Supplement 3: tappR User's Guide

tappR: A Toolset to Estimate Maple Syrup Yields in Southern Sugarbushes

Background

This package contains functionality that allows the user to input a tree list or stand table of red maples (*Acer rubrum* L.*;* rm) and/or sugar maples (*Acer saccharum* Marshall; sm) and estimate expected sap volume, sugar content (SSC), and maple syrup yield based on either DBH or crown class. The DBH model and routine will likely find more utility by users than the crown class routine, but both are included in the package for completeness. This guide details the procedures for input data preparation, selection of model routines (functions), specification of function arguments, and summarization of results and concludes with an example of estimating syrup yield in a simulated uneven-aged stand.

Input Data Preparation

tappR utilizes and imports data in data frame format with explicit rules for column names and field type. Tables 1 and 2 provide examples of properly specified data frames for input into *tappR* (depending on desired method). Within the input data frame, data may be specified as either individual tree entries or as a stand table. Input data frames must contain species under the "Sp" column, diameter at breast-height under the "DBH" column or crown class under the "CC" column, and the number of trees represented by each row entry under the "Freq" column. In the case of a complete tree list, entries in the Freq column should be specified as 1. Data types and acceptable values of each column are identified in Table 3. Errors will result if the input format is incorrect. Note that DBH should be input in inches; *tappR* does not support metric units at this time.

Table 1. Example input data frame using diameter at breast-height (DBH).

Sp	DBH	Freq
rm	20	8
rm	16	12
sm	22	4
sm	12	14

Table 2. Example input data frame using crown class (CC).

Sp	CC	Freq
rm	dominant	7
rm	codominant	13
sm	dominant	9
sm	codominant	18

Table 3. Data types and acceptable values of input data frame for *tappR*.

Column	Type	Acceptable values
Sp	Character, Factor	"rm", "sm"
DBH	Numeric	Any numeric value (unit = inches)*
CC	Character, Factor	"overtopped", "intermediate", "codominant", "dominant"
Freq	Numeric	Any numeric value

* Note: models were developed within a DBH range of 6-36 in.

Model Routines

tappR possesses two routines with which to estimate maple syrup production parameters based on input data format: a DBH routine and crown class routine. Each subsection illustrates the specification and utility of each routine.

DBH Routine. In this routine, tree size is specified in the input data using DBH. Given DBH, the routine estimates annual per-tap sap volume and SSC using the models constructed in this work and leverages the revised equation for Jones Rule (Perkins and Isselhardt 2013) to calculate expected syrup yield (see Formulae section). To determine total per-tree sap production, the number of taps per tree must be identified, which is performed via user-specified arguments in the main function call. For trees with more than 1 tap, it is assumed that production is equal across all taps. Specifically, minimum DBH for two taps (argument: taps2) and three taps (argument: taps3) per tree may be specified by the user; by default, taps2 = 16" and taps3 = 24". Similarly, the argument minDBH may be specified to set a minimum DBH threshold for tree tapping; below minDBH (default = 10"), yield will be set to 0 to indicate trees are not of sufficient size for tapping. Note, similar to DBH specification in the input data, values in inches for minDBH, taps2, and taps3 are required. There appears to be at least marginal evidence in the literature that trees with multiple taps may experience diminished per-tap sap volume production (Morrow 1963). The arguments *taps2.eff* and *taps3.eff* are available for users to set the increase in the efficiency of production by adding additional taps. The efficiency of tap 1 is always 1. *taps2.eff* is the relative increase in production from 2 taps per tree compared to 1 tap per tree; by default, this is set to 1.33 (Morrow 1963). Likewise, *taps3.eff* is the relative increase in production from 3 taps per tree compared to 2 tap per tree, and is set to 1.2 by default (Morrow 1963). Under the default parameterization, the improvement in production from 3 taps compared to 1 tap is a factor of approximately 1.6.

Crown Class Routine. Rather than specify tree size using DBH, this routine allows the user to estimate production using crown class. Crown class is a commonly used metric that describes both tree size and competitiveness. The Crown Class routines utilizes the mean estimates of syrup equivalent by species and crown class presented in Table 6 of this work to calculate expected yields. Similar to the DBH routine, a rule for number of taps per crown class must be established to calculate per-tree yield, and arguments for user-specified tap numbers are available in the function. By default, dominant (taps.dom) and codominant (taps.codom) trees are given two taps, while intermediate (taps.inter) and overtopped (taps.over) are given 1. In practice, some knowledge of the diameter distribution of the prospective sugarbush is necessary for proper planning and decision-making; thus, the utility of this routine may be of limited practical use.

Running the Function

The *boil* function is the main interface and only public function of *tappR*. The full model specification, including all arguments and default values, is presented below. The input data frame is specified with the "Data" argument. *boil* uses the columns (and column names) present in the input data frame to determine automatically the desired estimation routine: that is, if the column "DBH" is present in the input data, the estimation routine based on DBH will be applied, and the crown class estimation routine will be used automatically if "CC" is present in the input data frame. Arguments pertinent to the desired estimation routine should be specified in the function call (see previous sections on Model Routines). Note, if arguments are specified for the other model routine, they will be ignored.

```
boil(Data,
     minDBH = 10,
     taps2 = 16,
     taps3 = 24,
     taps2.eff = 1.33,
     taps3.eff = 1.2,
     taps.over = 1,
     taps.int = 1,
     taps.codom = 2,
     taps.dom = 2)
```

Function Outputs

boil generates two outputs: a storable data frame detailing individual-tree (or tree-class productivity) productivity and a printed summary of total predicted productivity for all trees. The storable data frame output possesses the same row dimension as the input data frame and includes the input data, in addition to estimated productivity measures, which vary depending on the estimation routine. Output in the input format permits the use of syrup estimates in further data processing and analyses. Descriptions of columns of output data frames created by each routine are provided below.

Columns – DBH Routine

Sp: species (from input)
DBH: diameter at breast-height (inch; from input)
Freq: number of trees represented by row entry (from input)
Sap.tap: estimated sap volume produced per year per tap (in gallons)
Taps: Number of taps per tree as specified by minDBH, taps2, and taps3 in *boil*
Sap.tree: total estimated sap volume per tree (in gallons)
Sap.class: total estimated sap volume per DBH class (row entry) based on Freq (in gallons)
SSC: estimated sap sugar content (in °Brix)
Syrup.tree: estimated syrup yield per tree (in gallons)
Syrup.class: estimated syrup yield per DBH class (row entry) per year (in gallons)

Columns – Crown Class Routine

Sp: species (from input)
CC: crown class (from input)
Freq: number of trees represented by row entry (from input)
Syr.eq: estimated syrup equivalent (yield) per tap per year
Taps: Number of taps per tree as specified by taps.over, taps.int, taps.codom, and taps.dom in *boil*
Syrup.tree: estimated syrup yield per tree per year (in gallons)
Syrup.class: estimated syrup yield per crown class (row entry) per year (in gallons)

Worked Examples

A worked example, complete with model specification and outputs, are provided for the two scenarios in which data are input with either crown class or DBH.

DBH Example

In this example, an upland stand is regulated under uneven-aged management practices (q-factor = 1.25; Figure 1). The maximum tree size is 30" DBH, with 3 trees in this DBH class. The red and sugar maple components of this stand are 14% and 10%, respectively. The stand table (per acre) generated from this stand is included as an example data set called *uplands* in the R package. A snippet of the data set is provided in Table 4.

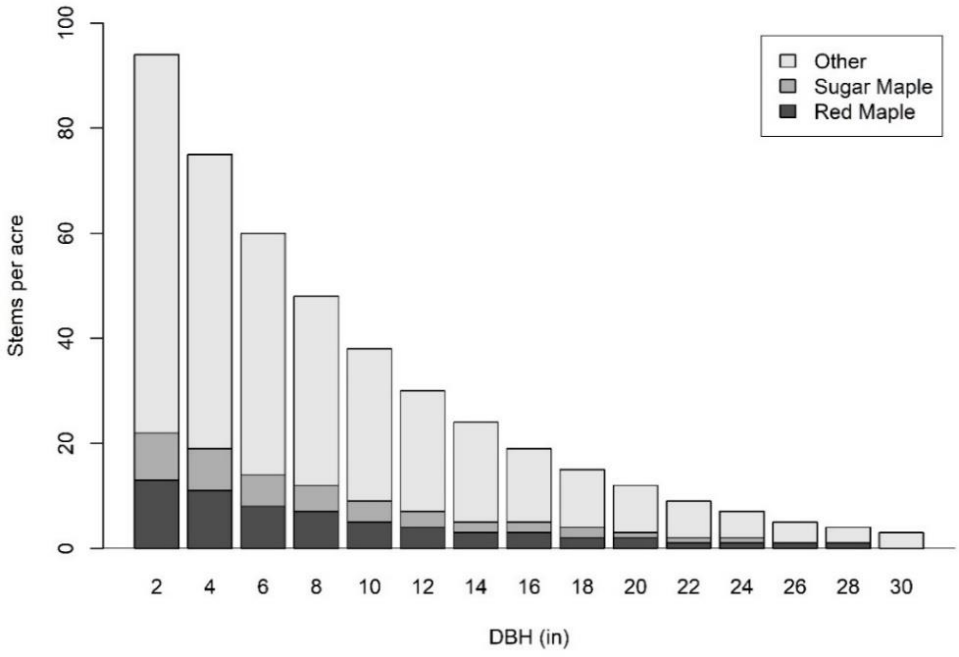

Figure 1. Diameter distribution and species composition of *uplands* uneven-aged stand.

Table 4. Snippet of *uplands* example data set.

Sp	DBH	Freq
rm	28	1
sm	2	9
sm	4	8
sm	6	6

If the estimated maple syrup yield of the *uplands* stand were of interest, these metrics could be calculated with use of *boil*. The function call and results are below. Default values for minDBH, taps2, taps3, taps2.eff, and taps3.eff were used.

```
boil(Data = uplands,
     minDBH = 10,
     taps2 = 16,
     taps3 = 24,
     taps2.eff = 1.33,
     taps3.eff = 1.2)
```

Printed summary statistics:

```
[1] "Total estimated number of tappable trees = 39"
[1] "Total estimated number of taps = 61"
[1] "Total estimated maple syrup yield = 7.6 gallons per year"
[1] "Average estimated sugar content per tree = 1.6 °Brix"
[1] "Average estimated sap yield per tap = 6.7 gallons per year"
```

Snippet of storable output data frame:

Sp	DBH	Freq	Sap.tap	Taps	Sap.tree	Sap.class	SSC	Syrup.tree	Syrup.class
rm	28	1	15.2	3	24.3	24.3	1.5	0.43	0.43
sm	8	5	0	0	0	0	0	0	0
sm	10	4	5.7	1	5.7	22.7	1.7	0.11	0.45
sm	16	2	9.2	1	12.2	24.4	2.0	0.28	0.56

* Note: values in this table are rounded.

Crown Class Example

Data from the *uplands* stand has been tabulated by crown class and included in the package as the *uplands.cc* data set. Like *uplands* data set, the *uplands.cc* data set is in appropriate format for input into *boil*. The *boil* function call to use the crown class routine to estimate yield parameters is below. Tap numbers per crown class and efficiencies of second and third taps were left at the default setting. Note, specification of more than 3 taps will result in an error. Results follow the function call.

```
boil(Data = uplands.cc,
     taps.over = 0,
     taps.int = 1,
     taps.codom = 2,
     taps.dom = 2
     taps2.eff = 1.33,
     taps3.eff = 1.2)
```

Printed summary statistics:

```
[1] "Total estimated number of tappable trees = 39"
[1] "Total estimated number of taps = 57"
[1] "Total estimated maple syrup yield = 5.6 gallons per year"
```

Row entries from storable output data frame

Sp	CC	Freq	Syr.eq	Taps	Syrup.tree	Syrup.class
rm	dominant	1	0.17	2	0.23	0.23
rm	intermediate	12	0.06	1	0.06	0.72
sm	codominant	7	0.21	2	0.28	1.96
sm	overtopped	0	0	0	0	0

From this example, we see that yield estimates vary by estimation method. Typically, use of DBH-based method will likely yield a more accurate prediction, and practitioners will likely find the use of DBH-based syrup estimation more appropriate in application.

Constants and Formulae

Red Maple Sap Volume (gal) $= 0.506\ \mathrm{DBH}^{1.021}$

Red Maple SSC (°Brix) $= 0.565\ \mathrm{DBH}^{0.3}$

Sugar Maple Volume (gal) $= 0.54\ \mathrm{DBH}^{1.021}$

Sugar Maple SSC (°Brix) $= 0.862\ \mathrm{DBH}^{0.3}$

Jones Rule (revised) to estimate syrup yield (equivalent) given sap volume and SSC:

$$\text{Sap Conversion Factor (gal)} = \frac{87.1}{\text{SSC}} - 0.32$$

$$\text{Syrup Equivalent (gal)} = \frac{\text{Sap Volume}}{\text{Sap Conversion Factor}}$$

Estimates of per-tap syrup equivalent (gallons) of red and sugar maples by crown class used in the crown class routine.

Crown Class	Red Maple	Sugar Maple
Dominant	0.17	0.28
Codominant	0.13	0.21
Intermediate	0.06	0.11
Overtopped	0.04	0.08

References

Morrow. R.R. 1963. Influence of number and depth of tap holes on maple sap flow. Bulletin 982. Cornell University Agricultural Experiment Station, Ithaca, NY, USA.

Perkins, T., and M. Isselhardt. 2013. The “Jones Rule of 86” Revisited. Maple Syrup Digest October 2013: 26-28.