ForSysR: Quick Start User Guide

ForSys Overview

ForSys is a multi-objective spatial prioritization system that was designed to explore a range of management options at different scales, from national forests and regions, to nationwide. This Quick Start Guide is designed to get users up to speed with the program's basic functionality, introduce inputs and results using a simple example ForSys run, and provide data descriptions and preparation recommendations for users who wish to leverage their own local datasets within the program. More detailed information can be obtained from the full ForSys manual.

ForSys is a core component of the Forest Service scenario planning effort. Scenario planning considers a set of potential futures that include many of the important uncertainties in the modeled system rather than to focus on the accurate prediction of a single outcome. It is a process that guides planners, community members, and other stakeholders through considerations of various futures. This helps planners and stakeholders consider how various elements of their planning might respond to these different scenarios, and eventually build a strategic plan that reflects diverse input, quantitative realities, and qualitative goals. Scenario planning combines data-driven decision-making with an inclusive, participatory approach to guide the development of better management plans, which are more likely to be implemented than plans created without stakeholder involvement.

ForSys currently exists in three formats: 1) as an executable C++ stand-alone executable program (ForSysR), 2) as an R script (ForSysR) described below, and 3) a ShinyApp web-based version (ForSysE) currently under development.

This manual is designed for a user to run ForSysR using the tutorial dataset as described at the end of this document (section 5), and use the manual text for reference to understand specific parameters and outputs.

Table of Contents

1. ForSysR Initial Configuration

ForSysR requires a configuration file with parameters specified by the user for the given data set and scenario (Table 1). The primary input is a CSV or DBF file that contains a table with all the stands within the study area (logic fields in the configuration file set the file type: **is_dbf** or **is_csv**). The fields that populate this file are used as input parameters to the model, and must be specified by the user (Table 2). These data include field identification, information about objective metrics, treatment thresholds, treatment targets, constraints, and study area management subdivisions. The treatment selection process in ForSysR is conducted at the level of planning area units. Planning areas may then be combined into larger containers such as watersheds, firesheds, or National Forests.

Table 1. Basic inputs for the ForSysR configuration file.

Parameter name	Input	Input type (required)	Example
scenario_name	Unique scenario name. This will be used to save outputs.	String (required)	"Idaho_test"
is_dbf	Defines if input stand file is a dbf file.	Logical (required)	TRUE or FALSE
is_csv	Defines if input stand file is a csv file.	Logical (required)	TRUE or FALSE
input_standfile	Pathway and name to stand layer file	CSV file pathway as string (required)	"data/IDHexnet_North20190523_Final.dbf"
write_stand_outputs	Flag to turn stand outputs on or off	Logical (required)	TRUE of FALSE
pcp_spm	Variables that must have the percent contribution to the problem (PCP) and the standardized percent of the max (SPM) computed. Must include the priority variable(s). *Equivalent to Calculate PCP and SPM in ForSysX.*	List of field names as string (required)	c("HUSUM_STND", "TVMBF_STND")
land_base	The basis for PCP and SPM calculations. Must be binary field. *Equivalent to Available for Management in ForSysX.*	Field name as string (required)	“man_alldis” or set to NULL
subunit	Field that contains the unique ID for each stand. Note this is Stand ID in ForSysX, not to be	Field name as string (required)	"Cell_ID"

	confused with Subunit in ForSysX.		
priorities	Priority values	List of field names as string (required)	c("HUSUM_SPM", "TVMBF_SPM")
subunit_group_by	Planning area ID. Each stand belongs to one planning unit. *Equivalent to Subunit in ForSysX.*	Field name as string (required)	"PA_ID"
pa_target	This is the variable target treatment for each planning unit. It may be an area-based metric (i.e. treat 30% of the area in each planning unit), or a value-based metric (i.e. treat 30% of the total building exposure in each planning unit). This value allows ForSys to vary the target by planning unit.	Field name as string (required)	"AREA_MAN"
pa_unit	This is the field that counts towards the treatment target when a stand is treated.	Field name as string (required)	"AREA_HA"
pa_target_multiplier	The multiplier can be used to calculate a proportion of the target, so the user does not have to recalculate the pa_target variable each time they want to increase or decrease it.	Decimal value between 0 and 1. (required)	0.15
nesting	Defines if nesting will be included. This allows the user to select planning areas within a larger container. *Equivalent to Master Subunit in ForSysX.*	Logical (required)	TRUE or FALSE
nesting_group_by	Nesting identifier, such as national forest ID. *Equivalent to Master Subunit in ForSysX.*	Field name as string (required for nesting == TRUE, otherwise NULL)	"FORESTID"
nesting_target	This is the variable treatment target for the larger planning areas. It may be an attainment target (i.e. harvest volume	Field name as string (required for nesting == TRUE, otherwise NULL)	"FOREST_HA" or NULL

	by national forest), or a cost constraint (spend a budget on fuel management in each fireshed).		
nesting_unit	This is the field that counts towards the treatment target when a planning area is treated.	Field name as string (required for nesting == TRUE, otherwise NULL)	"AREA_HA"
nesting_target_multiplier	The multiplier can be used to calculate a percentage of the target, so the user does not have to recalculate the nesting_target each time they want to increase or decrease it.	Decimal value between 0 and 1. (required for nesting == TRUE, otherwise NULL)	0.15
weighting_values	Defines the weights and integer steps between weights. The values are for min, max, and step.	List of three integers. (required)	c("0 5 1")
thresholds	Thresholds are defined first by treatment type (the first value in the string) and can be used to incorporate multiple treatment types. The current code only uses one type (Manageable). The 'Manageable' string is a **required** setting.	List of strings with treatment type and threshold values. Note the unusual syntax without a comma separating the two values. (required)	c("Manageable man_alldis ==1", "Precommercial TVMBF_STND > 1")
include_stands	This defines global threshold values to include stands - i.e. for any threshold type.	List of strings with threshold values. Inclusion criteria are "and", not "or". (can be NULL)	c("Treatable_HA > 0", "HUSUM_STND > 0")
output_fields	A list of the desired fields for the planning area treatment files. Planning area id, priority weights and treatment rank are added automatically.	List of field names as strings. (required)	c("AREA_HA", "TVMBF_STND", "TVMBF_PCP", "HUSUM_STND", "HUSUM_PCP")
grouping_variables	Any non-standard groupings, such as ownership or watershed.	List of fields as strings. (Minimum of one required – subunit_group_by)	c("PA_ID", "Owner")

fixed_target	Set to have either a fixed planning unit target (TRUE) or a variable planning unit target (FALSE). An example would be a specific target area for each planning unit vs. a 2000 ha area target for every planning unit. *The equivalent for FALSE in ForSysX is 'Constraint by Subunit'.*	Logical (required)	TRUE or FALSE
fixed_target_value	Set to the target value that will be used for every subunit when fixed_target == TRUE	Number	2000

1.A. Input stand data

ForSysR uses a stand table in which each row corresponds with a unique stand attributed with mandatory information, including a unique stand identification code, a planning unit identification code, and area metrics. The stand table also contains fields describing the characteristics of each stand with respect to the objectives, treatment thresholds, stand availability, investment or activity constraint, and other subdivisions, such as national forest (Table 2).

To normalize objective metrics among stands of varying size or create a standardized reporting metric to compare objectives of varying units, ForSysR automatically calculates PCP and SPM values for each objective metric with the **pcp_spm** parameter. This option calculates the percent contribution to the problem (PCP) for each selected metric such that the stand is assigned the percentage value it contributes to the entire landscape. This option also calculates the standardized percent of the maximum (SPM) for each selected metric such that the stand is assigned the percentage value of the maximum across the landscape. Weighting priorities based on the SPM value will reduce the potential bias of large stands. Both the PCP and SPM calculations can be set to be calculated on a user defined **land_base**. For example, if a user were interested in limiting the analysis to exclude wilderness areas, this would be defined here and those areas would not contribute to PCP or SPM calculations. The SPM metric is used to account for varying stand sizes when weighting objectives.

Table 2. Basic content of the stand table. Treatment thresholds may include expected wildfire behavior, timber volume, or other operational constraints that must be met for specific treatments to be considered within a stand. Simple treatment restrictions can also be integrated as a treatment availability flag (e.g. a field in which manageable = 1, non-manageable = 0 could be used to include only manageable areas). The user can employ stand-level "percent contribution to the problem" (PCP) objective metrics to homogenize units among the different objectives and facilitate output analysis and interpretation (see section 1.A).

Attribute	Description	Data type
Stand ID	Unique stand identification	integer
Planning area ID	Unique planning area identification	integer
Area	Area of the stand	numeric
$Objective_n$	$Objective\ metric_n$, stand value, and/or standardized percentage of the maximum (SPM), for objective n	numeric
Threshold	Treatment threshold	numeric
Available	Availability flag	categorical: 1-yes, 0-no
$Outputs_n$	Stand values or effects to be summarized and/or percentage contribution to the problem (PCP) for output or objective variable n	numeric

1.B. Objective priorities and weights

ForSysR allows the user to consider up to two priorities when selecting stands for treatment in the **priorities** line in the configuration file. In dual-objective projects, the user must specify the Min Weight, Max Weight and Step as integer values in the **weighting_values** parameter in the configuration file. The steps represent the intervals between the maximum and minimum weights that determine the objective weight combinations. These values are filtered to exclude repetitive weights (e.g. weights 1-1 will provide the same results as weights 2-2 or 3-3 for a set of two-priority scenarios). For two objectives if a user selects weights between 0 and 3, ForSysR will run nine scenarios. Each scenario represents one combination of weights. For example, if objective1 is weighted 0 and objective2 is weighted 3, ForSysR will prioritize stands with high values of objective2 and will not consider objective1. If both objective1 and objective2 are weighted 1, ForSysR will prioritize stands that contribute to both objectives. To run a single objective set the **weighting_values** to c("1 1 1").

1.C. Treatment thresholds

Treatment thresholds are conditions that must be met in order for a stand to be considered for treatment. In ForSysR these thresholds are additive, meaning all conditions must be met in order for a stand to be included in the selection process and can be applied in two parameters within the configuration file. The **thresholds** parameter defines thresholds *by treatment type*. Currently ForSysR only includes one type "Manageable" but in the future additional treatment types may be added. This

means the term "Manageable" is required in the thresholds parameter (thresholds <- c("Manageable man_alldis == 1")). Thresholds are designed to allow for multiple treatment types, but this functionality is currently limited. A global stand filter can also be applied with the **include_stands** parameter and is applied to all stands, for example that the area of the stand must be greater than 10 acres (c("standarea_acre >= 10")).

1.D. Constraints

The user must specify a planning unit-level treatment constraint that represents the total possible investment in management activities for a given planning unit. Typically, this is expressed in terms of area treated, a budget, or a target harvest volume. This can be a static value (e.g. treat 2000 acres) where **fixed_target** is set to TRUE, or can vary by subunit (**fixed_target** is set to FALSE). Constraints provide parameters for treatment solutions based on attributes within the csv table. An area constraint, for example, specifies the total area that can be treated in a given planning area, and the field in the stand table that contains the area of each stand is set as the **pa_unit**. This is similar to subunit constraints in ForSysX. For variable targets, the target varies for each planning unit; here the **fixed_target** is set to FALSE, the **pa_target** is set to the field containing the area within each planning area and the **pa_target_multiplier** is set to the proportion of the planning area that should be treated. Thus the **pa_target** value will be duplicated for each stand within the same planning area. The variable target is the equivalent to running ForSysX with Constraint by Subunit checked.

1.E. Output fields

The output fields are the data the user wants summarized by planning unit, which includes statistics about area treated and treatment effects. These are set in the **output_fields** parameter. The program sums the outputs for each planning unit and reports these values in the pa_all output results file. If the user defines other grouping categories in the **grouping_variables** parameter, such as summarizing results by ownership group, these outputs will be available in the pa_subunit output file. The reported results include one field for the sum of all treated stands indicated with the ETrt prefix, and another field for the sum of *all* stands, indicated with the ESum prefix. ESum is the total of both treated and untreated stands that are considered available for treatment. Remember to add your area field to summarize area "treated". ForSysR also outputs planning area solutions for planning areas that contain no treated stands; these are indicated with a treatment_rank = 0 in the output files.

1.F. Output files

The **pa_all.csv** lists all the planning areas with a summary of the initial planning area values (ESum_x fields), a summary of the treated areas (ETrt_x fields), the weighted priority for a given planning area (weightedPriority), the weight assigned to each of the two priorities (Pr_1_x, Pr_2_x), and the final treatment rank for each planning area

(treatment_rank). The treatment rank designates the order in which planning areas should be treated, with the highest priority treatment rank equal to one. The **pa_subset.csv** files break out the planning area information in the pa_all.csv by other grouping categories (as listed in the input **grouping_variables** and described in section 1.E). This may include categories within planning areas such as ownership, forest type, or management designation. If the user needs detailed stand outputs, they can set the **writeStandOutputs** parameter to true. **Stand_x_y.csv** files are then produced for each pair of weighted priorities. These files include a list of the stands that are treated for the given weighted scenario.

2. Saving Runs

The user must create a new configuration file for each scenario or set of weighted scenarios.

3. Data preparation and structure

ForSysR input data are stored in a CSV or a DBF stand table. The variables described in this section are used to populate the fields described in section 1.A. There are five primary types of stand data included in the table for most ForSysR runs: 1) land base variables, 2) exclusion variables, 3) priority or objective variables, 4) contribution variables, and 5) target variables. See "Creating a Custom Dataset for ForSysR" for more details on creating a custom dataset.

3.A. Land base variables

For Forest Service datasets, stands may include these location-descriptive land base attributes: a unique stand identifier (**subunit <- "**CellID**"**), planning area identifier (**subunit_group_by** <- "PA_ID"), national forest (**nesting_group_by** <- "FORESTID"), and region (**nesting_group_by <- "**Region"). Additional potential extent variables may include (but are not restricted to) districts, PODS, or ownership. These variables allow the user to define where stands should be selected. Typically stands are selected within planning areas, then planning areas are selected for treatment based on priority ranking within a larger extent (e.g. five planning areas may be selected per national forest to meet a restoration treatment goal, or the number of planning areas required to meet a regional timber target).

3.B. Exclusion variables

ForSysR excludes stands that have been designated as non-treatable by the user, such as wilderness and other protected areas. These exclusions are managed through the **include_stands** parameter as described in section 1.C. In addition to treatment exclusions, stands may be excluded for treatment based on a threshold such as

merchantable volume, a forest or cover type, ownership, or any local variables that would preclude entry into a stand using the treatment threshold options.

3.C. Priority/value variables

Priority variables describe values on the landscape that matter to managers and decision-makers and are quantitative links to management questions. These may include timber volume, building exposure from wildfire ignitions, wildfire hazard potential, wildfire risk to drinking water or biodiversity as examples. These are variables that ForSysR uses to meet treatment targets in pre-defined planning areas. ForSysR prioritizes stands based on a standardized percent of the maximum (SPM) value for each of these variables (described in section 1.A) to rank and select stands, subject to a constraint and thresholds. The SPM value is calculated as the percent of the maximum value for each priority. In addition, a percent contribution to the problem (PCP) value is calculated for each variable within each stand. The PCP is calculated as the percent of the sum of all stand values for a given priority. In some cases the meaning of the PCP is clear, for example the total percent of building exposure that is treated for a given scenario or a given planning area. For priorities that are based on an index or non-market value, describing this output is more challenging. Treating X% of the wildfire hazard potential, for example, may be less meaningful than an analysis of the pre- and post-treatment expected flame length of treated stands. Managers who wish to include new local priorities should consider how to understand the progress being made towards key performance indicators.

3.D. Contribution variables

Stand contribution variables are the value each stand provides to meet a larger target. These variables may include anything that can be summed across stands, including timber volume, area, building exposure, and more, and may be the same as a priority or objective value variable. A common method is to set a treatment area target for planning areas and select stands based on their contribution to that target until the treatment target is met but not exceeded. These values are summed over planning subunits, and the summations can be used to meet targets at greater extents as well. For example, we can identify how many planning areas can be treated within a forest, while staying within a forest-level target.

3.E. Treatment target variables

Target variables are used to describe a treatment goal, such as total volume and area treated. Targets work in concert with stand contribution variables, which are more descriptively called the stand contribution to the target. Targets can be incorporated at the planning area level (e.g. treat 10% of each planning area), the forest (treat planning areas until a boardfoot target is met), or any other extent beyond stands themselves.

3.F. Determining suitability of data for use in ForSysR

The resolution and extent of spatial data must meet certain criteria for use in ForSysR. Data that are intended for use as priority variables must be at a higher resolution than the planning area scale, and ideally a higher resolution than the average stand size. Data intended for use as stand exclusion variables have no restrictions to their resolution, as they act as a filter. Past work has shown that very large variability in stand size can affect results, and as a rough guide stands ranging in size from 1 to 100 acres have functioned well in the program, although SPM values will correct for differences in most cases. *Data included in the model must align with management objectives and questions; and scenarios, including priorities, constraints and treatment thresholds, must be well developed prior to developing a final dataset for input into ForSysR.*

3.G. Preparing data for use in ForSysR

There are five steps to preparing data for inclusion in ForSysR scenarios recognizing that it is import to first identify key objectives and management questions and how to use quantitative metrics to address these questions: 1) determine what dataset will be used as a stand layer, 2) identify the type of data you are adding, 3) determine how to attribute the data to the stand layer depending on data type, 4) spatially link data with stands using tools such as the ArcGIS tool Zonal Stats as Table, and 5) join the zonal statistic output data to the stand attribute table. Stand layers can be forest-level stand layers, hexnets intersected with land base variables such as ownership or manageability, or fine-scale polygon-based vegetation spatial data. ForSysR requires certain variables to have specific data types (see Table 2) and none of the variables in the dataset can contain null values. Users need to examine maps of each priority variable and summary statistics prior to running scenarios to understand how the values are distributed across the landscape. For instance, two priorities that are highly spatially correlated will reveal the same answers and not identify tradeoffs.

4. Example ForSysR Application: Northern Idaho Study Area

In this example application, we present a simple all-lands two-priority tradeoff analysis in which stand selections occur within pre-defined planning areas based on HUC12 watersheds within Northern Idaho. Stands are prioritized by the highest timber volume in one direction, while in the other direction stands are prioritized to reduce building exposure from wildfires ignited on the national forest. The study area is approximately 5 million hectares and is comprised of 612 pre-defined planning areas (Fig. 1) averaging 8,000 ha in size. Stands are based on a regular hexnet grid bisected by watershed and ownership boundaries. There are a total of n= 314,104 treatment units or stands ranging in size from 2 to 25 hectares. Wilderness areas, water bodies, and other protected areas or stands that are not available for mechanical treatment

were excluded from the stand layer, resulting in 3.2 million hectares of treatable area that has not be recently disturbed. For more information on scenario planning for shared stewardship in Idaho, see the full report.

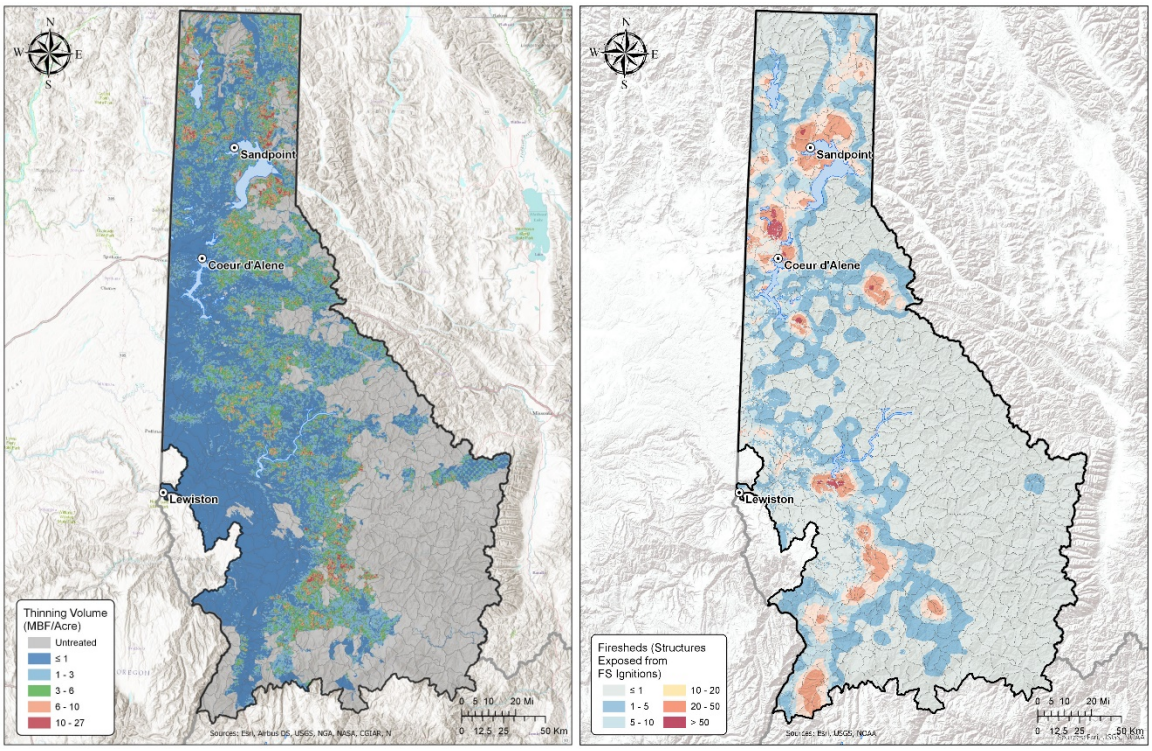

Figure 1: Northern Idaho study area with two priority metrics: A) merchantable timber volume, and B) areas where wildfires ignite and expose buildings. Figures are from Idaho Shared Stewardship: Assessment of priorities and potential outcomes report.

5. Running the ForSysR script

The following section describes how to install ForSysR, load and run an example ForSysR scenario, explore the outputs that ForSysR produces, and provide some ideas on how these outputs can be used to make decisions regarding treatment locations, sequencing, and tradeoffs among different priorities.

5.A. Step-by-step instructions:

1. To run ForSysR you must have R Studio installed. The pacman package must be installed before running the script. The following packages are required and will be installed or loaded using pacman: dplyr, data.table, rgdal, ggplot2, sp, grid, maptools, rgeos, ggsn, roxygen2, foreign, gtools, hexbin, and stringr.

2. Download the following ForSysR file:

- ForSysR package (ForSysR_IdahoDemo.zip), which includes the program and associated example dataset.

3. Create a folder to store the program and data.

4. ForSysR_IdahoDemo.zip file includes:

   - ForSysR.R script. This is the model script. It calls the configuration file, which sets all the variables for a specific scenario.
   - Config_Idaho.R script. The example configuration script. This script must be updated every time a new scenario is created.
   - The R folder contains the forsys_functions.R script. This is called by the ForSysR.R script and should not be altered. If you discover a problem with a function, please inform the author as soon as possible (see Contact Info).
   - Input stand file. Within the data folder there is a dbf file that describes all the stand information.
   - Data dictionary for all fields in the stand file dbf.
   - Planning area or HUC12 watershed shapefile for manual mapping of summary results prioritization.

5. Open the ForSysR.R script and the Config_Idaho.R script in RStudio. The first scenario is set up to run a northern Idaho, all-lands study area. The user will need to update the pathway to the Config_Idaho.R script for their specific machine within the ForSys.R script. All other pathways are relative.

6. Run the entire ForSysR.R script in RStudio. It should run in only a couple of minutes and will report the stage of the run in the console. Outputs will be exported to the ForSysR\output folder.

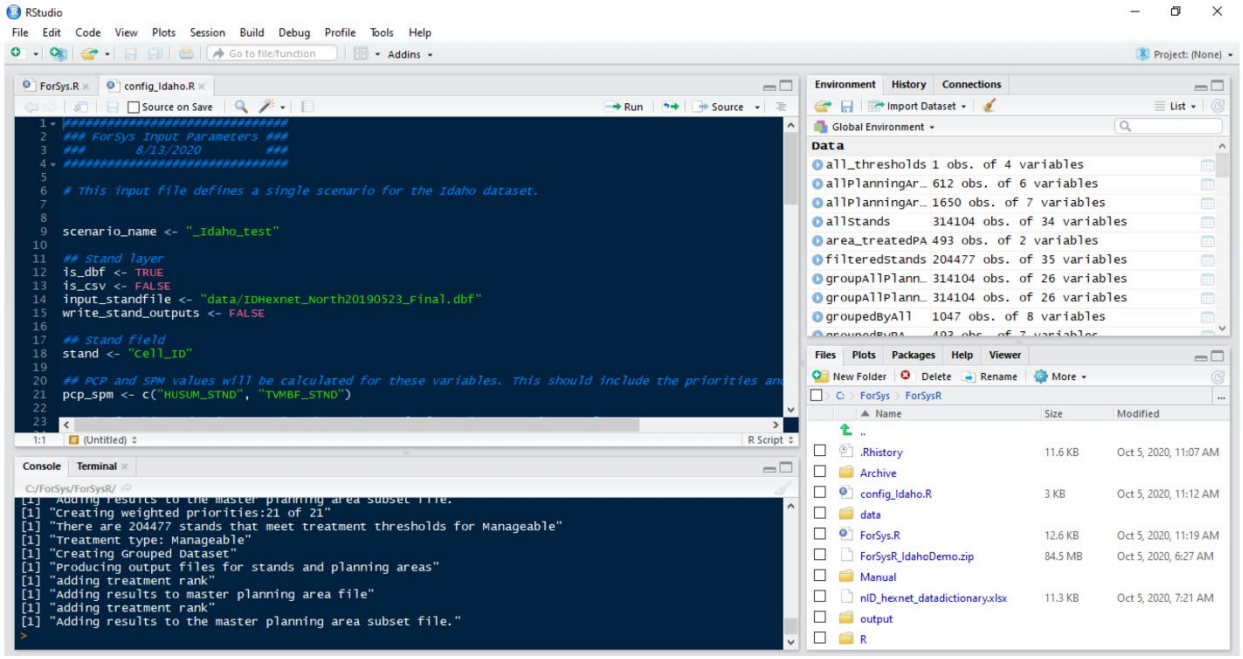

Figure 2: Configuration file in RStudio for the northern Idaho study area timber volume versus building exposure from wildfire ignitions tradeoff scenarios. This set up will run and output results for 21 scenarios.

7. The script will output the following files:

    - If the **write_stand_outputs** flag is TRUE, stand_x_y.csv files are produced for each pair of weighted priorities. These files include a list of the stands that are treated for the given weighted scenario.
    - The pa_all_Idaho_test.csv lists all the planning areas with a summary of the initial planning area values (ESum_x fields), a summary of the treated areas (ETrt_x fields), the weighted priority for a given planning area (weightedPriority), the weight assigned to each priority (Pr_1_x, Pr_2_x), and the final treatment rank for each planning area (treatment_rank). Treatment rank designates the order in which planning areas should be treated, with the highest priority treatment rank equal to one.
    - The pa_subset_Idaho_test.csv breaks out the planning area information in the pa_allIdaho_test.csv by other categories, in this case ownership (as listed in the input **grouping_variables**). This may include other categories within planning areas such as forest type, or management designation as defined in the input data.

8. This example analysis from the northern Idaho study area explores tradeoffs between timber volume and building exposure from wildfires ignited on national forest stands that spread to communities. In this analysis, stands available for

treatment are set by the **include_stands** parameter, which in this case describes whether active management is permitted in stands that have not been recently disturbed. The analysis explores priority metrics for **TVMBF_SPM** and **HUSUM_SPM** with weighting combinations ranging from 0 to 5 in 1 increment steps. No treatment thresholds are defined, meaning all manageable stands will be considered, but in this particular case the available stands attribute was also listed as a threshold (see **thresholds** in the config file). The analysis constrains treatments to 2,500 hectares for each of the 612 planning areas. The **output_fields** parameter shows that ForSysR will report the following treatment effects: timber volume (TVMBF), percentage timber volume attained, building exposure (HUSUM) and percentage building exposure potentially reduced. The suffix STND reflects absolute values while PCP describes the percent of the total produced. ForSysR is set to output stand csv files of stand selections. Stand file output can be turned off in the configuration file to avoid the production of many large output files. A data dictionary for the input dbf is provided with the tutorial.

9. The program will progress messages as it steps through the 21 scenarios.
    - Files generated by ForSys are saved to an output folder in the working directory of the configuration file set in step 5.

5.B. Outputs

ForSysR generates a series of output files for each scenario, which are listed below. Note that the data in this run are for example only.

1. **Main results.** The **pa_all_Idaho_test.csv** file is a planning-area level dataset containing the summarized treatment variables for all treated stands within all planning areas for all weighted scenario combinations. For example, an individual planning area will contain a row in the output results dataset where timber is weighted 1 (Pr_2_TVMBF_SPM) and building exposure 0 (Pr_1_HUSUM_SPM), then again where it is weighted 1 and building exposure is weighted 1 etc.
    - For most analyses, this file will contain the most important results. As a result, ForSysR will always produce this file and there is no option to deselect this output.
2. **Stand-level treatments.** Each csv file (one for each weighted scenario) contain stands that were selected for treatment within each planning area. These data are used to add information about treatments based on other attributes such as individual forest districts, and other spatial statistics that exist at the stand level but are lost at the level of the aggregated planning area data. For example, in this example scenario **stands_1_0_Idaho_test.csv** the "1_0" represents where building

exposure is prioritized (the first metric listed in the **pcp_spm** parameter) and volume is not.

- These outputs are most useful for identifying which stands were selected in a given weighted scenario and for comparing how those selections change as priority weights shift.

- In the example analysis, stand-level treatment outputs are not selected. Change **write_stand_outputs** to TRUE to output stand files.

3. **Planning Area Results by Group.** The **pa_subset_Idaho_test.csv** file is a planning-area level dataset containing the summarized treatment variables for all treated stands within all planning areas for all weighted scenario combinations and by a grouping variable, in this case ownership. Therefore, users can examine the contribution to the treated area by these groupings. For example, how many acres were treated on USFS lands, and how much volume or building exposure was treated on USFS lands.

5.C. Post-processing ForSysR results

There are three primary figures used for interpreting ForSysR outputs: (1) cumulative attainment graphs, (2) production frontiers (PFs), and (3) maps. Each of these are built using the data stored in the pa_all_x.csv. These figures are created outside ForSysR using a combination of Excel, R or other graphing programs, and ArcGIS. See the Quick Start Guide for ForSysX for instructions on using the automated Excel graphing program. Below is a brief description of the primary means of interpreting ForSysR outputs.

1. **Cumulative attainment graphs.** These graphs describe results in two ways: 1) how much of a total problem is treated (cumulative attainment of the PCP values), and 2) how much of something is produced (total timber volume, potential building exposure mitigated). Planning areas are ordered by **treatment_rank** for a specific weighted scenario and effects are summed as a successive number of planning areas are considered. Cumulative attainment graphs are shown for four scenarios where objectives are prioritized individually (Fig. 3). For instance, Fig. 3 shows attainment in reduction of building exposure when exposure is prioritized *and* when three other objective are each individually prioritized. In addition, these graphics can show attainment by ownership, forest, region, and other subcategories.

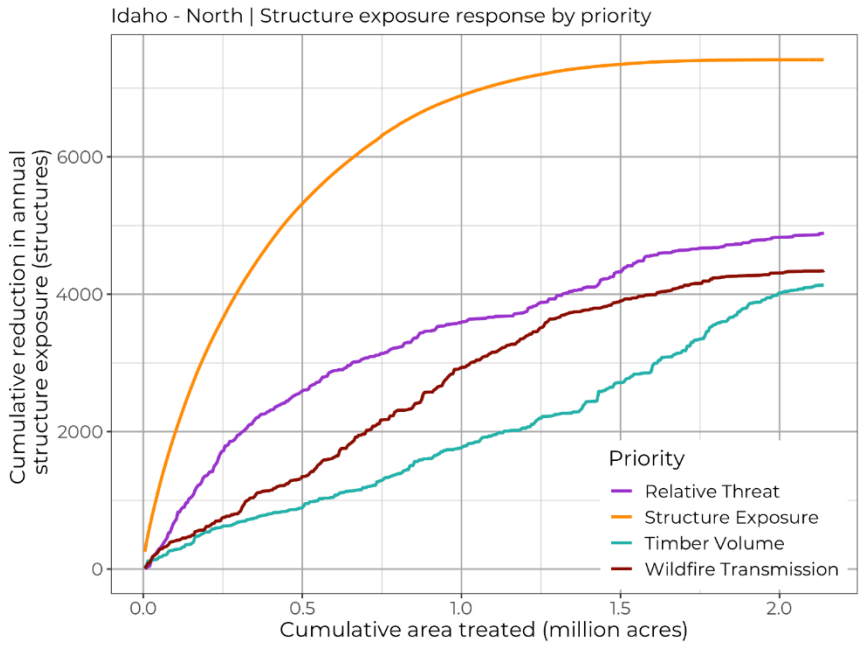

Figure 3: Cumulative attainment curves for building exposure for four different scenarios where each objective is individually prioritized. The rate of attainment under a building exposure priority is much higher than any other priority, suggesting a strong tradeoff exists between protecting buildings and efficient timber production, for example. This graph was created using pa_all_*.csv files for multiple scenario runs and cumulatively summing the ETrt_HUSUM_STND and Treat_Area metrics for each output. Figures are from Idaho Shared Stewardship: Assessment of priorities and potential outcomes report and not explicitly from the results in this tutorial.

2. **Production Frontiers.** Production frontier (PF) curves are typically grouped at the predefined planning area level. Each curve graphs the total attainment of two priorities for a given range of weighted scenarios for each single planning area (Fig. 4). In most cases, producing more of one variable will necessarily mean producing less of the other variable. This allows a manager to identify two things: 1) planning areas where both values can be produced at high levels, and 2) solutions for a given planning area where one priority can be increased with a small opportunity cost relative to the other priority. For example, the PF curve for planning area 1439 in Fig. 4 has the highest attainment for both objectives, although skewed towards exposure reduction. It is important to understand that each point on a single curve is a different selection of stands within the planning area where one objective is weighted more, less, or equal to the other (as set in the **priorities** and **weighting_values** parameters). The shorter the curve the fewer combinations of stands are available to increase attainment for a given priority. The longer the curve, the more opportunities there are on the landscape to change a selection of treatment stands to emphasize one metric or another.

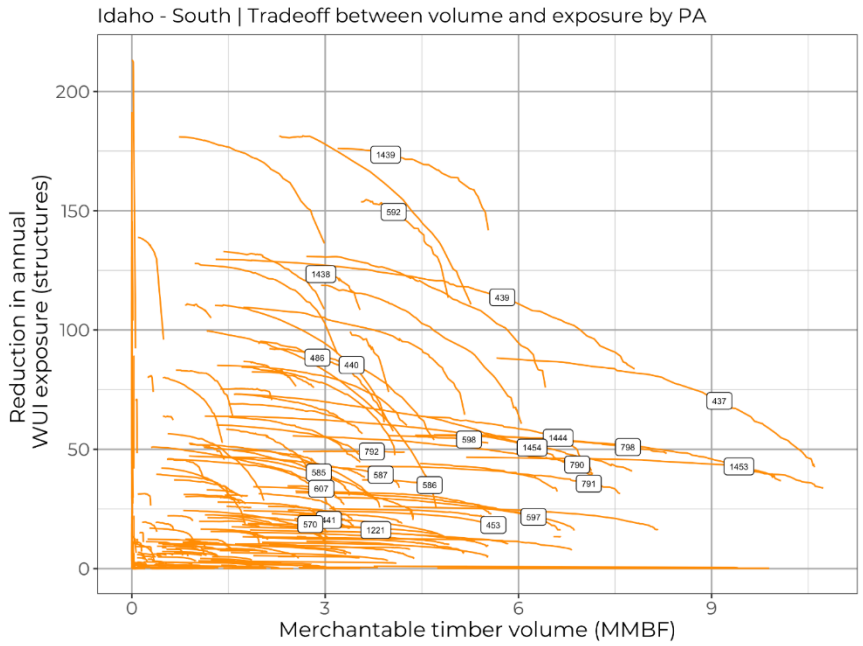

Figure 4: Production frontiers for a timber-building exposure tradeoff in the northern Idaho study area. This graph was created using the pa_allIdaho_test.csv file and graphing the two ETrt_* metrics shown above. Each line represents a single planning area with points along the line the different weight combinations (two *_SPM columns). Numbers reference the planning area ID. Figures are from Idaho Shared Stewardship: Assessment of priorities and potential outcomes report and not explicitly from the results in this tutorial.

3. **Maps.** Maps are produced within ArcGIS, which are typically most useful to identify and sequence planning areas. Mapping requires filtering the **pa_all_Idaho.csv** data to a single priority weighting combination (say 0 for timber volume and 1 for structure exposure; or where Pr_2_TVMBF_SPM = 0 and Pr_1_HUSUM_SPM = 1) and joining the rows from that selection to the project areas shapefile using the **subunit_group_by** field. The **treatment_rank** indicates the planning area rank for that scenario ordered by the priority of interest or the weighted value. Maps similar to those shown in Fig. 5 could be created for each weighting combination or scenario. For this example, there were 21 different weighted scenarios, which in turn could produce 21 different maps. Doing so would show how stand selection gradually shifts between the two extremes shown in Fig. 5 under different combinations of weighted priorities. Note also that in this example, some planning areas could not meet the treatment target of 2500 hectares, such as those planning areas partially or completely within designated wilderness. A planning area shapefile for the example dataset has been provided (**ID_PA_North20190523_Final.shp**).

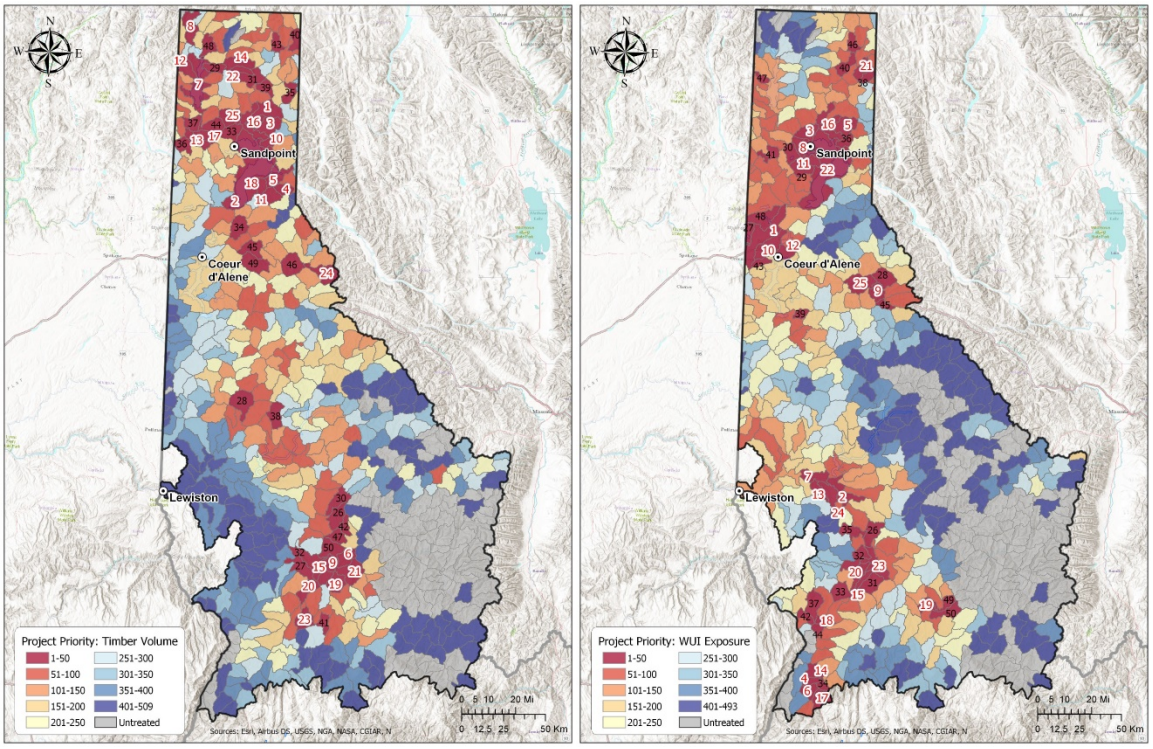

Figure 5: Planning area treatment ranking when prioritizing only A) timber volume or b) building exposure. The top 50 projects are labeled. Stands are available for treatment on any land tenure; 2500 ha of each planning area are treated. Figures are from Idaho Shared Stewardship: Assessment of priorities and potential outcomes report and not explicitly from the results in this tutorial.

Acknowledgments

This manual was written by Rachel Houtman and Michelle Day. Stu Brittain and Alan Ager designed version 1 of ForSysX (formerly the Landscape Treatment Designer), the executable version of ForSys. Ken Bunzel has provided all updates and programming for version 2 of ForSysX.

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