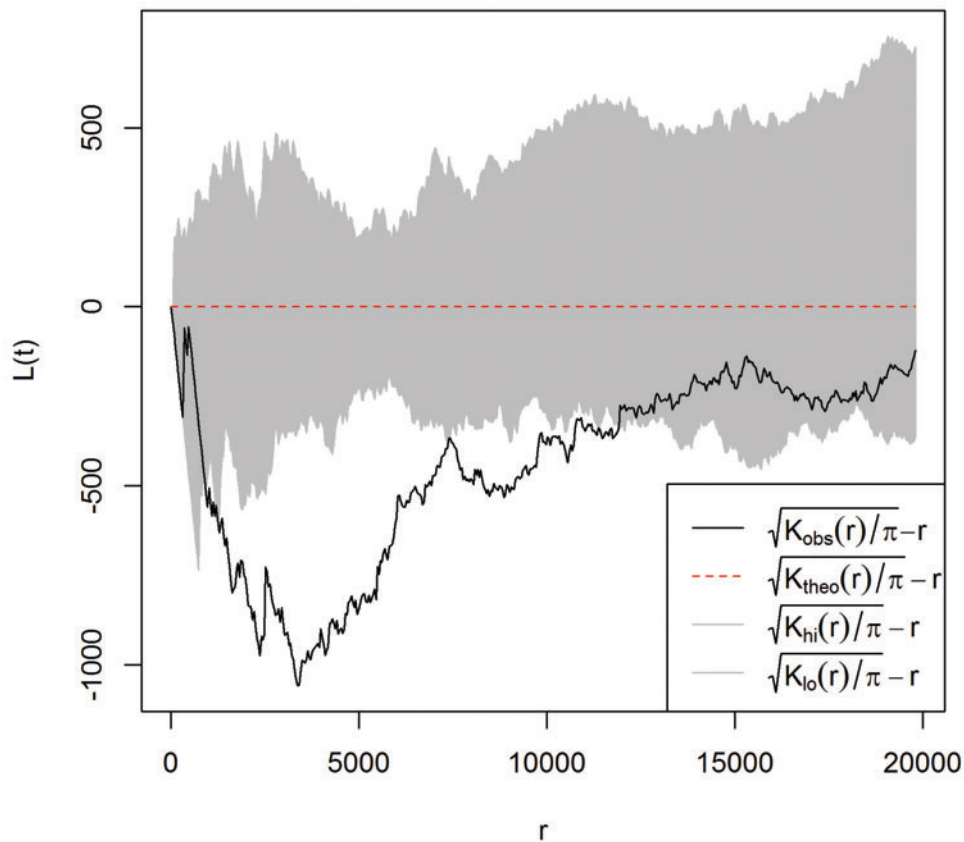


Figure 22—Ripley's K statistic values for a randomly placed plot located within each of the 303 P2 hexes, clipped to BNF boundary (~186 plots), where the mean distance between plots is 3193 meters. The horizontal axis indicates distances in meters, while the red-line is the theoretical K value and the shaded area represents a 95% confidence band for this K estimate.

K values were also calculated for plots with no P2 hex constraint imposed (303 plots randomly placed within the P2 hex boundary). The distribution of K values from a random drawing of 303 plot locations within the P2 hex boundary, clipped to the BNF boundary, is provided in figure 23. The mean distance between these plot locations is 2383 meters, which is a much shorter distance than that obtained with the P2 hex constraint in place (figure 22). Note that without the P2 hex constraint in place, a large majority of K values for these plots are within the 95% confidence bands.

For additional contrasts to the intensification methods, graphs of the K values were created for existing FIA base plots as well as P2 hex centroids. In figure 24, K values are shown for the existing FIA base plots within the study area's 303 P2 hexes, after this plot set has been clipped to the BNF boundary (192 FIA plots). The mean distance between these plot locations is 4196 meters, which is somewhat near the point where the actual K values line begins moving upward

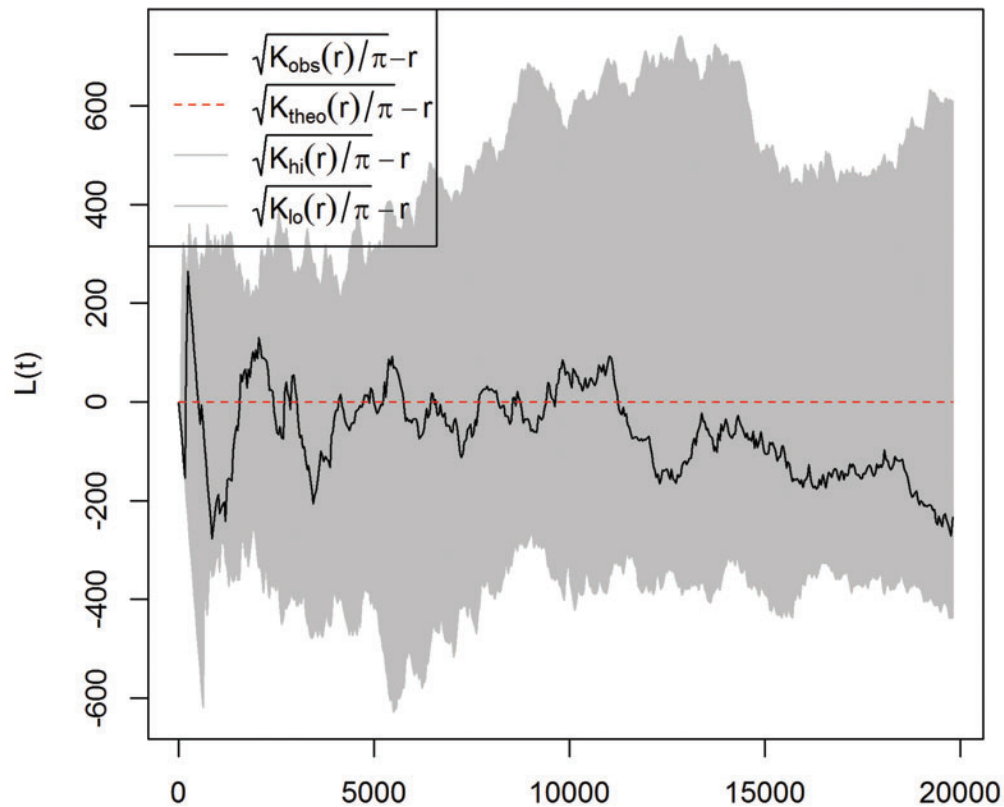


Figure 23—Ripley's K statistic values for randomly placed plots not constrained within the P2 hexes, clipped to BNF boundary (~187 plots), where the mean distance between plots is 2383 meters. The horizontal axis indicates distances in meters, while the red-line is the theoretical K value and the shaded area represents a 95% confidence band for this K estimate.

towards the 95% confidence bands. This figure displays a similar trend as shown in figure 22 regarding statistically significant dispersion patterns at relatively shorter distances. The somewhat irregular, spiky pattern shown in figure 24 may be due in part to the manner in which the existing FIA base plots were selected. FIA plots had previously been established along a 5000 meter grid in Wyoming. After the annual inventory system was initiated and P2 hexagons were created, the closest existing plot to the P2 hex centroid was selected to represent that particular P2 hex. Consequently, the FIA base plots in Wyoming are typically more uniformly spaced at approximately 5000 meters when compared to creating a randomly selected point within a given P2 hex. This spatial pattern is also evident when comparing the mean distance of the existing FIA base plots for figure 24 (4196 meters) to that of the randomly placed plot locations for figure 22 (3193 meters).

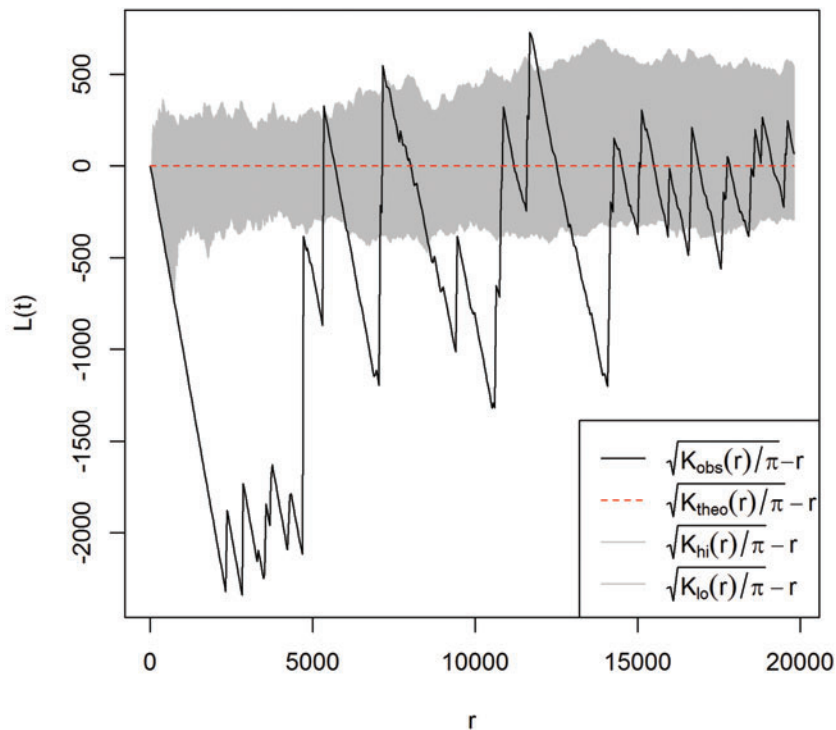


Figure 24—Ripley's K statistic values for the existing FIA base plots within the 303 P2 hexes, clipped to BNF boundary (192 FIA plots), where the mean distance between plots is 4196 meters. The horizontal axis indicates distances in meters, while the red-line is the theoretical K value and the shaded area represents a 95% confidence band for this K estimate.

Figure 25 provides K values for the centroids of the 303 P2 hexagons after being clipped by the BNF boundary (183 plots). The mean distance between these plot locations was found to be 4972 meters, which is about where the actual K values line begins to move upward towards the 95% confidence bands of a random distribution. This figure was expected to indicate a somewhat uniform distribution (below the red-line), which is generally the case. However, the actual K value line is very erratic, jumping from a dispersed (or uniform) to a clustered pattern over relatively short distances. This pattern is likely a result of the number of new neighbors (typically six in this scenario) being acquired over specific intervals, which likely causes the actual K line to move from dispersed (below the lower 95% confidence band) to clustered (above the upper 95% confidence band).

For example, as shown in figure 25, the actual K line slope changes abruptly near 5000 meters, moving sharply from a dispersed to a clustered pattern. This tends to correlate with the mean distance of 4972 meters, where six new neighbors are gained. From this point, there will be no new neighbors until about 9000 meters, where six new neighbors are again added, and the actual K line moves upward from about 9000 meters to near 1100 meters. Consequently, this pattern repeats itself over increasing distances for the P2 hex centroid plots, as new neighbors are gained at specific intervals (Joe McCollum, USFS, personal communication, 2014).

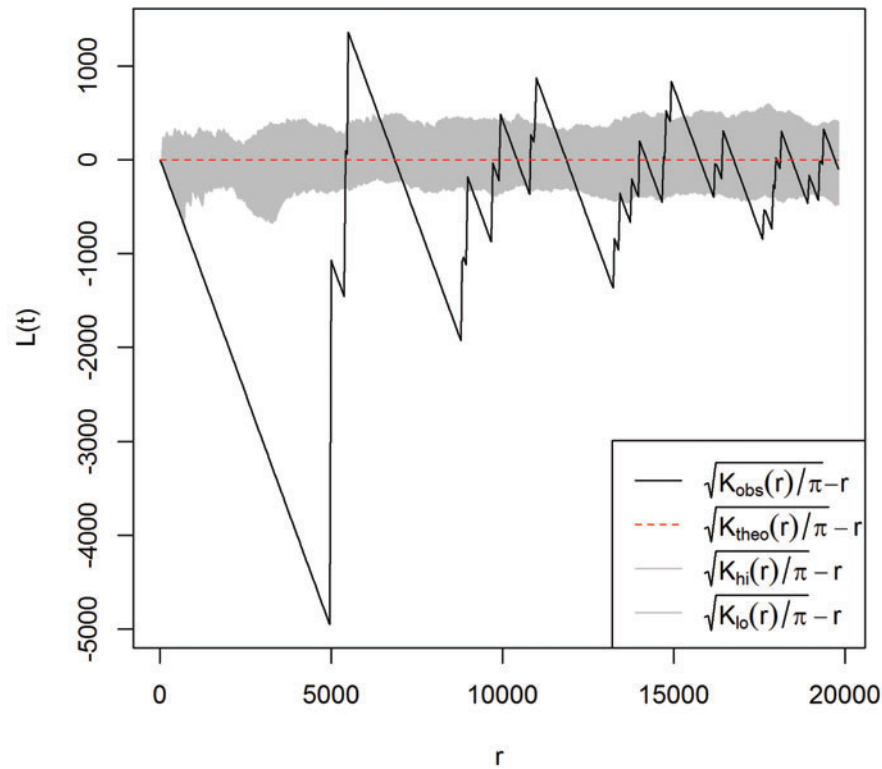


Figure 25—Ripley's K statistic values for the P2 hex centroid points within the 303 P2 hexes, clipped to BNF boundary (183 plots), where the mean distance between plots is 4972 meters. The horizontal axis indicates distances in meters, while the red-line is the theoretical K value and the shaded area represents a 95% confidence band for this K estimate.

Next, K values for the eight intensification methods under consideration were determined. For each method, K values were calculated for FIA base and intensified plots combined within the 303 P2 hexes, then clipped to the BNF boundary.

For the GRID method, K values are given in figure 26. Next, the K values for the R5 method are shown in figure 27, while those for the NIMAC or SFC method are provided in figure 28. The RIPL method is given in figure 29, and the Python4x method is displayed in figure 30. The Repeating Shapes method is provided in figure 31, with the R4 method given in figure 32. Finally, the Simple Random Sample (SRS) method is shown in figure 33.

All of these distributions tend to initially fall below the lower 95% band and then “bottom-out” near their mean distance value, and then climb within the 95% band range at longer distances. These are similar results as those for the previous plot sets examined, where a statistically significant dispersed (uniform) pattern (compared to a random distribution) exists at relatively shorter distances. As previously noted, the overall trend seems to become more randomly distributed as distance increases and more neighbors are obtained.

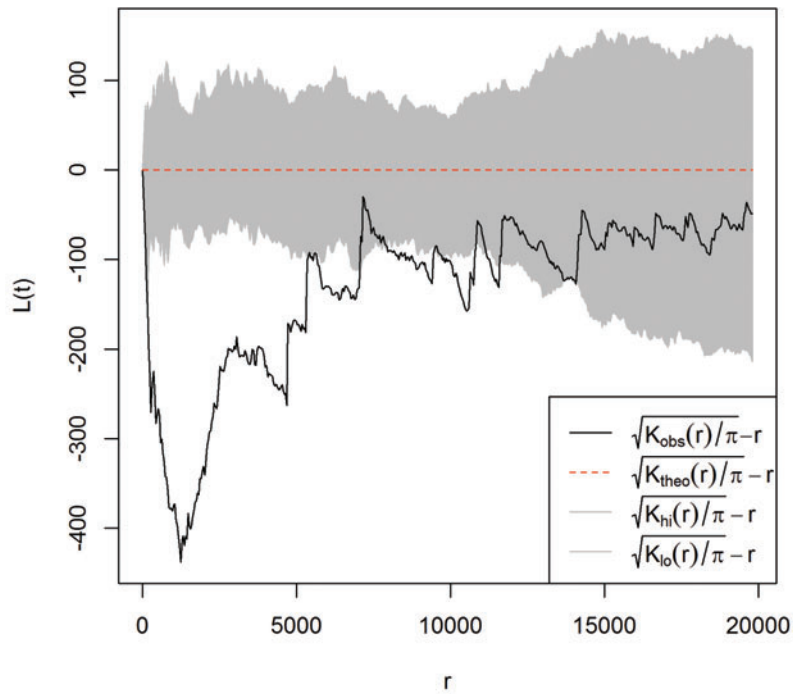


Figure 26—Ripley's K statistic values for the GRID method (includes 192 FIA base plots and 560 intensified plots), clipped to BNF boundary (752 total plots), where the mean distance between plots is 1505 meters. The horizontal axis indicates distances in meters, while the red-line is the theoretical K value and the shaded area represents a 95% confidence band for this K estimate.

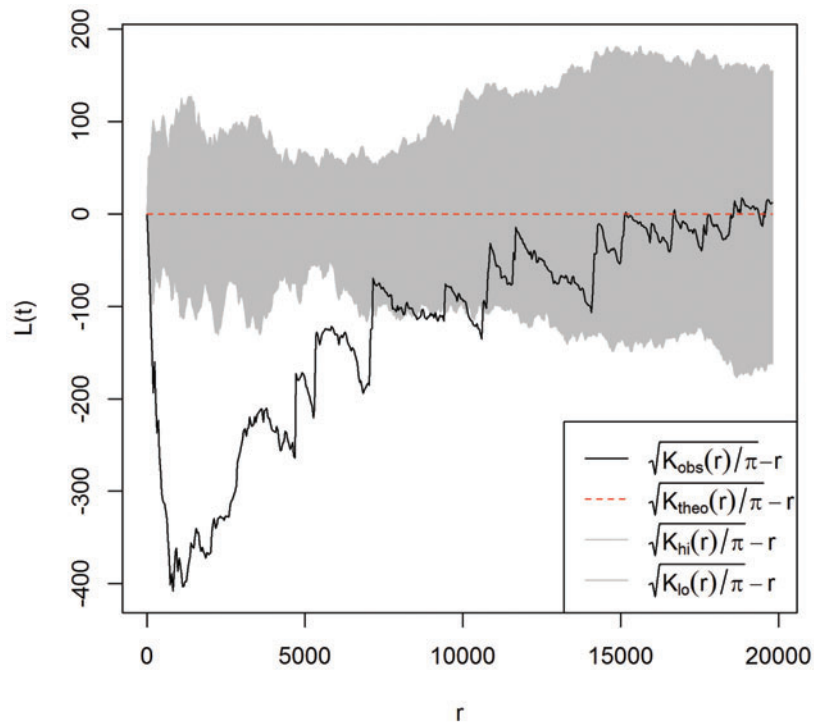


Figure 27—Ripley's K statistic values for the R5 method (includes 192 FIA base plots and 549 intensified plots), clipped to BNF boundary (741 total plots), where the mean distance between plots is 1531 meters. The horizontal axis indicates distances in meters, while the red-line is the theoretical K value and the shaded area represents a 95% confidence band for this K estimate.

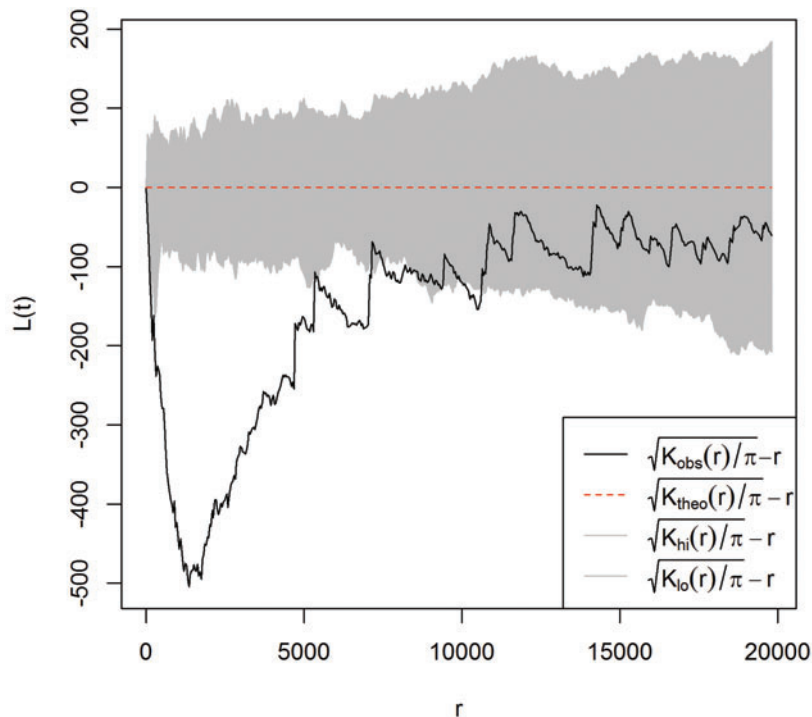


Figure 28—Ripley's K statistic values for the NIMAC or SFC method (includes 192 FIA base plots and 565 intensified plots), clipped to BNF boundary (757 total plots), where the mean distance between plots is 1571 meters. The horizontal axis indicates distances in meters, while the red-line is the theoretical K value and the shaded area represents a 95% confidence band for this K estimate.

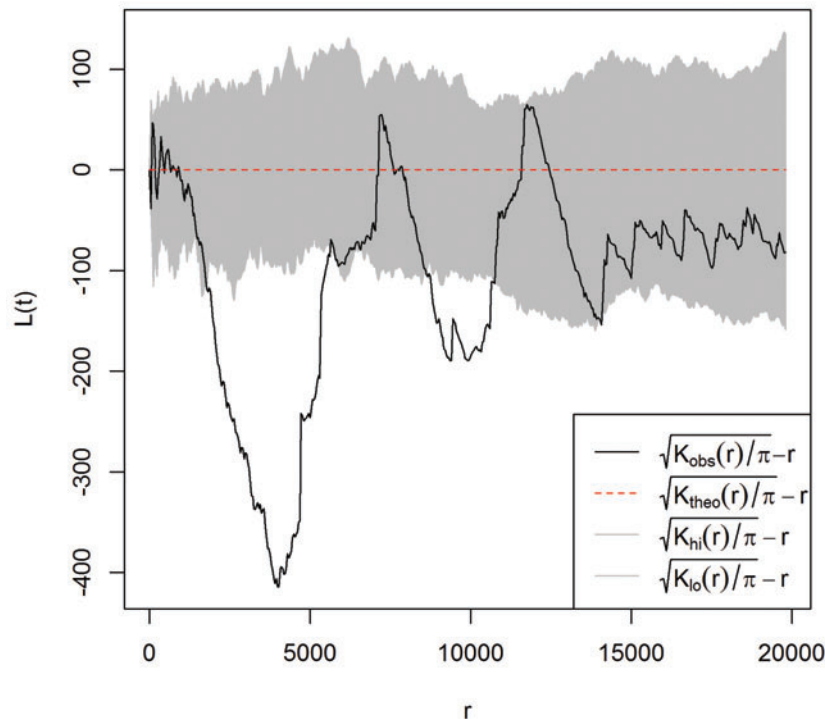


Figure 29—Ripley's K statistic values for the RIPL method (includes 192 FIA base plots and 553 intensified plots), clipped to BNF boundary (745 total plots), where the mean distance between plots is 1191 meters. The horizontal axis indicates distances in meters, while the red-line is the theoretical K value and the shaded area represents a 95% confidence band for this K estimate.

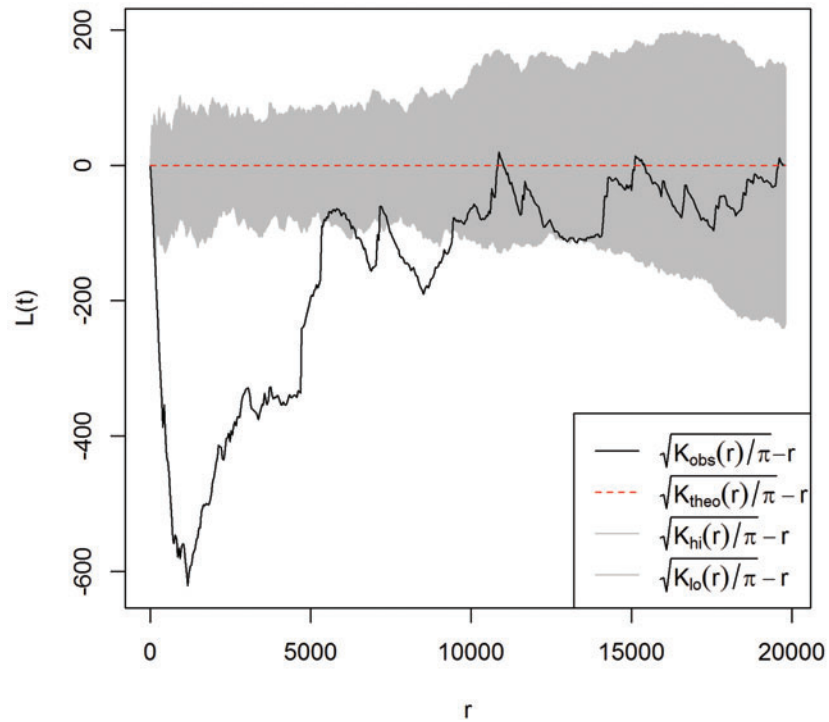


Figure 30—Ripley's K statistic values for the Python4x method (includes 192 FIA base plots and 552 intensified plots), clipped to BNF boundary (744 total plots), where the mean distance between plots is 1659 meters. The horizontal axis indicates distances in meters, while the red-line is the theoretical K value and the shaded area represents a 95% confidence band for this K estimate.

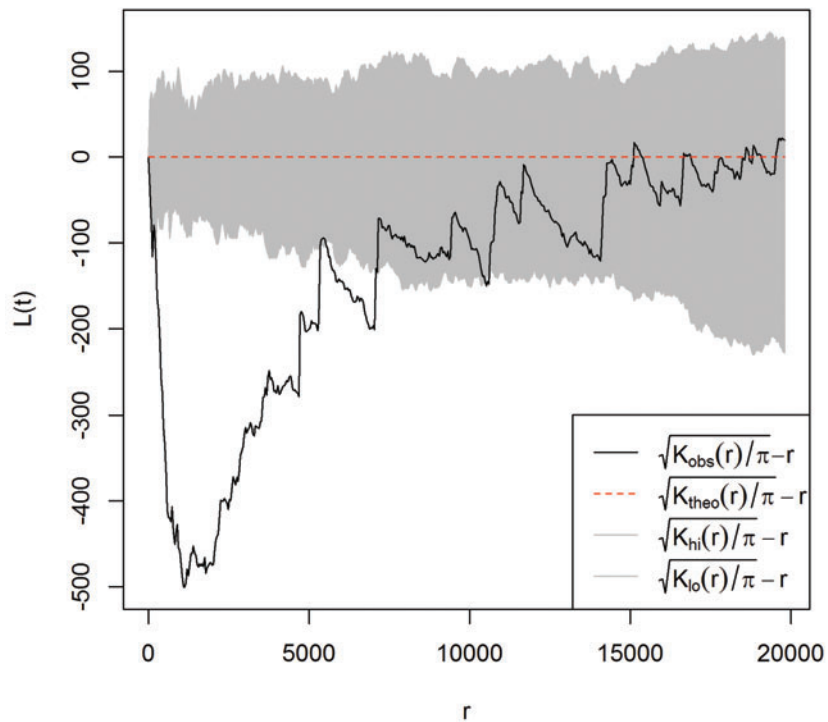


Figure 31—Ripley's K statistic values for the Repeating Shapes method (includes 192 FIA base plots and 518 intensified plots), clipped to BNF boundary (710 total plots), where the mean distance between plots is 1613 meters. The horizontal axis indicates distances in meters, while the red-line is the theoretical K value and the shaded area represents a 95% confidence band for this K estimate.

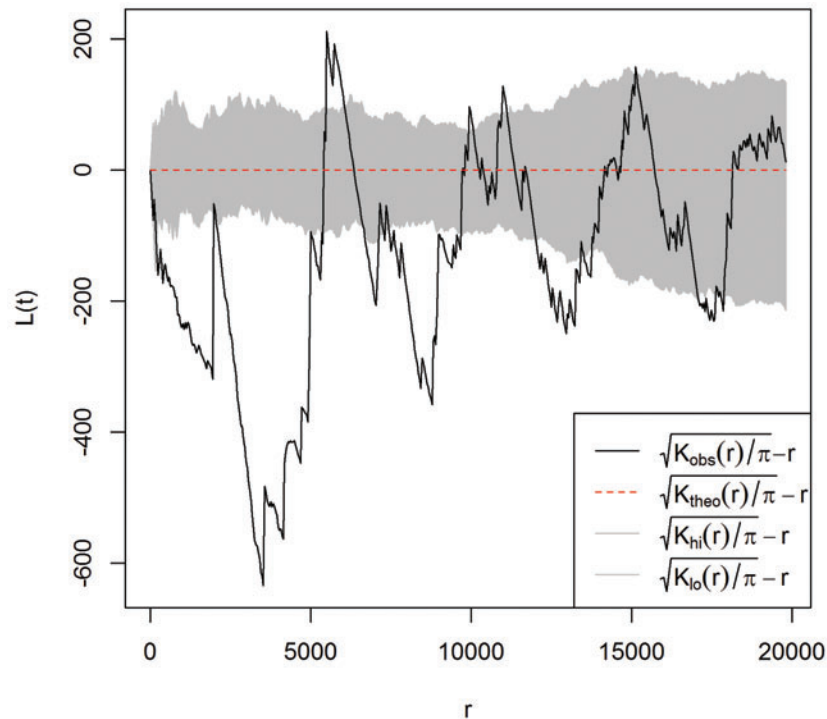


Figure 32—Ripley's K statistic values for the R4 method (includes 192 FIA base plots and 560 intensified plots), clipped to BNF boundary (752 total plots), where the mean distance between plots is 1312 meters. The horizontal axis indicates distances in meters, while the red-line is the theoretical K value and the shaded area represents a 95% confidence band for this K estimate.

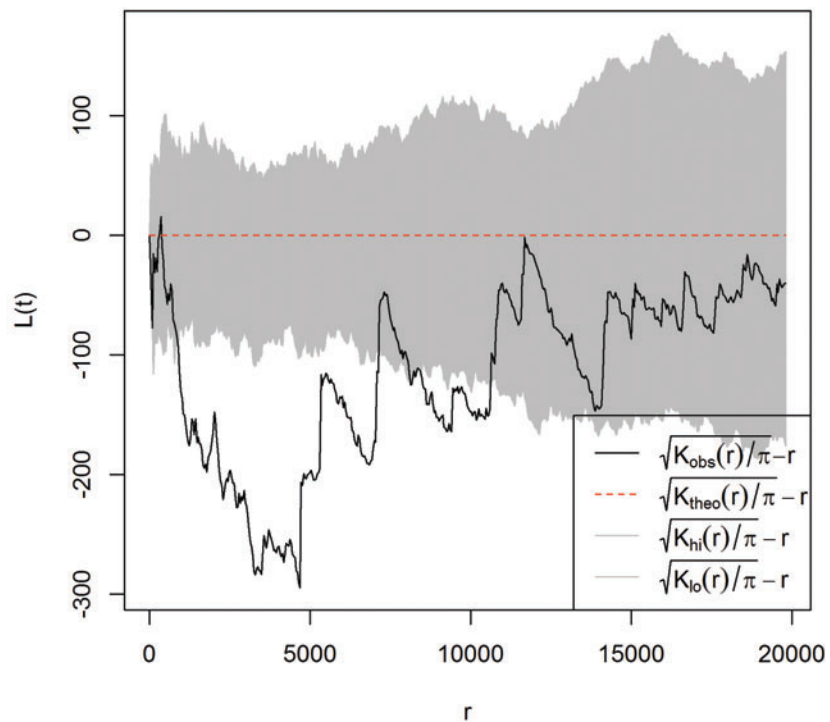


Figure 33—Ripley's K statistic values for the Simple Random Sample method (includes 192 FIA base plots and 559 intensified plots), clipped to BNF boundary (751 total plots), where the mean distance between plots is 1283 meters. The horizontal axis indicates distances in meters, while the red-line is the theoretical K value and the shaded area represents a 95% confidence band for this K estimate.

Intensification Team Survey

In an attempt to capture various subjective measures under consideration during plot intensification procedures, a brief survey with eleven questions was posed to the team members. These questions and their corresponding results are listed in Appendix B.

From the survey results, some of the highest “above neutral” rankings indicate the following: (a) intensification should be based on the existing FIA P2 hex framework, (b) it is critical to maintain the statistical properties of existing FIA design and layout when doing plot intensification (as described in the Methods section), (c) it is important for an intensification program to have adaptability to various intensification levels (2x, 3x, etc.), and (d) a consistent intensification procedure between neighboring Regions (both FIA and NFS Regions) is important.

The second highest rankings included the following: (a) it is important to have a simple routine, ease of use, adaptable GIS-based tool for plot intensification purposes, and (b) it is important for the user to understand the processes involved in plot intensification, compared to those methods with a “black-box” transparency.

The only question that failed to receive a response in its highest category was: “How open is your Region to consider new intensification methods?” although this question did receive 45% above neutral category ranking.

Panelizing Plots

The CE values were calculated for all panel.subpanel combinations for both the EBM and AM panel assignments for the intensified plots that were generated using the GRID method. Table 5 contains the CE values using plots from the 303 P2 hexes after being clipped by the BNF boundary, when EBM was used. Also, table 6 contains the CE values when AM was used for plots within the 303 P2 hexes and clipped by the BNF boundary. The CE values calculated for both EBM and AM are comparable. For both procedures, the FIA base plots (labeled GRID Base Plots in the tables) tend to have a higher CE value than their intensified plot counterparts (labeled GRID INT Plots in the tables). Also, except for panel.subpanel 2.2, the CE values for the AM approach are higher than the CE values for their corresponding entry with the EBM approach. And for all but two panel.subpanels, the CE values for intensified plots assigned using the EBM approach are less than one, indicating these sets of plots are more clumped than would be expected for randomly assigned plots. Both of these observations are not surprising since the EBM approach assigns the intensified plots to a panel.subpanel in the same band as the base plot (see the Methods section). In addition, figures 3 and 4 visually indicate that those plots assigned to panel.subpanels using the EBM procedure appear to be more clumped than those assigned using the AM procedure.

Table 5—Clark and Evans (CE) statistic values for the GRID method by panel.subpanel assignments using the EBM procedure, all plots clipped within the BNF boundary, and estimates adjusted by the BNF boundary.

Method (4x intensification)	Number of plots	CE value (R)	
		naïve	cdf
Panel = 1 AND Subpanel = 1			
GRID Base Plots	19	1.607828	1.400854
GRID INT Plots	52	1.05519	0.9915176
GRID Merged Plots	71	1.0222332	0.9849817
Panel = 2 AND Subpanel = 1			
GRID Base Plots	22	1.636066	1.144658
GRID INT Plots	57	0.9450777	0.8841021
GRID Merged Plots	79	1.0009643	0.9860507
Panel = 3 AND Subpanel = 1			
GRID Base Plots	17	1.545258	1.215154
GRID INT Plots	56	1.0536045	0.9817857
GRID Merged Plots	73	1.064819	1.011784
Panel = 4 AND Subpanel = 1			
GRID Base Plots	20	1.553358	1.283203
GRID INT Plots	59	1.0352277	0.9892683
GRID Merged Plots	79	1.070693	1.020971
Panel = 5 AND Subpanel = 1			
GRID Base Plots	19	1.761144	1.411915
GRID INT Plots	55	1.0053288	0.9044992
GRID Merged Plots	74	1.1039951	0.9641386
Panel = 1 AND Subpanel = 2			
GRID Base Plots	18	1.445129	1.289399
GRID INT Plots	60	1.101987	1.08957
GRID Merged Plots	78	1.148238	1.073027
Panel = 2 AND Subpanel = 2			
GRID Base Plots	18	1.695251	1.390884
GRID INT Plots	53	1.0061688	0.9395895
GRID Merged Plots	71	1.0598921	0.9911559
Panel = 3 AND Subpanel = 2			
GRID Base Plots	18	1.547681	1.40584
GRID INT Plots	56	0.9426903	0.9191406
GRID Merged Plots	74	0.9664182	0.9028755
Panel = 4 AND Subpanel = 2			
GRID Base Plots	20	1.661935	1.461924
GRID INT Plots	53	0.9874192	0.9107843
GRID Merged Plots	73	1.004806	1.003047
Panel = 5 AND Subpanel = 2			
GRID Base Plots	21	1.717448	1.470648
GRID INT Plots	59	1.072981	1.003578
GRID Merged Plots	80	1.065801	1.019942

Table 6—Clark and Evans (CE) statistic values for the GRID method by panel.sub-panel assignments using the AM procedure (same subpanel as base plot), all plots clipped within the BNF boundary, and estimates adjusted by the BNF boundary.

Method (4x intensification)	Number of plots	CE value (R)	
		naïve	cdf
Panel = 1 AND Subpanel = 1			
GRID Base Plots	19	1.607828	1.400854
GRID INT Plots	57	1.252529	1.1529
GRID Merged Plots	76	1.212677	1.078708
Panel = 2 AND Subpanel = 1			
GRID Base Plots	22	1.636066	1.144658
GRID INT Plots	53	1.0061688	0.9395895
GRID Merged Plots	75	1.143829	1.071205
Panel = 3 AND Subpanel = 1			
GRID Base Plots	17	1.545258	1.215154
GRID INT Plots	56	1.238285	1.131449
GRID Merged Plots	73	1.224895	1.139537
Panel = 4 AND Subpanel = 1			
GRID Base Plots	20	1.553358	1.283203
GRID INT Plots	54	1.316243	1.220132
GRID Merged Plots	74	1.257403	1.186814
Panel = 5 AND Subpanel = 1			
GRID Base Plots	19	1.761144	1.411915
GRID INT Plots	56	1.0705954	0.9105516
GRID Merged Plots	75	1.00134	0.887915
Panel = 1 AND Subpanel = 2			
GRID Base Plots	18	1.445129	1.289399
GRID INT Plots	55	1.1867	1.1529
GRID Merged Plots	73	1.220516	1.169793
Panel = 2 AND Subpanel = 2			
GRID Base Plots	18	1.695251	1.390884
GRID INT Plots	57	0.9450777	0.8841021
GRID Merged Plots	75	1.0472238	0.9777041
Panel = 3 AND Subpanel = 2			
GRID Base Plots	18	1.547681	1.40584
GRID INT Plots	56	1.336255	1.203079
GRID Merged Plots	74	1.207627	1.133973
Panel = 4 AND Subpanel = 2			
GRID Base Plots	20	1.661935	1.461924
GRID INT Plots	58	1.324649	1.27467
GRID Merged Plots	78	1.219833	1.199673
Panel = 5 AND Subpanel = 2			
GRID Base Plots	21	1.717448	1.470648
GRID INT Plots	58	1.250365	1.19005
GRID Merged Plots	79	1.155314	1.153889

As done for the Clark and Evans statistic, Ripley's K values were calculated for each panel and subpanel combination using the GRID method. As a comparison, the K values for panel 1 and subpanel 1 generated from both EBM and AM, for plots within the 303 P2 hex area and clipped by the BNF boundary, are shown in figure 34. Note that the mean distance between EBM plot locations is 4067 meters, while that for the AM plot locations is 4663 meters. From figure 34a, the K values calculated from the EBM tend to drop below the lower 95% line at distances between 10,000 and 12,000 meters, then returns above that line near 20,000 meters. This distribution seems to be different from the observed trends we have reviewed for other plot sets, as well as for the overall GRID method results shown in figure 26. In those cases, the K values fell below the lower 95% line for distances typically less than 5000 meters but then climbed within the 95% range at longer distances. Similarly, the K values calculated from the AM in figure 34b also dropped below the lower 95% line at a point near 5000 meters and then climbed into the 95% range near the 13,000 meter mark. For this case, the K values calculated from the AM seem more similar to the observed trends from the overall GRID method results than those calculated from the EBM.

Rather than display the remaining panel.subpanel combinations as individual figures, each of the ten panel.subpanel combinations for the GRID method were combined into one figure. In figure 35, the K values for the GRID method with different panel.subpanel combinations, using all 303 P2 hexes (then clipped to the BNF boundary), are shown for both the EBM and the AM. Note that in most panel.subpanel combinations for the EBM, there tends to be a similar trend as shown for the panel 1 subpanel 1 figure. It seems that at 15,000 meters, the K values for these individual panel.subpanel combinations are at their maximum dispersed pattern. For the AM, many of the panel.subpanel combinations tend to follow the trend from their corresponding panel 1 subpanel 1 figure as well. But, it also looks as though the K values for these individual panel.subpanel combinations are more varied at their maximum dispersed pattern; some combinations peak at less than 5000 meters, while others are somewhere near 12,000 meters.

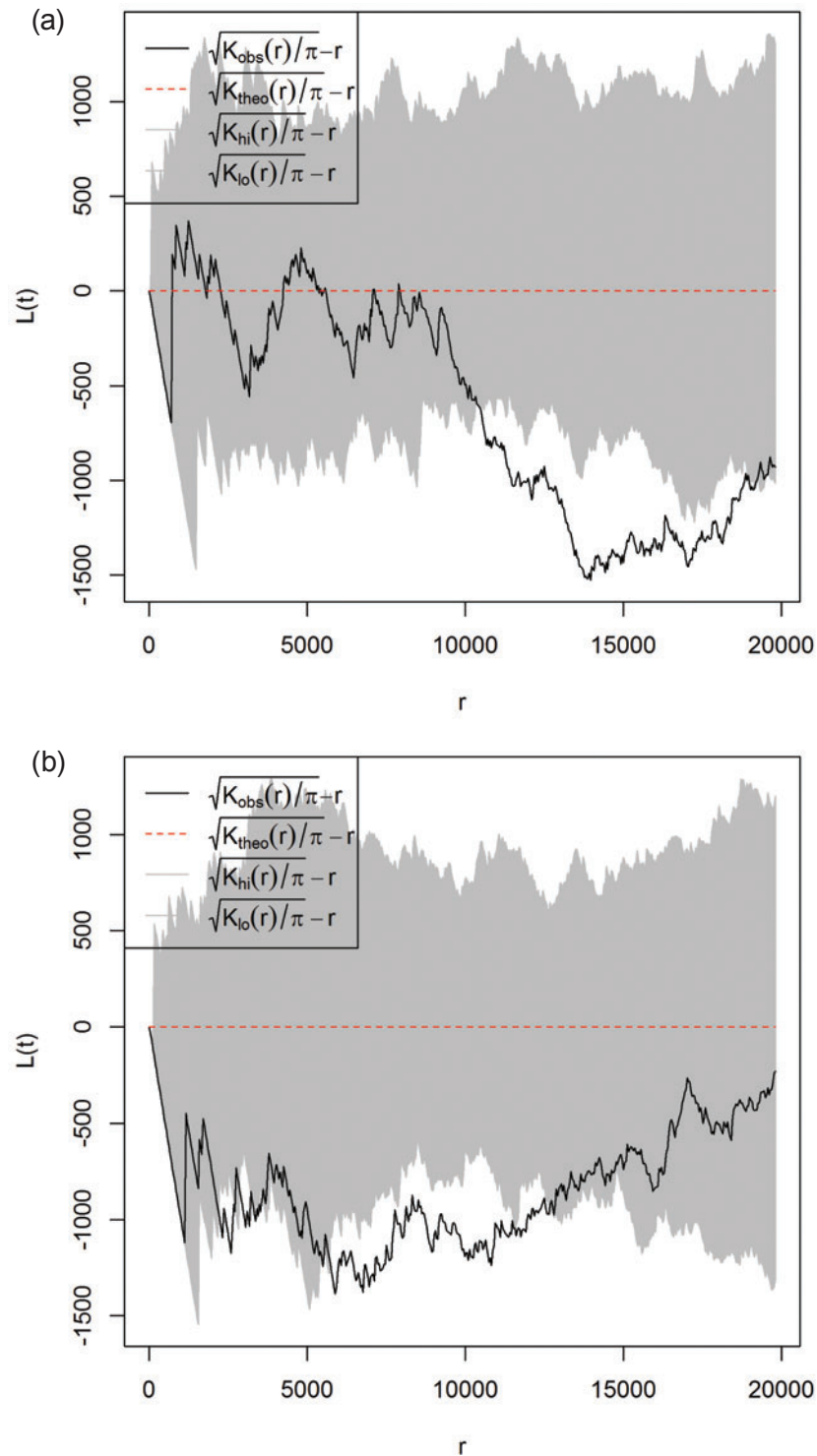
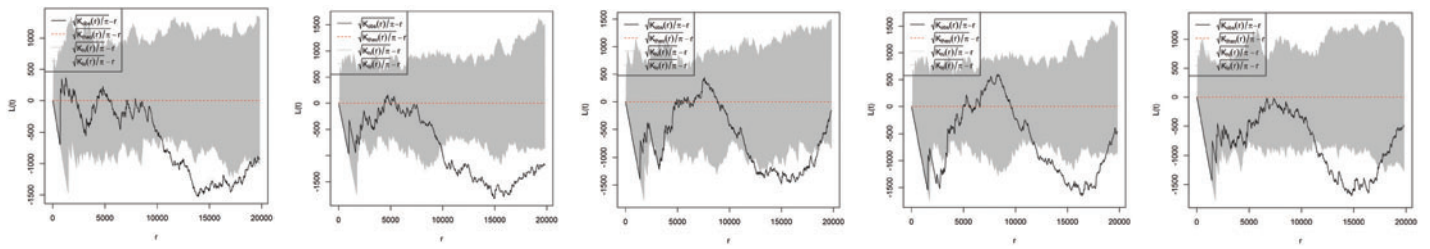
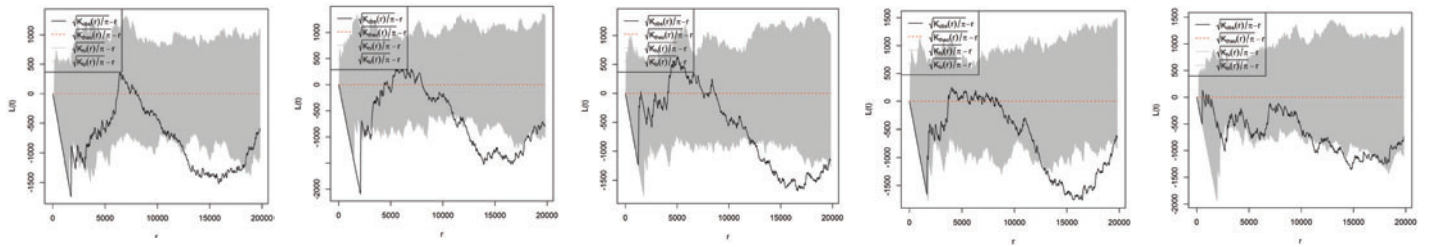


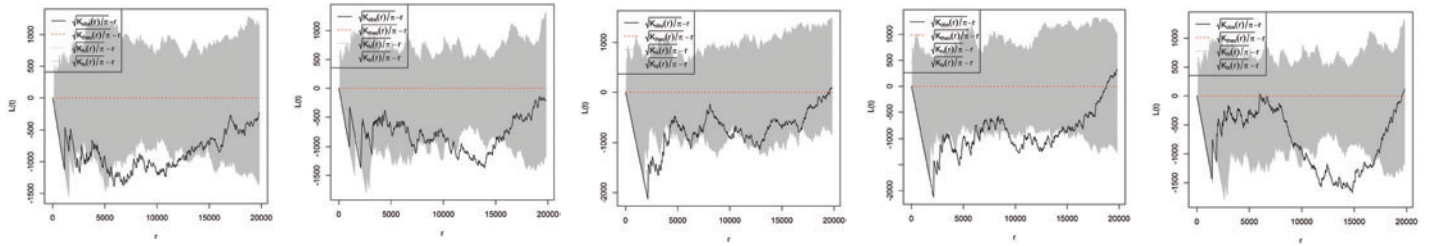
Figure 34—Ripley's K statistic values for the GRID method with both FIA base plots in panel=1 and subpanel=1 and intensified plots that were assigned to panel=1 and subpanel=1, clipped to the BNF boundary. Figure 34a displays the K values using the EBM panel.subpanel assignment procedure (mean distance between plots is 4067 meters) for the intensified plots, while figure 34b shows the alternative (AM) panel.subpanel assignment procedure (mean distance between plots is 4663 meters). The horizontal axis indicates distances in meters, while the red-line is the theoretical K value and the shaded area represents a 95% confidence band for this K estimate.



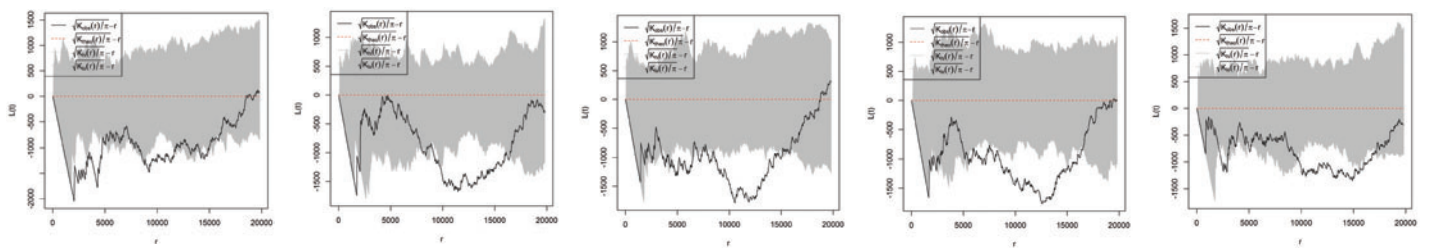
(a) EBM procedure, Panels 1-5 / Subpanel 1



(a) EBM procedure, Panels 1-5 / Subpanel 2



(b) AM procedure, Panels 1-5 / Subpanel 1



(b) AM procedure, Panels 1-5 / Subpanel 2

Figure 35—Ripley's K statistic values for the GRID method with both FIA base and intensified plots for different panel.subpanel combinations, clipped to the BNF boundary. Figure 35a displays the K values using the EBM panel.subpanel assignment procedure for the intensified plots, while figure 35b shows the alternative panel.subpanel assignment procedure. The horizontal axis indicates distances in meters, while the red-line is the theoretical K value and the shaded area represents a 95% confidence band for this K estimate.

Discussion and Conclusions

Intensifying Plots

As shown in table 1, the CE value for an idealized FIA sample (1 random plot per P2 hex) is approximately 1.26. This CE value is also supported by the values obtained for the same category in table 2, as well as the simulation runs presented in figure 20. For comparison, figure 21 represents CE values without any P2 hex constraint, which are centered on a mean near 1.0, as expected.

The CE values obtained from both the intensified plots only (table 3) as well as the combined set of plots (table 4) suggest that all the methods except for SRS, R4, and RIPL (zero distance constraints) have estimates close to this idealized FIA sample (near 1.26).

For the SRS method (table 3, CE value of 1.03), this was somewhat expected since it is the method that more closely resembles a total random placement of intensified plots (which would result in a $CE = 1.0$). The R4 method (table 3, CE value of 1.10) is also near the value of 1.0, likely influenced by placing one random plot and two systematic B-grid plots for every P2 hex. For the RIPL method, as mentioned earlier, the output was edited to ensure that three intensified plots were placed within each P2 hex (since this was not an option in the version we tested). This editing procedure allowed for a large proportion of plots being randomly placed within applicable P2 hexes.

As shown in figure 22, the Ripley's K values for an idealized FIA sample (1 random plot per P2 hex) are shown with statistically significant dispersion at relatively shorter distances (near 4000 meters). In contrast, figure 23 shows the distribution of K values with no P2 hex constraint, with no corresponding break from the 95% confidence band. This comparison demonstrates the influence of having a P2 hex constraint on Ripley's K calculations.

While viewing the various Ripley's K graphs for the eight intensification methods, it seems apparent that the same three methods identified above (SRS, R4, RIPL) exhibit a different K line than that of the remaining five methods. While the GRID (figure 26), R5 (figure 27), SFC (figure 28), Python4x (figure 30) and RS (figure 31) methods all tend to have similar K lines as an idealized FIA sample (figure 22); the SRS (figure 33), R4 (figure 32) and RIPL (figure 29) all seem to display a more erratic K line with greater amplitude, which may frequently travel above and below the 95% confidence bands. After reviewing these trends, we would be prone to support those five intensification methods that exhibit similar K lines as that of an idealized FIA sample.

We had difficulty implementing our version of RIPL without access to USFS Region 1 data layers. We did eventually run RIPL over CITRIX as an ESRI add-in tool, which worked more easily than our previous test version. However, we still needed to edit the resulting set of plots so that each P2 hex contained only three intensified plots. This method appears to be more appropriate when intensification is needed for an area without P2 hex centric restrictions. We remain confident, however, that a RIPL package can be developed to suit FIA intensification needs, if desired. RIPL offers a wide assortment of constraints to the user, who can then conduct an intensification task that approaches an optimal solution. But as with most optimization procedures, additional time is required for the tool to find a “best” solution. RIPL displays much promise with its heuristic approach and adaptability to various constraints, and we remain open to investigating future versions.

We also had concerns for the applicability of the R4 method for those regions that do not have B-grid or other historic plots available for their intensification needs. While these historic plots do provide useful information, there is no guarantee that their plot design, quality control, placement criteria or other related issues meet the current FIA annual plot standards. The R4 method also does not incorporate any type of nested polygon within a P2 hex, which was one of our desired traits when comparing candidate intensification methods.

While the SRS method was generally used as a comparison method of intensification in our study, it has an advantage in that an analyst can easily add additional plots to a given P2 hex after that area has previously been intensified. However, the SRS also has many disadvantages that are well summarized in Lister and Scott (2008).

Due to their resulting CE and K values as well as other concerns, we are reluctant at this time to recommend the SRS, R4 or RIPL method as a national FIA plot intensification procedure.

One of the advantages of the Repeating Shapes (RS) method is that it is very easy to download, install, and run in ESRI’s ArcMap. It enables the user to create hexagons, or other types of polygons, based on a user-defined area as well as other parameters. So, while it is a good product to create intensified polygons for a given area, it is very hard to align new polygons within an existing framework of P2 hexes. During our testing, we were unable to “snap” (geographically coincident) the new hexagons to the P2 hexes, which created overlaps such as those depicted in figure 17. With this spatial alignment problem, there are several challenging issues that can frequently arise. Since one of our basic assumptions is that the intensification should be P2 hex centric, we cannot recommend the Repeating Shapes method to be used as a national FIA plot intensification procedure.

We were intrigued by the Python4x method of intensification, which is based on the coordinates of the P2 hex centroid and the location of an existing FIA base plot. In a process that simulates having sub-hexes nested within a given P2 hex, Python4x places an intensified plot on the opposite side of the hex from the existing FIA base plot, at a random distance and slightly random azimuth. It then compares this plot's location with its corresponding P2 hex center and places random points in the other quadrants of the hex (at right angles to the initial bearing). It is also written in python, which has frequently been used for various GIS applications.

While Python4x simulates having sub-hexes in place, it does not permit a plot to be located within all parts of the overlying P2 hex. The script allows a user to specify a maximum distance to extend beyond the P2 hex centroid, and a random number is then generated to select some percentage of distance from the hex centroid based on that user-provided maximum distance. Since we want all intensified plots to lie within the same P2 hex as the existing FIA plot, the user must base this maximum amount on the distance from the hex centroid to the edge of the hexagon. If the P2 hexagon was shaped as a circle, this approach would be adequate. However, a hexagon will have portions that are not included in this circular area. That is, those areas near the hexagon vertices will likely not be available for intensified plot placement, which goes against our basic assumption that all areas within a P2 hex should be eligible for plot placement.

Since this method produces areas within a P2 hex without an equal probability of selection, we cannot recommend that the current version of Python4x be used as a national FIA plot intensification procedure.

Each of the three remaining intensification methods (GRID, R5, and SFC) has similar properties related to their respective CE and K statistics. They also produce smaller polygon areas that are nested within an overlying P2 hexagon. This trait demonstrates one of our basic assumptions that plots should be established within a framework that encourages more spatial balance between plots. Another commonality between these three methods is that after this framework has been created, the resulting intensified plots are established in the same manner (randomly placed within each smaller polygon, random assignment of intensity number, calculation of panel.subpanel numbers, and clipped to the BNF boundary). Consequently, we will compare these remaining three methods, based in part, on some of the decision rules and technical characteristics presented in the Methods section.

First, each of these three remaining methods produces smaller polygon areas that are nested within an overlying P2 hexagon. However, the shape and/or pattern of these smaller polygon areas are different. Both the GRID and R5 methods produce sub-hexes that align somewhat differently within their respective P2 hexes.

The GRID method (figure 6) contains one sub-hex centered within the P2 hex, while the R5 method (figure 10) creates three whole sub-hexes aligned in a triangular-shape that is centered near its P2 hex centroid. This difference may be a minor consideration for some analysts, but for others it presents an undesirable trait—having three sub-hexes intersecting near the P2 hex centroid—due to the potential of having from zero to three plots clustered near the P2 hex centroid.

While the GRID and R5 methods produce sub-hexes, the SFC method generates “clusters,” (figures 11 and 12) for their nested polygon shapes. For a 4x intensification, these clusters typically bisect the P2 hex centroid, similar to the R5 method. Overall, the 4x intensification pattern seems to split the P2 hex into quadrants. All three methods enable their smaller polygons (clusters or sub-hexes) to “nest” within the overlying P2 hexagon.

Based on the position of the sub-hex shapes within each P2 hex, we would tend to prefer those produced by the GRID method over the R5 and SFC methods for typical FIA intensification tasks. The rationale for our preference of the sub-hex position produced by the GRID method is that one sub-hex is spatially centered within each P2 hex, which results in one plot relatively near its respective P2 hex centroid.

Another aspect to consider is the degree of flexibility in selecting an intensification factor for each method. While the GRID method has some limitations upon which intensification factors are available, the SFC method allows the user to select a factor without restriction. The R5 method script is hardcoded to produce a 4x intensification, while both the GRID and SFC methods require the user to specify this factor. Although the R5 method is easily implemented as a python script, this limitation to the intensification factor may be a disadvantage to some analysts.

Another issue to consider is the study area represented by an intensification project. Both the GRID and R5 methods primarily utilize polygon layers, while the SFC method incorporates raster layers and their corresponding pixel-centroid point layers for relatively short distances (30-meter pixels). It is generally accepted that GIS-based storage requirements and processing speed of relatively large geographic areas is greater and more time consuming for raster layers compared to vector geospatial layers. Thus, using the SFC method to conduct a state-wide intensification task, using 30-meter pixels, would likely require more time and resources as compared to a similar operation based on vector layers. Some analysts working on intensification projects with such limitations may select the GRID or R5 methods over the SFC method based on these factors.

Another issue when using raster layers would be the “stair-step” effect that is produced when converting a study area boundary from pixels to a polygon feature. For some applications, this may be a disadvantage for their project, depending on the relative size and shape of the study area as well as its sensitivity to representing an exact study area boundary. Depending on the analyst and the intensification project, this aspect of the SFC method may be a deterrent.

As for ease of use, all three of these methods have scripts that are already written and successfully demonstrated in previous intensification tasks. They are also transparent in their design and operations, without any “black box” mystic surrounding them. The SFC method uses an AML program and common GIS functionality to develop its clusters, while the R5 method uses a python script to establish its sub-hexes. The GRID method has a more convoluted approach that involves the use of C and AML programs, with a variety of program parameters to learn. However, once an analyst becomes accustomed to this approach, it turns out to be a very resourceful tool for plot intensification tasks.

Overall, based on the topics previously discussed, we would recommend the GRID method as the technique for FIA to adopt as a national plot intensification procedure. However, we would also suggest that the current version of the GRID method be updated by converting the C scripts and AMLs to an ESRI ArcGIS add-in tool (ESRI, Inc. 2012; also <http://blogs.esri.com/esri/arcgis/2010/05/05/add-ins-for-arcgis-desktop-10/>). The update will make it more user-friendly; an FIA analyst would be able to execute the GRID method for some intensification project within the confines of ESRI's ArcMap, and not need to rely on importing/ exporting files from other software programs that may or may not be available on their workstation. Other alternatives, such as Oracle Spatial, may also be utilized for such an update or conversion process. However, since the USFS has employed ESRI products for many years and likely for many more, it seemed appropriate at this time to recommend creating an updated version of the GRID method as an ESRI ArcGIS add-in tool.

Panelizing Plots

A temporal partitioning was achieved by assigning panel.subpanel values to intensified plots based on the procedures described in the Methods section. The plot distributions created using EBM for panel 1 subpanel 1 plots from the GRID method are shown in figure 3b, while figure 4a gives the plot distributions for all ten panel.subpanel combinations, where the banding phenomenon is quite evident.

In an effort to distribute the intensified plots with more spatial balance over each year of a 10-year cycle, we investigated the effect of keeping the subpanel value of intensified plots the same as that of the existing base plot for each P2 hex, a procedure we designated as AM. The plot distributions using AM for panel 1 subpanel 1 plots using the GRID method are shown in figure 3c. Note how the spatial banding effect was reduced using this alternate method as compared to EBM shown in figure 3b. Figure 4b gives the plot distributions using AM for all ten panel.subpanel combinations using the GRID method, which generally supports this assessment.

We also determined the CE statistic values for these intensified plots using the AM procedure. Table 6 presents CE statistics for those plots using the GRID intensification method and panel.subpanel assignments by the AM procedure for all plots within the 303 P2 hexes clipped by the BNF boundary. Overall, CE values for these plots obtained from the AM panel.subpanel assignments seem to be closer to our desired distribution pattern obtained by placing one random plot per P2 hex (CE values near 1.26), as compared to the EBM procedure listed in table 5 (CE values near 1.0). Based on these findings, we recommend using the alternative panelizing procedure for the BNF. We qualify “for the BNF” since the panel.subpaneling procedure will likely depend somewhat on the overall geospatial properties of a given region utilizing a ten-panel arrangement.

Since the panel.subpaneling procedure used is likely dependent on the geospatial properties of a specific region, this may lead other analysts to investigate other panel.subpaneling routines than what we have suggested. One way to contemplate plot panelization tasks is to consider the graphical representations given in Appendix F, which details how we calculated panel.subpanel values for intensified plots from using the EBM or AM procedures. If an analyst lets $x = 1$ and $x = 2$ (creating two tables), then each panel.subpanel will appear once in the “Base Plot” column and three times in the combined three columns for “Intensity Numbers.” Other panel.subpaneling procedures would be rearrangements of panel.subpanel numbers in the last three columns with the restriction that each panel.subpanel number occurs exactly three times. Since the intensification of BNF was only for a test study of the various methods, we did not investigate any other panel.subpaneling procedures besides the AM procedure.

Another approach for assigning panel.subpanel values to intensified plots is to utilize either the HIERARCHICAL_ID field or PANEL_70 field in FIA’s NIMS_BASE_HEX table (John Coulston, USFS, personal communication, 2012). An analyst may visually compare panel.subpanel values as they span across several years of an inventory cycle. Any such banding or clumping of intensified plots, as we noticed in our case study, could potentially be adjusted using these attributes so that plot distributions exhibit a more spatially balanced spread across the landscape. Additional details or suggestions for using this approach varies, and could involve several trial-and-error attempts by an analyst so that plot distributions are adequate visually, as well as spatially and temporally balanced over an intensification area.

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Appendix A: National FIA Plot Intensification Task Team^a

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^a All members are with the U.S. Forest Service.

Appendix B: FIA Plot Intensification Team Survey Results

FIA Plot Intensification Team Survey																		
<i>Characteristics and Assumptions to consider for Plot Intensification</i>																		
<i>Response Options</i>																		

Appendix C: R Script Example to Calculate the Clark and Evans Statistic

R script example, with assistance from John Coulston:

```
-----  
library(maptools)  
library(spatstat)  
#read in shapefiles  
bnf<-readShapeSpatial("C:/.../bnf_noholes.shp") # boundary shapefile  
bnf.plt<-readShapeSpatial("C:/.../MTWY_afc_clip.shp") # base grid shapefile  
bnf.4x<-readShapeSpatial("C:/.../x4.shp") # 4x intensification plots  
bnf.plt.b<-readShapeSpatial("C:/.../Bnf_grid_plots_alb83_reportclip.shp") # both plots  
#show plots  
plot(bnf)  
points(bnf.plt,col="black")  
plot(bnf)  
points(bnf.4x,col="red")  
plot(bnf)  
points(bnf.plt.b,col="green")  
  
#do clark and evans  
pts<-coordinates(bnf.plt)  
the.pat<-ppp(x=pts[,1],y=pts[,2],window=as.owin(bnf))  
ce.pat<-clarkevans(the.pat)  
pts.4<-coordinates(bnf.4x)  
the.pat4<-ppp(x=pts.4[,1],y=pts.4[,2],window=as.owin(bnf))  
ce.pat4<-clarkevans(the.pat4)  
pts.b<-coordinates(bnf.plt.b)  
the.pat.b<-ppp(x=pts.b[,1],y=pts.b[,2],window=as.owin(bnf))  
ce.pat.b<-clarkevans(the.pat.b)  
  
#examine results look at the cdf corrections  
ce.pat  
ce.pat4  
ce.pat.b  
-----
```

Appendix D: R Script Example to Calculate the Ripley's K Statistic

R script example, with assistance from John Coulston:

```
-----  
#horizontal line graph procedure  
library(maptools)  
library(spatstat)  
#read in shapefiles  
bnf<-readShapeSpatial("C:/.../bnf_noholes.shp") # boundary shapefile  
bnf.BASE<-readShapeSpatial("C:/.../MTWY_afc_clip.shp") # base grid shapefile  
bnf.INT<-readShapeSpatial("C:/.../BNF_GRID_REPORTclip.shp") # GRID_4x  
bnf.BOTH<-readShapeSpatial("C:/.../BNF_GRID_plots_merge_afc_clip.shp") # both plots  
  
#show plots  
plot(bnf)  
points(bnf.BASE,col="black")  
points(bnf.INT,col="red")  
  
#do Ripleys K  
ptsBASE<-coordinates(bnf.BASE)  
ptsINT<-coordinates(bnf.INT)  
ptsBOTH<-coordinates(bnf.BOTH)  
the.patBASE<-ppp(x=ptsBASE[,1],y=ptsBASE[,2],window=as.owin(bnf))  
the.patINT<-ppp(x=ptsINT[,1],y=ptsINT[,2],window=as.owin(bnf))  
the.patBOTH<-ppp(x=ptsBOTH[,1],y=ptsBOTH[,2],window=as.owin(bnf))  
  
#graphs using zero horizontal adjustments, simulation envelopes=50sims  
HGenvINT <- envelope(the.patINT, Kest, nlarge=Inf, nsim=50)  
plot(HGenvINT, sqrt(./pi)-r~r, lty=c(1,2,3,3), col=c(1,2,3,3), ylab="L(t)")  
HGenvBOTH <- envelope(the.patBOTH, Kest, nlarge=Inf, nsim=50)  
plot(HGenvBOTH, sqrt(./pi)-r~r, lty=c(1,2,3,3), col=c(1,2,3,3), ylab="L(t)")  
-----
```

Appendix E: NIMAC Method AML Script

```
/* This AML runs a spatialorder and collocate in order to locate INTENSIFIED
/* PLOTS within specific area. Initial development by Andy Lister.
&s pts = bhhxptc          /* INPUT: name of the gridpointed hex file (hexes turned to a grid
where hexid=value, then gridpointed)
&s grid_code = grid_code /* name of item that identifies the hexid (created from the arcmap
spatial analyst routine)
&s numclust = 4           /* number of clusters you want (ie, intensification level... 4x would
be a 4 numclust value)

&s hexes = bhhexa83       /* INPUT: original hex id as a polygon coverage
&s hex_id = USFIAPT_ID    /* hex identifier for the hex poly coverage
&s numrec = 304           /* number of records in hex coverage + 1

&s ptgrid = bh_ahxg       /* INPUT: name of grid used to make points
&s pixsize = 30           /* size of the pixels used to convert hex poly coverage to a hex
grid
&s coll_fld = class       /* field name for collocate class
&s i = 1

&if [exists tmpgr -grid] &then
  kill tmpgr all
&else
  &type /// checked tmpgr
grid
tmpgr = %ptgrid%.count
quit
&describe tmpgr
/* this is the cluster capacity for collocate
&s clustsize = [calc %grd$zmax% / %numclust%]
/* Note, hex coverage must have labels created; if you use shapearc,
/* you need to run the createlabels command in arc
createlabels %hexes%
/* cycle through each hex_id value in points coverage
&do &until %i% = %numrec%
  /* get hex_id value
  ae
  editcov %hexes%
  &s v = [show label %i% item %hex_id%]
  quit
  /* spatialorder-collocate routine for each hex_id value
  ap
  reselect %pts% points %grid_code% = %v%
```

```

spatialorder %pts% point order
calculate %pts% point %grid_code% = 1
collocate %pts% point order %grid_code% %clustsize% %coll_fld%
calculate %pts% point %grid_code% = %v%
clearselect
&type ///
&type /// Finished record number %i% (hex %v%) !!!
&type ///
&s i = %i% + 1
quit
&end

grid
setwindow %ptgrid% %ptgrid%
setcell %ptgrid%
&if [exists tmpptgr -grid] &then
  kill tmpptgr all
&else
  &type /// checked tmpptgr
  /* points-to-grid for points coverage
  tmpptgr = pointgrid(%pts%, %coll_fld%, #, #, %pixsize%)
  &if [exists polygr%numclust% -grid] &then
    kill polygr%numclust% all
  &else
    &type /// checked polygr%numclust%
    /* grid-to-poly for points coverage
    polygr%numclust% = gridpoly(tmpptgr, .000000001)
    &if [exists tmpcov -cover] &then
      kill tmpcov all
    &else
      &type /// checked tmpcov
      /* grid-to-poly for original hex grid
      tmpcov = gridpoly(%ptgrid%, .000000001)
      quit
      &if [exists final%numclust% -polygon] &then
        kill final%numclust% all
      &else
        &type /// checked final%numclust%
        /* UNION: points coverage (cluster value) with original hex grid
        /* union polygr%numclust% tmpcov final%numclust% .000000001 join
        &type ///
        &type /// Done. Your final polygon zone (subhex) coverage is final%numclust%.
        &type ///
        &type /// You need to the arctoolbox (data management) dissolve tool (with
        &type /// tmpcov-id, grid-code as the dissolve fields) to dissolve to create
        &type /// 1 record for each subhex, even though they are spatially
        &type /// nonconitugous (final%numclust%_diss).
        &type ///

```

```

&type /// After dissolving, AddItem (Hex_ID, long) to the dissolve shapefile,
&type /// then join it back to tmpcov (both by tmpcov_id), then calculate
&type /// Hex_ID = joined.GRID-CODE... release join.
&type ///
&type /// From the dissolve coverage output, choose one random point per
&type /// polygon (Create Random Points-management). Then, join (CID) back to
&type /// the dissolve shapefile (FID) to get HEX_ID and GRID_CODE fields.
&type /// Remove join after creating final random_pts shapefile.
&type ///
&type /// To remove a random point that lies in same polygon as an existing
&type /// FIA plot, use select by location, then export random plots...
&type ///

```


Appendix F: 10-year Panel.Subpanel Assignments for Intensified Plots

Table F.1—The panel.subpanel assignments for intensified plots using the *Extension of Base Method* or *EBM* procedure, based on the sequences used to generate the 10-year cycle panel assignments from the 5-year cycle panel assignments.

Panel.Subpanel Value of Base Plot	Intensity Number of Intensified Plot		
	2	3	4
1.x	3.x	5.x	2.y
2.x	4.x	1.y	3.y
3.x	5.x	2.y	4.y
4.x	1.y	3.y	5.y
5.x	2.y	4.y	1.x

Panel values for intensified plots are shown in bold, and are based on the panel.subpanel value of the base plot and the intensity number of the intensified plot.

Subpanel values {1, 2} for intensified plots will alternate from the base plot's subpanel value when the intensified plot's panel value (1-3-5-2-4 sequence) moves from the 1-3-5 value range to the 2-4 value range, and vice-versa. This subpanel "switch" is denoted by the {x, y} identifier; where a "x" listed for the intensified plot's subpanel value indicates the same value as the base plot's subpanel value, and a "y" designates a different subpanel value from the base plot's subpanel value.

For example, an existing FIA plot has a panel=3 and subpanel=1. For the 3 intensified plots for that P2 hex, the following assignments will be made based on their intensity number:

Intensity Number=2: panel=5, subpanel=1

Intensity Number=3: panel=2, subpanel=2

Intensity Number=4: panel=4, subpanel=2

with 3.1 (year 3), 5.1 (year 5), 2.2 (year 7) and 4.2 (year 9) all in the odd year band.

Table F.2—The panel.subpanel assignments for intensified plots using the *Alternative Method* or *AM* procedure, based on a variation of the sequences used to generate the 10-year cycle panel assignments from the 5-year cycle panel assignments.

Panel.Subpanel Value of Base Plot	Intensity Number of Intensified Plot		
	2	3	4
1.x	3.x	5.x	2.x
2.x	4.x	1.x	3.x
3.x	5.x	2.x	4.x
4.x	1.x	3.x	5.x
5.x	2.x	4.x	1.x

The panel.subpanel assignment is based on the sequence (1-3-5-2-4) and the subpanel values {1, 2} for intensified plots remain the same value as its base plot's subpanel value. Intensified plots whose odd or even year band is opposite of the odd or even year band of its base plot are shown in bold.

For example, an existing FIA plot has a panel=3 and subpanel=1. For the 3 intensified plots for that P2 hex, the following assignments will be made based on their intensity number:

Intensity Number=2: panel=5, subpanel=1

Intensity Number=3: panel=2, subpanel=1

Intensity Number=4: panel=4, subpanel=1

with 3.1 (year 3) and 5.1 (year 5) in the odd year band and 2.1 (year 2) and 4.1 (year 4) in the even year band.

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