Data Management and Analysis of Ozone Injury to Pines

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This section outlines the procedures for data management and analysis developed by the data archiving group located at the USDA Forest Service's Pacific Southwest Research Station, Riverside, California. The field data were gathered annually at approximately 33 FOREST plot locations from 1991 to 1994.

Data Entry

Tree– and whorl–level data—either from written data sheets or entered into a field data recorder (FDR)—can be merged into a master database, and the ozone injury index (OII) can then be calculated for each tree. Information from data sheets can be entered on a PC using customized software available from the Data Archiving Group (*appendix B*). After proofreading, copies of the electronic data files as well as the original data sheets should be archived. Site data should then be proofread, reformatted, and entered into the FOREST database.

Database Description

The FOREST relational database contains several files related by a key field for each site (*table 1*). The key field is composed of an abbreviation of the site name, the plot number and the tree tag number. Every site has one "plot" file containing one record for each tree tagged. Other fields in the plot file contain data such as whether the tree is currently alive, and other information that will not change, such as elevation. A tree file—one for each year data is collected—has one record for each live tree in the plot and contains data relating to crown and bole condition. The whorl file—one for each year data is collected—contains

Table 1—*Variables included in the FOREST relational database.*

Plot	Tree	Whorl	Index
ID	**ID**	**ID**	**ID**
Forest	Date	Branch #	EII
Site	Position	Whorl #	VI
Plot #	Species	Chlorotic Mottle	RET
Tag	DBH	Retention	LGT
Crew	Height	Needle Length	CD
Aspect	Pct Live Crown	Biotic Injury	height
Slope	Live Crown Ratio	Abiotic Injury	DBH
Elevation	Rock	Comment	Foliated Length
Landform	Mistletoe		Needle Length
Slope Position	Conk		
Community	Bark Beetle		
Year	Fire Scar		
Alive	Lightning Scar		
Year dead	Broom		
	Microrelief		
	Bole comment		
	Foliated Length Branch 1–5		

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all the data collected from the whorls and has one record for each whorl. A yearly OII index file is created from data in the tree and whorl files by the dBase program, "Index.prg," and contains the calculated OII for each live tree.

Development and Application of the Ozone Injury Index (formerly the Eridanus Injury Index)

Index Components

The ozone injury index (OII) is a modified version of the additive Eridanus injury index (EII) proposed by Duriscoe (1988), and is comprised of the primary effects of ozone air pollution on pines:

- Production of chlorotic mottle symptoms;
- Accelerated senescence of needles and subsequent reduced whorl retention from ozone stress that also reduces the amount of carbon fixation;
- Reduced percent live crown as lower branches die first in ozone declining trees;
- Reduced needle length in newly initiated needles as carbon reserves become limiting (Miller and others 1963).

Whorl retention is weighted 40 out of 100; mottle is weighted 40 out of 100; needle length is weighted 10 out of 100; and live crown ratio is rated 10 out of 100. The OII incorporates the degree of pollution injury at the branch level to give a tree level score. The maximum injury score is 100 and indicates a tree that has only one whorl of needles remaining, greater than 40 percent chlorotic mottle injury on that whorl, short needles (1 centimeter or less), and a percent live crown of less than 10 percent. The minimum index score is zero and indicates a tree with no chlorotic mottle symptoms on any of the foliage (an asymptomatic tree): if no chlorotic mottle is found on any needles, i.e., if the chlorotic mottle factor is zero, then reductions in whorl retention, live crown ratio, and needle length cannot be attributed to ozone air pollution. Therefore, these factors are not computed and the composite OII is set to zero for asymptomatic trees regardless of condition of the crown.

The index weights whorl retention (40 percent) and chlorotic mottle (40 percent) greater than the other index components—percent live crown (10 percent), average needle length (10 percent)—and is therefore not strictly monotonic (if an index is not strictly monotonic there should be a valid reason for increased emphasis on any one factor) (Muir and McCune 1987). The increased emphasis on whorl retention and mottle is based on physiological studies by Patterson and Rundel (1989). Their work also indicates that all whorls are significant contributors of fixed carbon. Thus, the index fulfills the requirements elucidated by Muir and McCune (1987) for assessing pollution injury on vascular plants.

Caveats

Chlorotic mottle has a relatively linear effect in reducing net photosynthesis of Jeffrey and ponderosa pine to about 40 percent of needle surface. After 40 percent of the surface area is affected, increasing levels of mottle on photosynthesis is negligible (Patterson and Rundel 1989). Therefore, when the visible injury ratings of the whorls are averaged for a branch, all ratings above three are set to three. If no chlorotic mottle is present on any whorl, the injury index is zero. Mottle injury is also weighted by the whorl on which it occurs. If only two whorls are present on a branch the mottle rating from each is weighted

equally. If there are three whorls the mottle is weighted, .35, .35, .30 for the first, second, and third whorls, respectively. If the branch has four or more whorls, the mottle is weighted .28, .28, .24, .20 for the first to fourth whorls. Mottle appearing on a fifth or older whorl does not contribute to the index and is used only to delineate a symptomatic/asymptomatic branch. The maximum mottle score is 40, the minimum score is zero (a mottle injury score of zero implies an overall OII of zero).

Whorl retention evaluation assumes that retention of five annual whorls indicates a healthy ponderosa pine (Munz and Keck 1973). Although Jeffrey pines can be expected to retain eight or more whorls, the use of five as a threshold for ozone effects is reasonable since retention of more than five whorls indicates a relatively healthy pine tree. If a pine has chlorotic mottle on whorls five or older the mottle factor of the injury index will indicate the tree is asymptomatic, and the whorl retention factor of the index will record no injury. A pine is not likely to be even moderately impacted if it retains more than five whorls of needles. Whorl retention, and percentage of fascicles retained per whorl (1 = 1–33 percent; 2 = 34–66 percent; 3 = 67–100 percent), are scored on the data sheet to indicate missing whorls or portions of missing whorls because of insect predation, fungi, or other stresses (non–air pollution causal agents). The index computes whorl retention as fractions of whole whorls (i.e., 1, .66, .33), except for less than one whorl retention. Branches with less than one whorl are considered to have a full whorl in the index, since retention of 1 whorl or less produces the maximum injury score (40) for whorl retention (see example below). Maximum injury score for whorl retention is 40 (only one whorl of needles), minimum score is 0 (five or more full whorls of needles).

Modal needle length in centimeters of representative needles is measured in the middle of each year's whorl of needles. This assumes that maximum expansion of the needle has occurred and that the needle length of a very healthy ponderosa is 21 centimeters and Jeffrey pine needle is 19 centimeters. Needle lengths shorter than one centimeter are computed as one centimeter. Maximum injury score for needle length is 10 (needles 1 centimeter or less), minimum score is 0 (needles 21 or 19 centimeters or greater).

Percent live crown is the proportion of the total crown that has any live branches with any number of live needles. This assumes a crown retention of 10 percent as a minimum value. Maximum injury score for percent live crown is 10 (10 percent or less of the bole with a live branches), minimum score is 0 (80 percent or more of bole with live branches).

Equation for Calculating the Ozone Injury Index (OII)

Definitions and Weightings

Each of the following four variables require individual calculation before summation. These calculations provide averaging and introduce the specified weightings.

$$OII = VI + RET + LGT + CD$$

in which:

VI = Visible injury (chlorotic mottle)

RET = Number of needle whorls present and fascicle retention

LGT = Modal length of needles (average all whorls)

CD = Percent live crown

Visible injury (VI) (chlorotic mottle)

VI includes weighted average of up to the first four whorls:

5+ Whorls: VI=1+{40*((CM1*.28)+(CM2*.28)+(CM3*.24)+(CM4*.20))/3}

4 Whorls: VI=40*((CM1*.28)+(CM2*.28)+(CM3*.24)+(CM4*.20))/3

3 Whorls: VI=40*((CM1*.35)+(CM2*.35)+(CM3*.30))/3

2 Whorls: VI=40*((CM1*.50)+(CM2*.50))/3

1 Whorl : VI=40*(CM1)/3

in which:

CM1 (chlorotic mottle) is the average mottle on all current year whorls (except if mottle rating of a whorl is > 3 it is set to 3 before average is calculated). CM2 is the average mottle on all one–year–old whorls, and so on.

Retention (RET)

If oldest whorl on any branch is 1:

FWHORL=WR1*.33

If oldest whorl on any branch is 2–6:

FWHORL=(oldest whorl–2)+(sum fascicle retention 2 oldest whorls*.33)

If oldest whorl on any branch is > 6:

FWHORL = oldest whorl – 1

Then:

RET = 40*[100.37/(1+e^(1.72*(FWHORL–4.532)))+.6304]/100

in which:

e=2.718

WR1=Average fascicle retention of all current year whorls on all 5 branches.

WR2=Average fascicle retention of all 1–year–old whorls on all 5 branches.

WR3=Average fascicle retention of all 2–year–old whorls on all 5 branches.

Needle length (LGT)

If species is Jeffrey pine:

LGT=(18–Len)*10/18

If species is ponderosa pine:

LGT=(21–Len)*10/21

in which:

Len is the average needle length of all whorls.

Percent live crown (CD)

CD=(80–percent live crown)*10/70

OII Calculation

Sample Data Set for One Tree

BRANCH	WHORL	CM	RET	NL
1	1	0	3	20.5
1	2	0	3	17.5
1	3	0	3	21.0
1	4	1	1	13.0
2	1	0	3	17.0
2	2	0	3	18.5
2	3	0	3	20.0
2	4	5	3	14.0
3	1	0	3	16.5
3	2	0	3	17.5
3	3	0	3	21.0
3	4	1	2	11.5
4	1	0	3	21.0
4	2	0	3	20.0
4	3	0	3	20.0
4	4	1	2	15.0
4	5	0	0	0 (This whorl is missing)
4	6	2	1	15.0
5	1	0	3	18.0
5	2	0	3	17.0
5	3	1	3	19.0
5	4	1	1	13.0
5	5	0	0	0 (This whorl is missing)
5	6	0	1	13.0

Weighting of Components and Computation of the OII

Chlorotic mottle

Oldest whorl is 6

CM1=(0+0+0+0+0)/5 = 0

CM2=(0+0+0+0+0)/5 = 0

CM3=(0+0+0+0+1)/5 = .2

CM4=(1+3+1+1+1)/5 = 1.4

VI=1+{40*[(0*.28)+(0*.28)+(.2*.24)+(1.4*.20)]/3}=5.37

Retention

Oldest whorl is 6

Fascicle retention of two oldest whorls is:

WR5 = 0

WR6 = (0+0+0+1+1)/5 = .4

FWHORL = (6–2)+((0+.4)*.33)]} = 4.132

RET = 40*[100.37/(1+2.718^(1.720*(4.132-4.532)))+.6304]/100

= 26.97

Needle length

LEN=17.2, Species is ponderosa

LGT=(21–17.2)*10/70 = 1.81

Percent live crown

Percent live crown = 66

CD=(80–66)*10/70 = 2

Result

OII=VI+RET+LGT+CD = 5.37 + 26.97 + 1.81 + 2.0 = 36.15