

Buds, Leaves and Global Warming

John O'Keefe

Harvard Forest

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- www.harvardforest.harvard.edu/schoolyard-liter-program
- www.harvardforest.harvard.edu/buds-leaves-global-warming
- www.harvardforest.harvard.edu/autumn-foliage-color

What is **phenology**?

The science of the relations between climate and periodic biological phenomena (i.e. leaf emergence, flowering, leaf senescence/drop, animal migration, hibernation etc.)

Why study phenology?

- Data provide markers to track mass and energy interactions between the atmosphere and biosphere.
- Long-term data sets are records of the biosphere's responses to global change.
- Individual plant observations, 'phenocam' images and satellite data document the timing and pattern of annual 'green-up' and 'green-down'.
- Native species and inter-regional indicator plant (clones) observations can be used to calibrate satellite and 'phenocam' digital data.
- Leafout and leaf senescence in temperate regions influence meteorological (cloud cover/type) and hydrological (stream flow) phenomena.

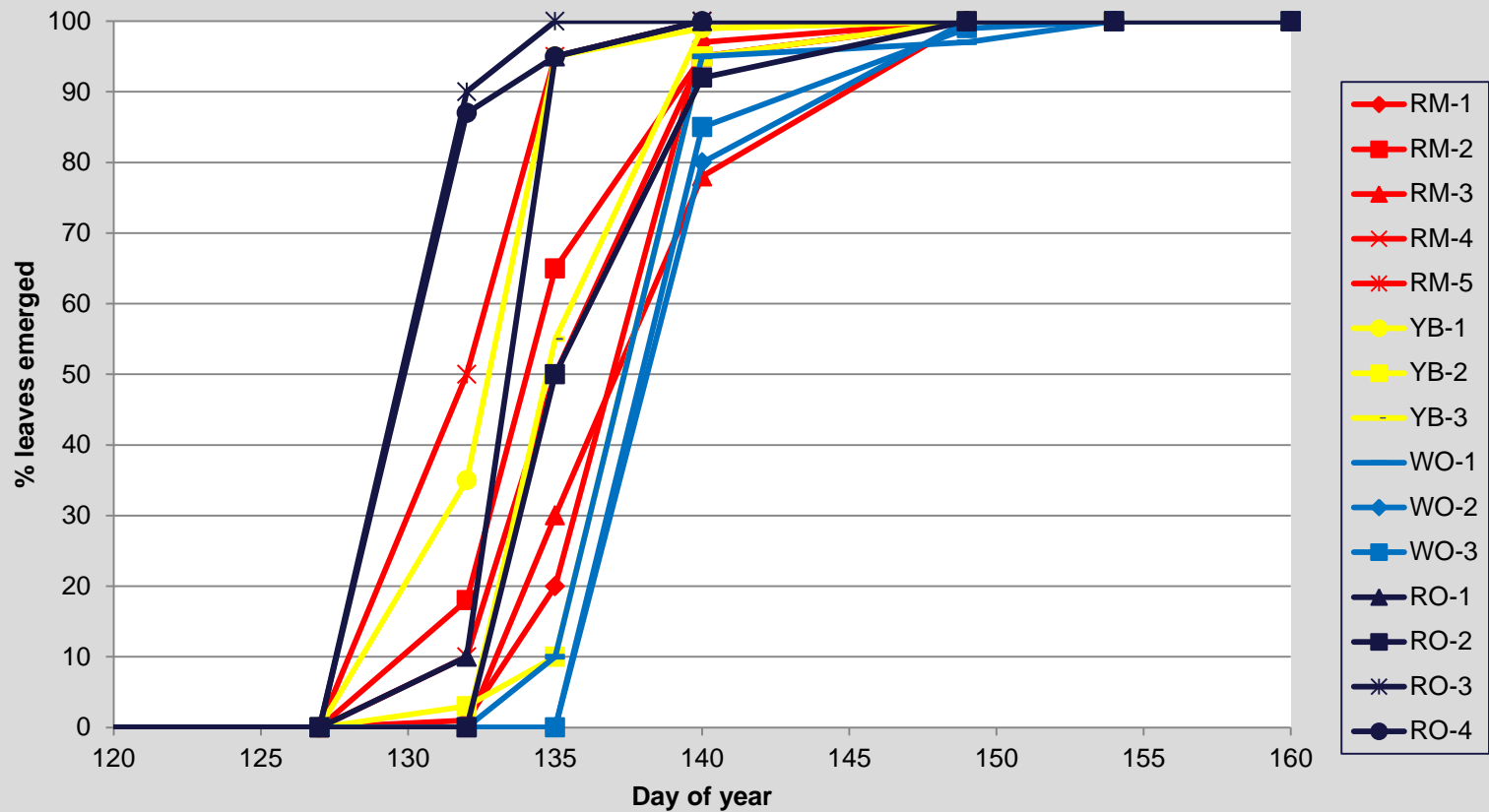
What are the main factors affecting the timing of woody species leaf phenology?

- **Spring leafout**
 - Cold treatment
 - Cumulative heat sum (growing degree days)
 - Day length
- **Fall leaf drop**
 - Temperature and frosts
 - Day length
 - Drought
 - Wind

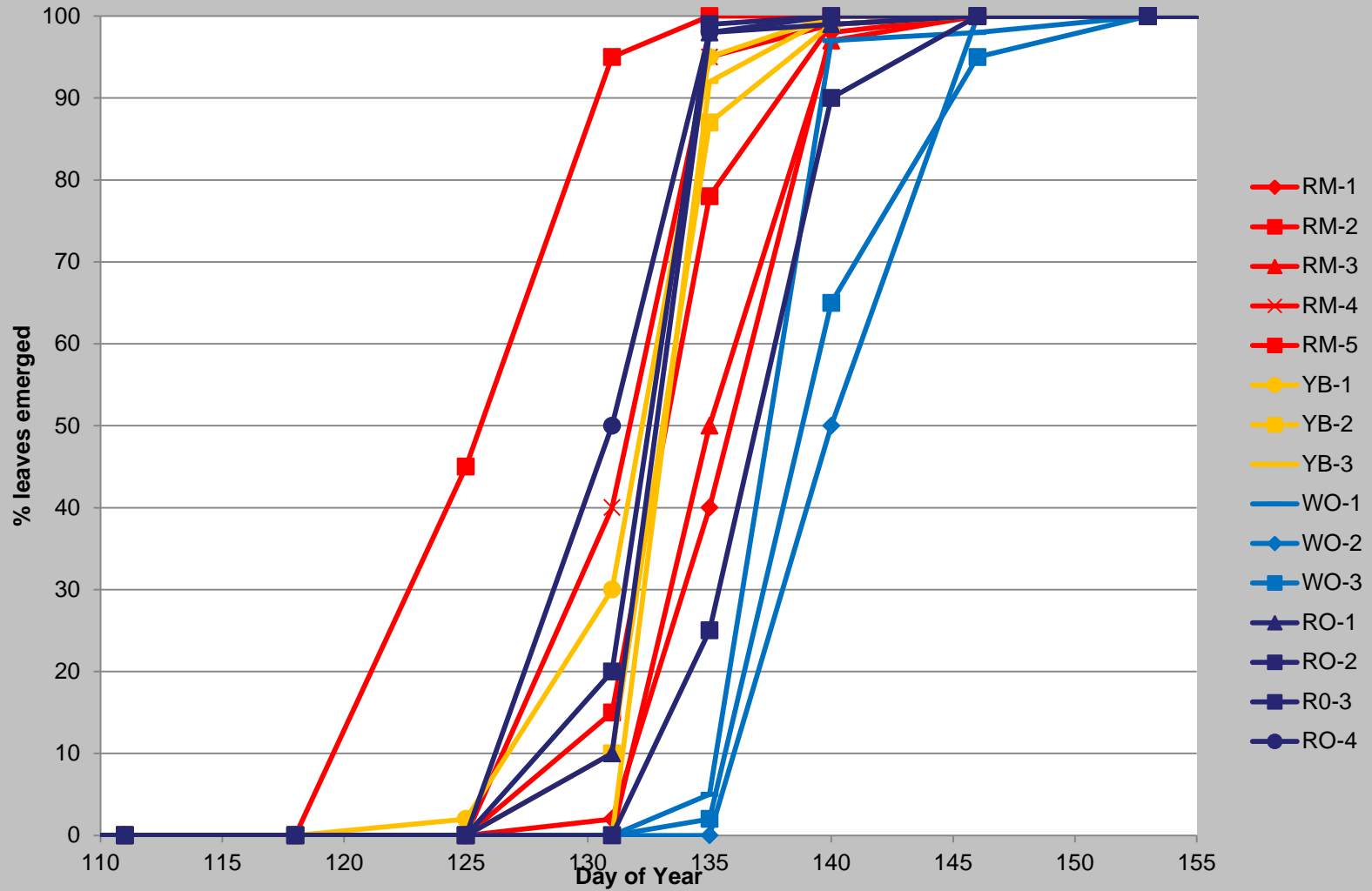
Harvard Forest Study

- Started in 1990 (spring) and 1991 (fall, but fall 1992 not done).
- Originally 33 species of trees and shrubs (3-5 individuals per species), but in 2002 decreased to 15 species in fall and 9 species in spring to reduce the time needed for the study.
- I observe about weekly, but more often in late April-early May and early October when events are progressing most rapidly.
- I observe and estimate % values (leaf emergence, leaf development, leaf color, leaf drop) over the entire tree (rather than a set number of tagged leaves/bids), which is in fact easier than labeling and counting individual leaves, but doesn't work with younger students.

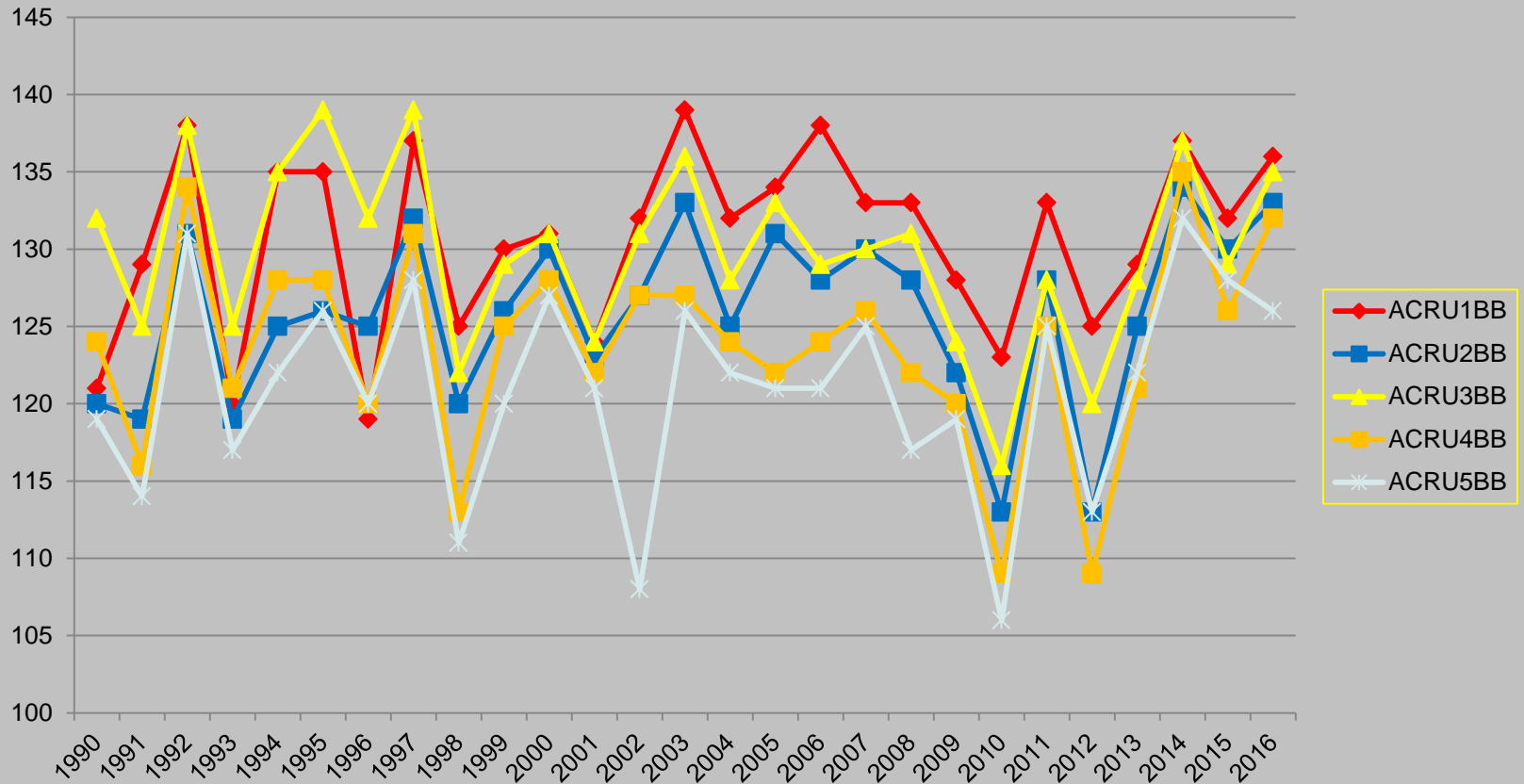
% leaf emergence by tree - 4spp 2014



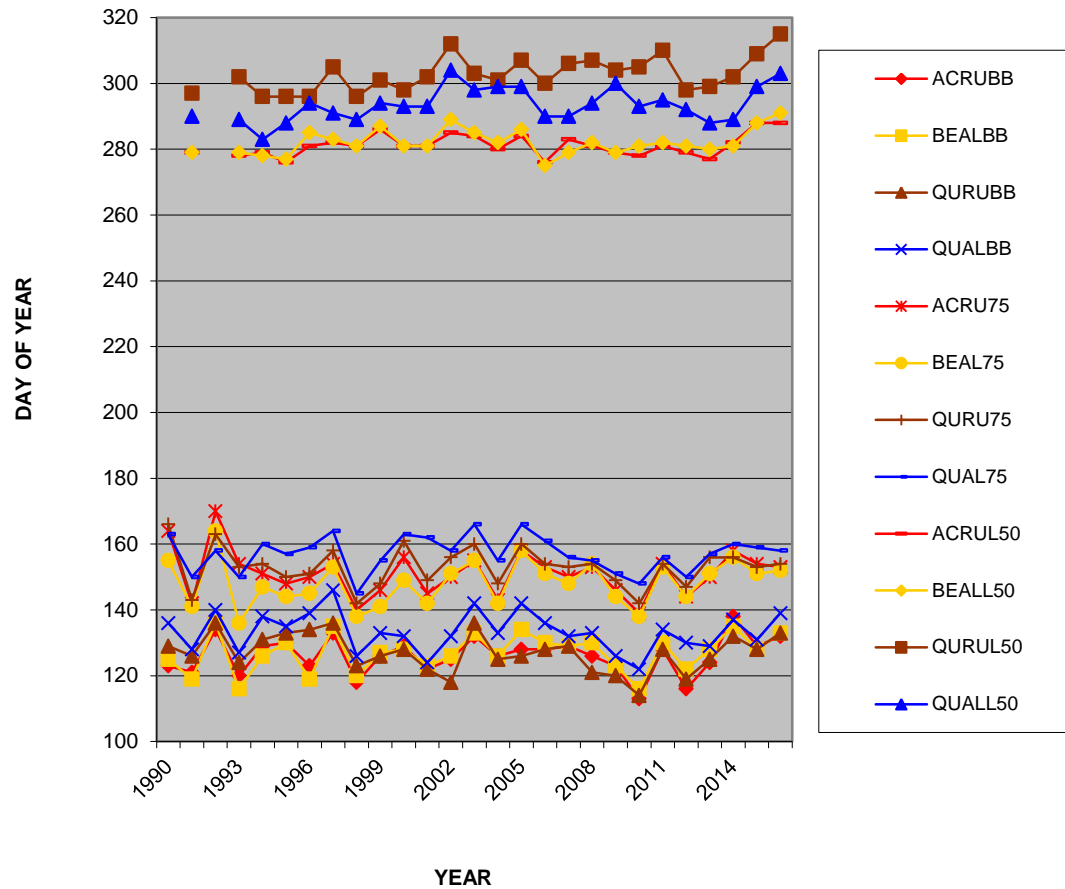
% leaf emergence by tree - 4 spp -2016



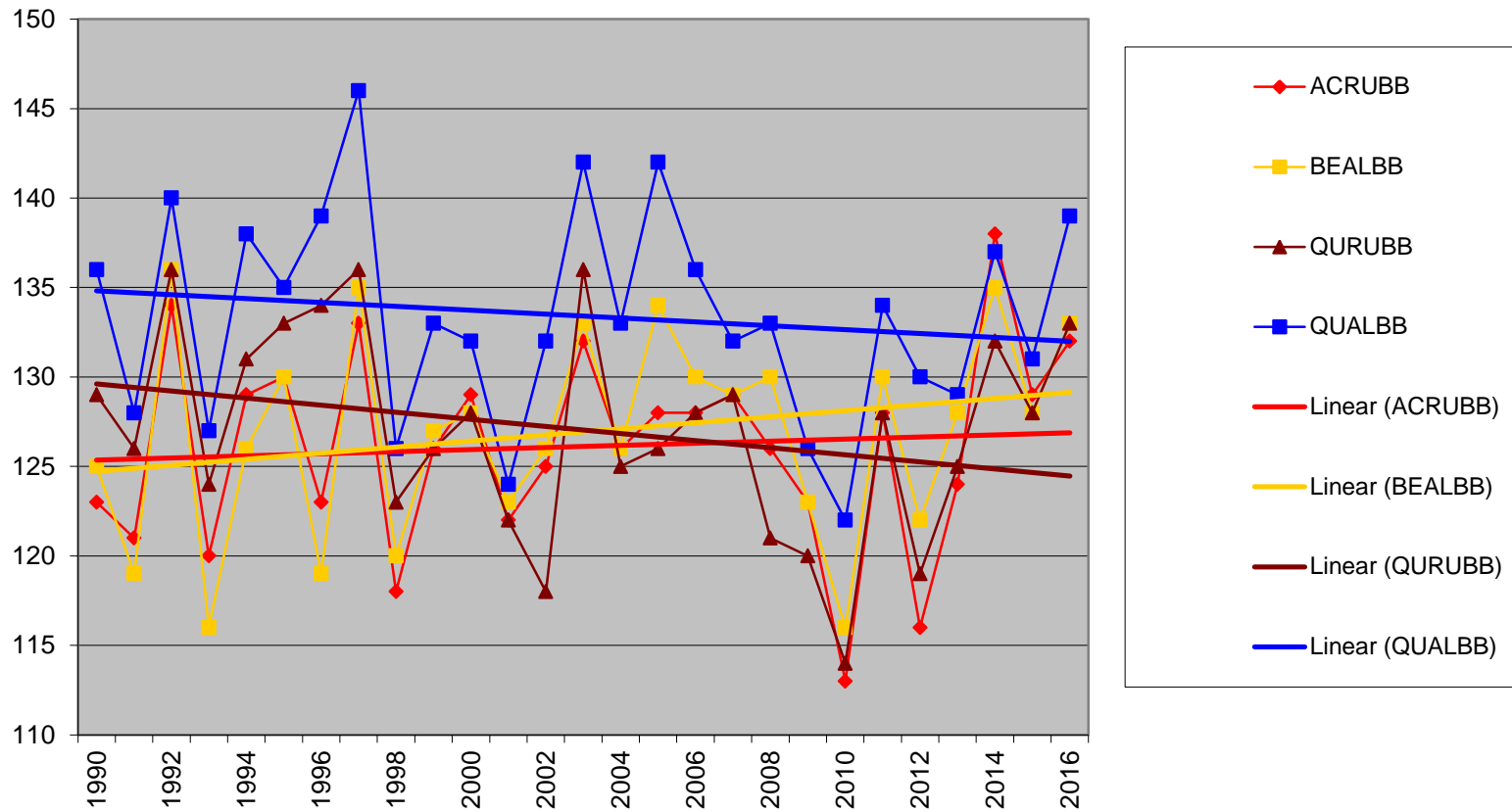
50% budbreak date for 5 red maples 1990-2016



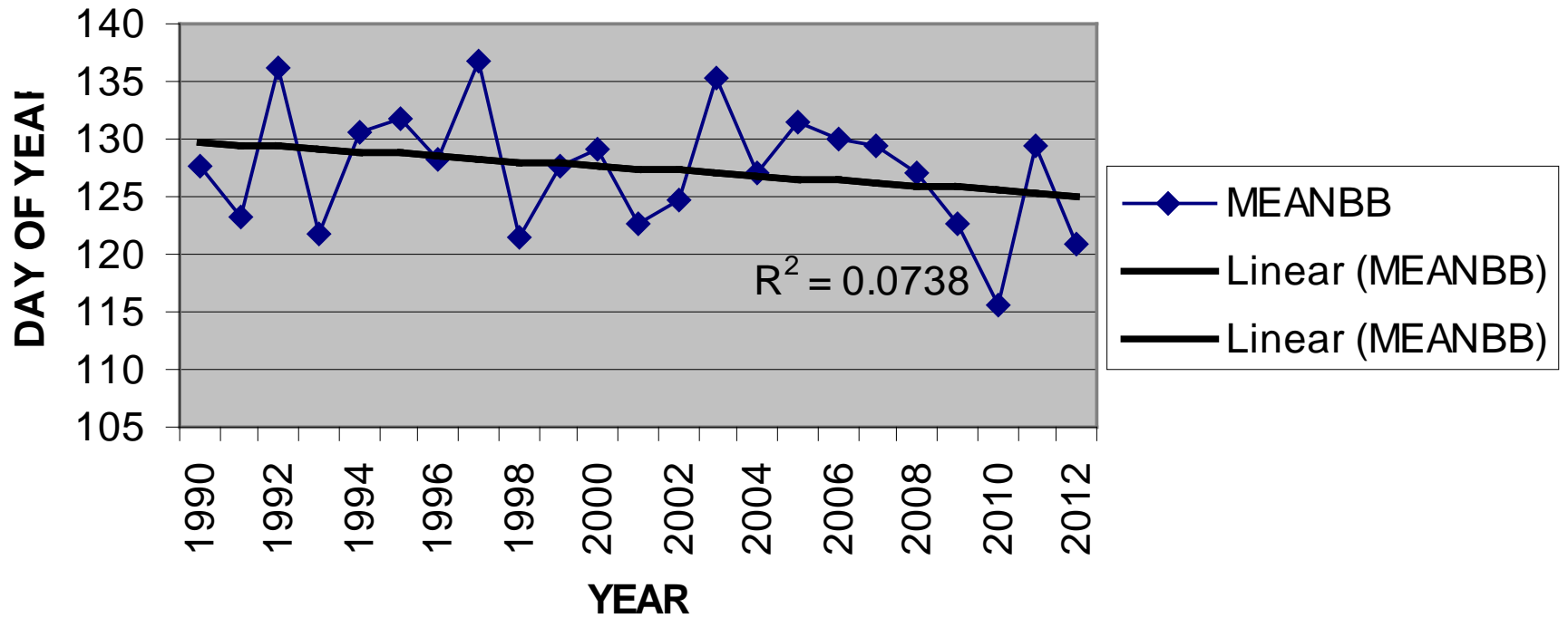
Mean 50% bud break(BB), 75% leaf development(75) and 50% leaf fall(L50) for 4 species (*Acer rubrum*-ACRU n=5, *Betula alleghaniensis*-BEAL n=3, *Quercus rubra*-QURU n=4 and *Q. alba*-QUAL n=3)



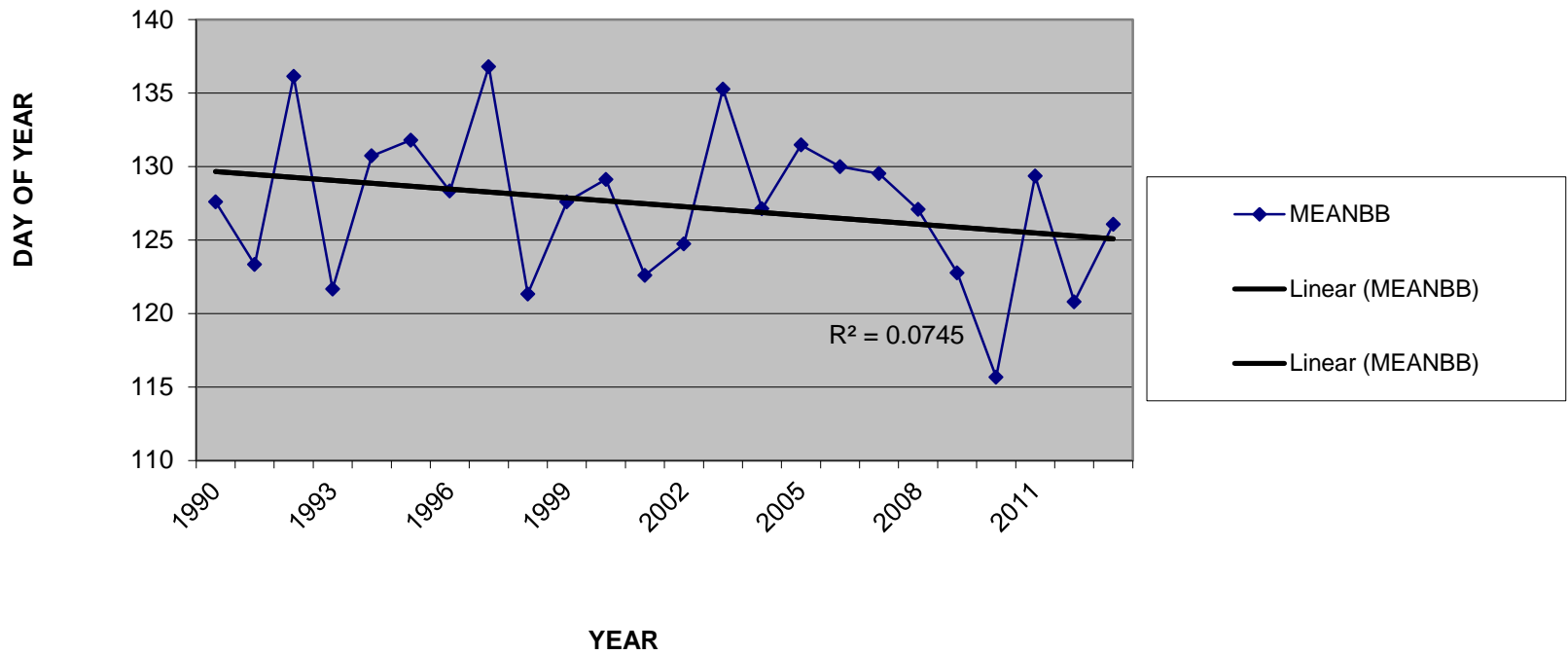
Mean 50% budbreak dates for four species 1990-2016



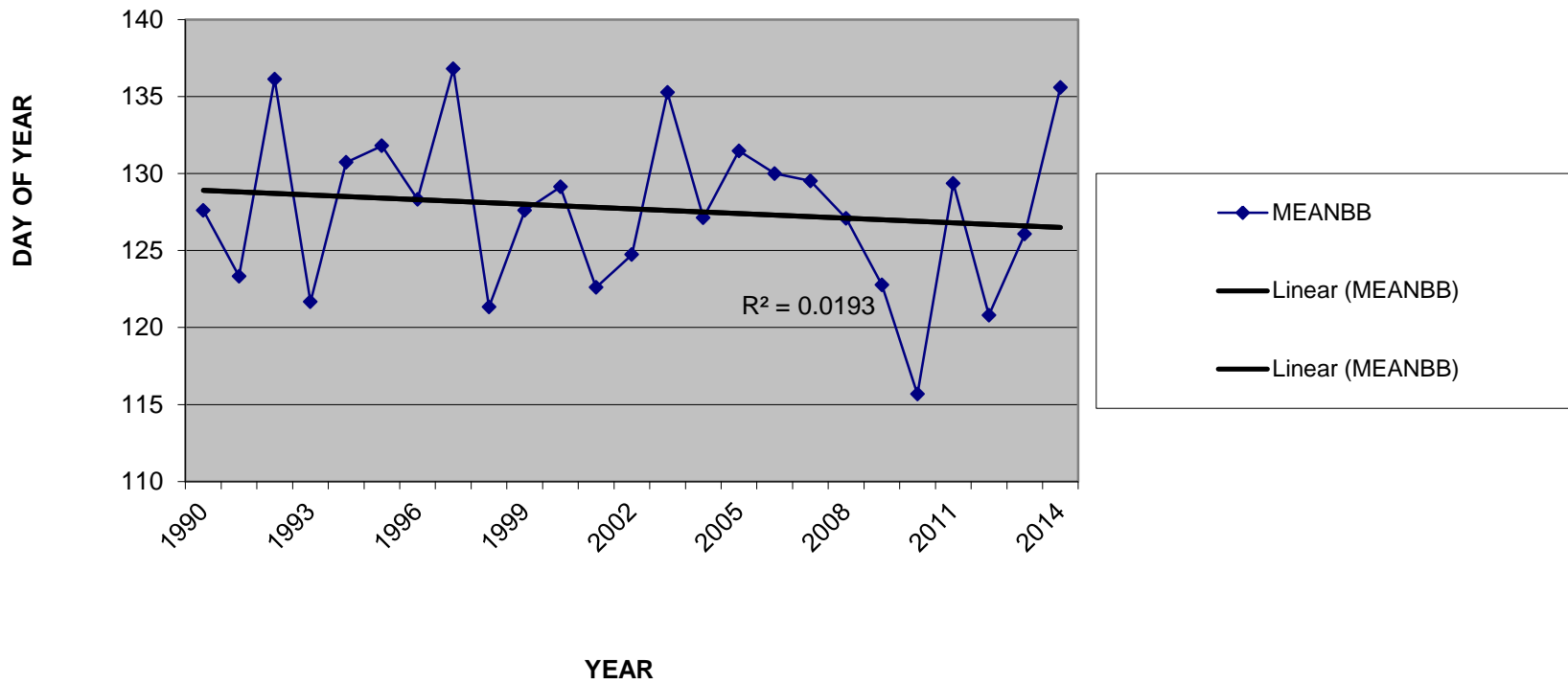
MEAN BB50 (4 SPP, N=15)



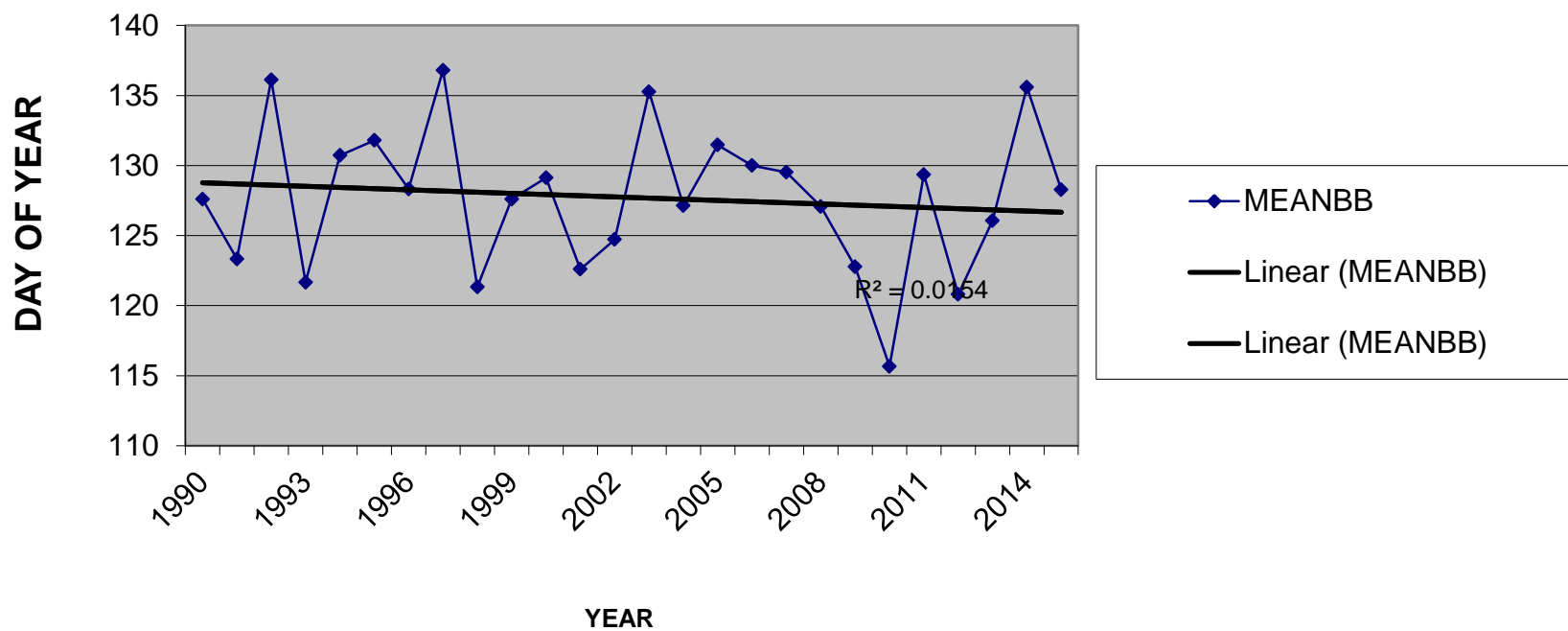
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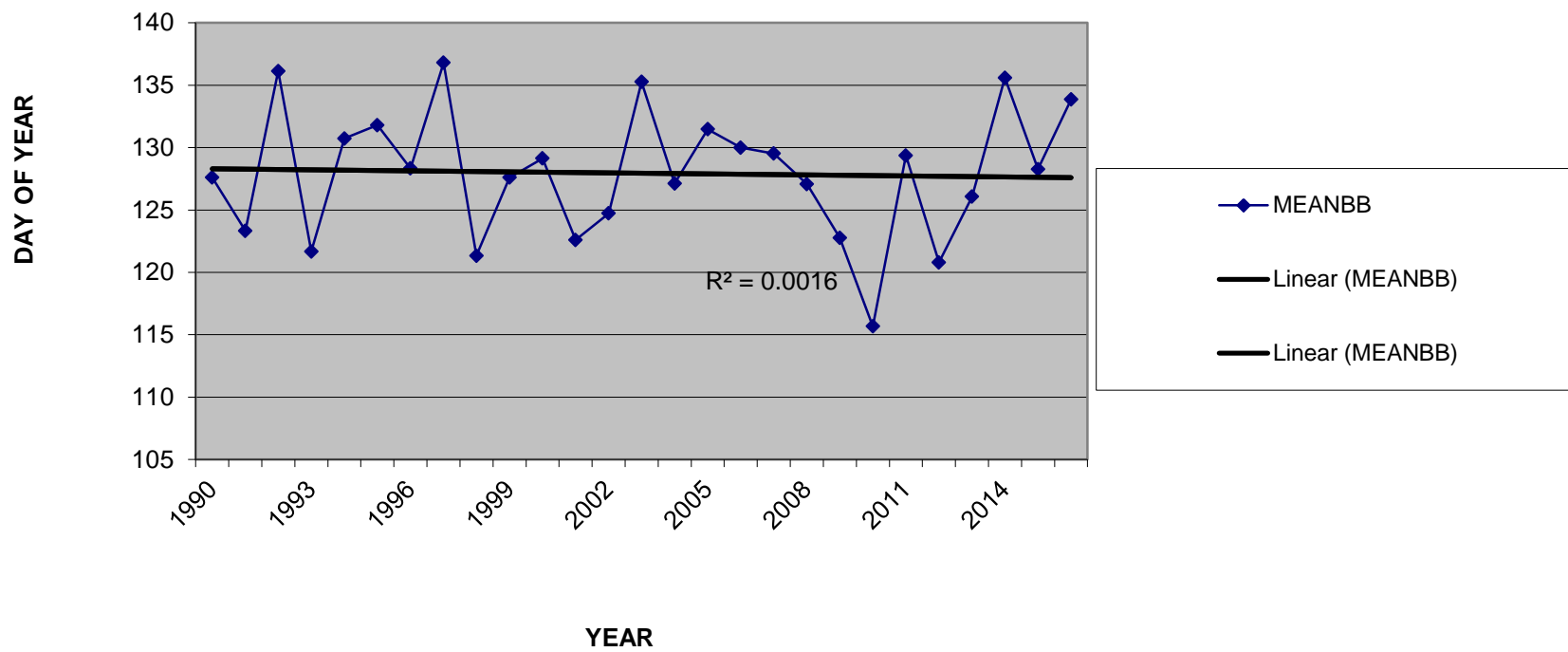
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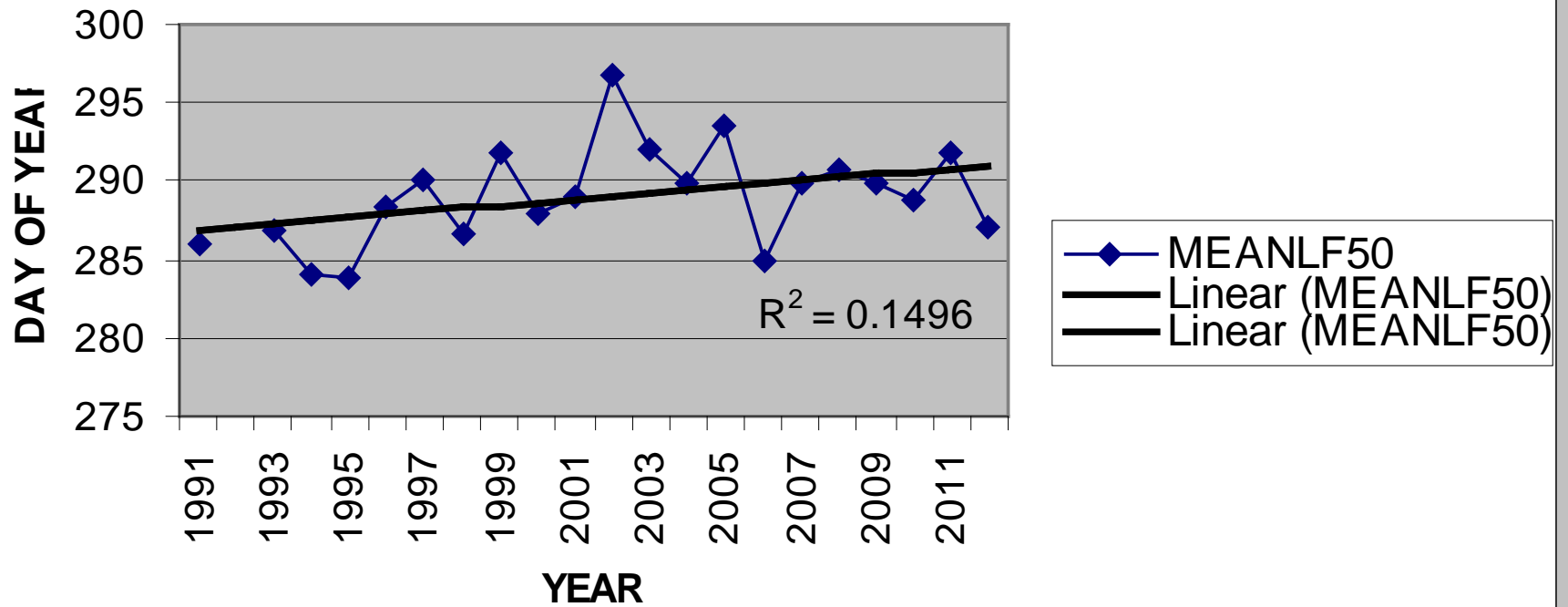
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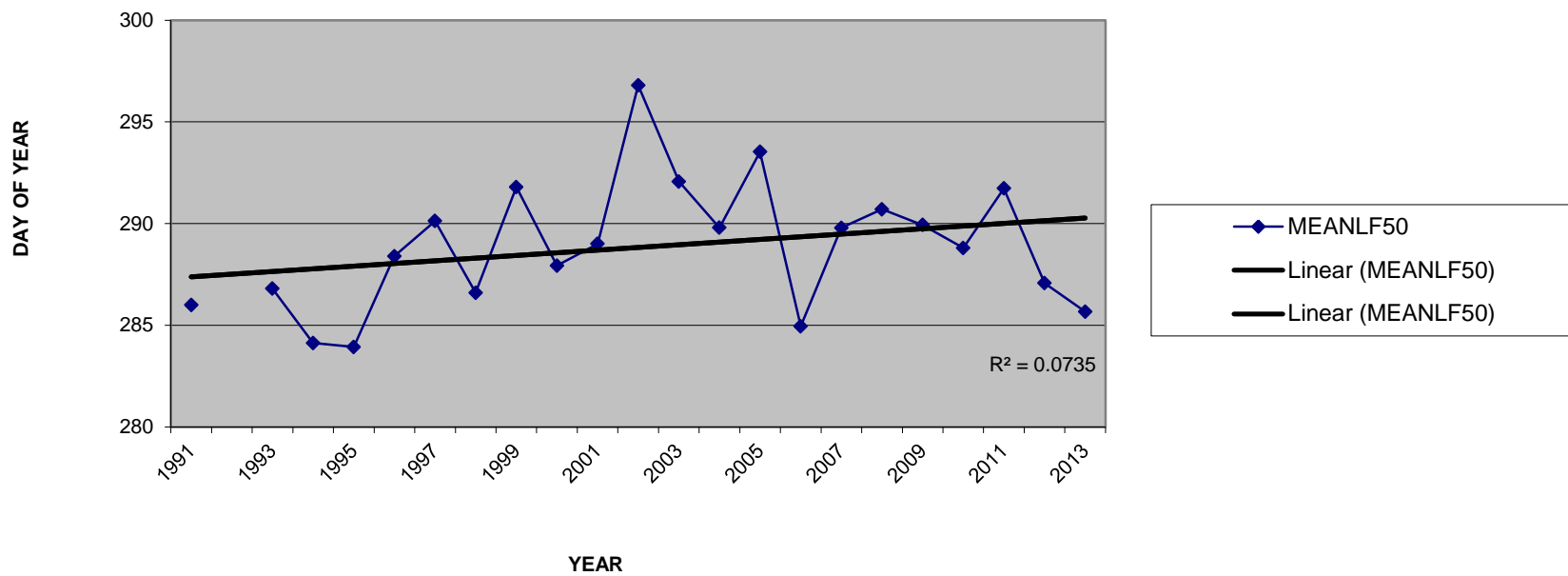
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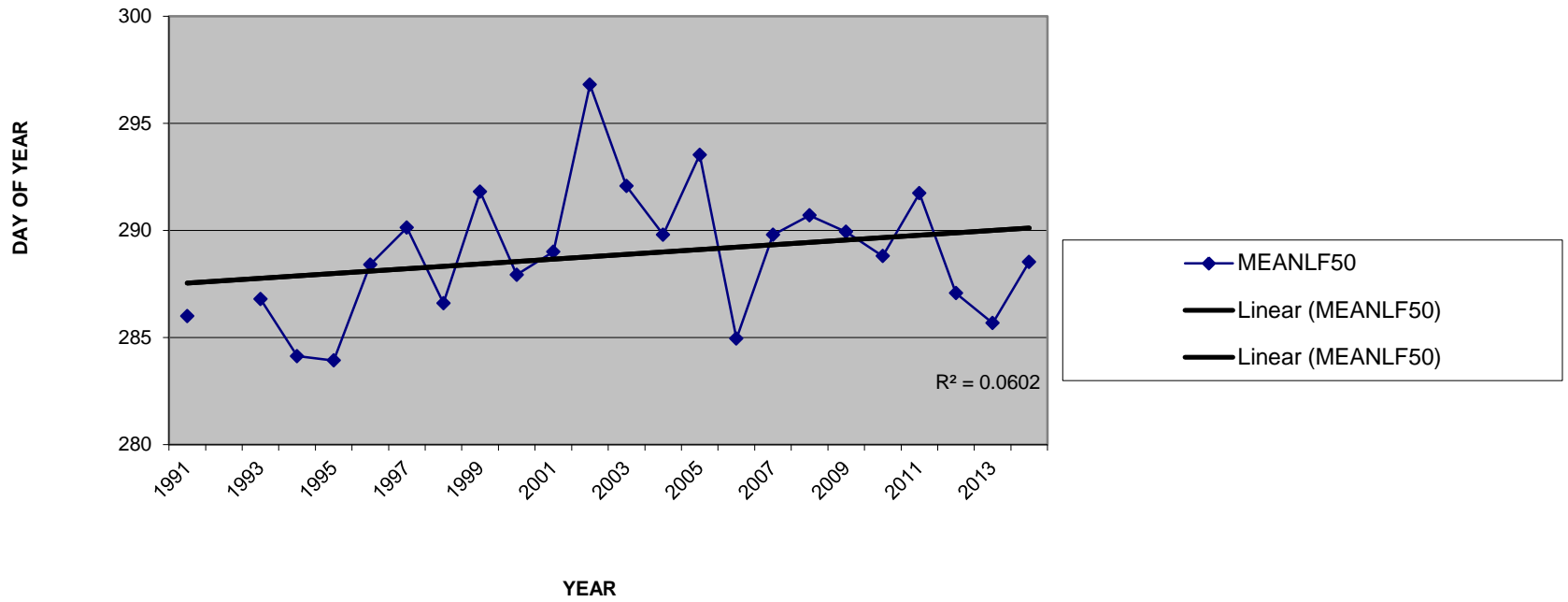
MEAN LF50 (4 SPP, N=15)



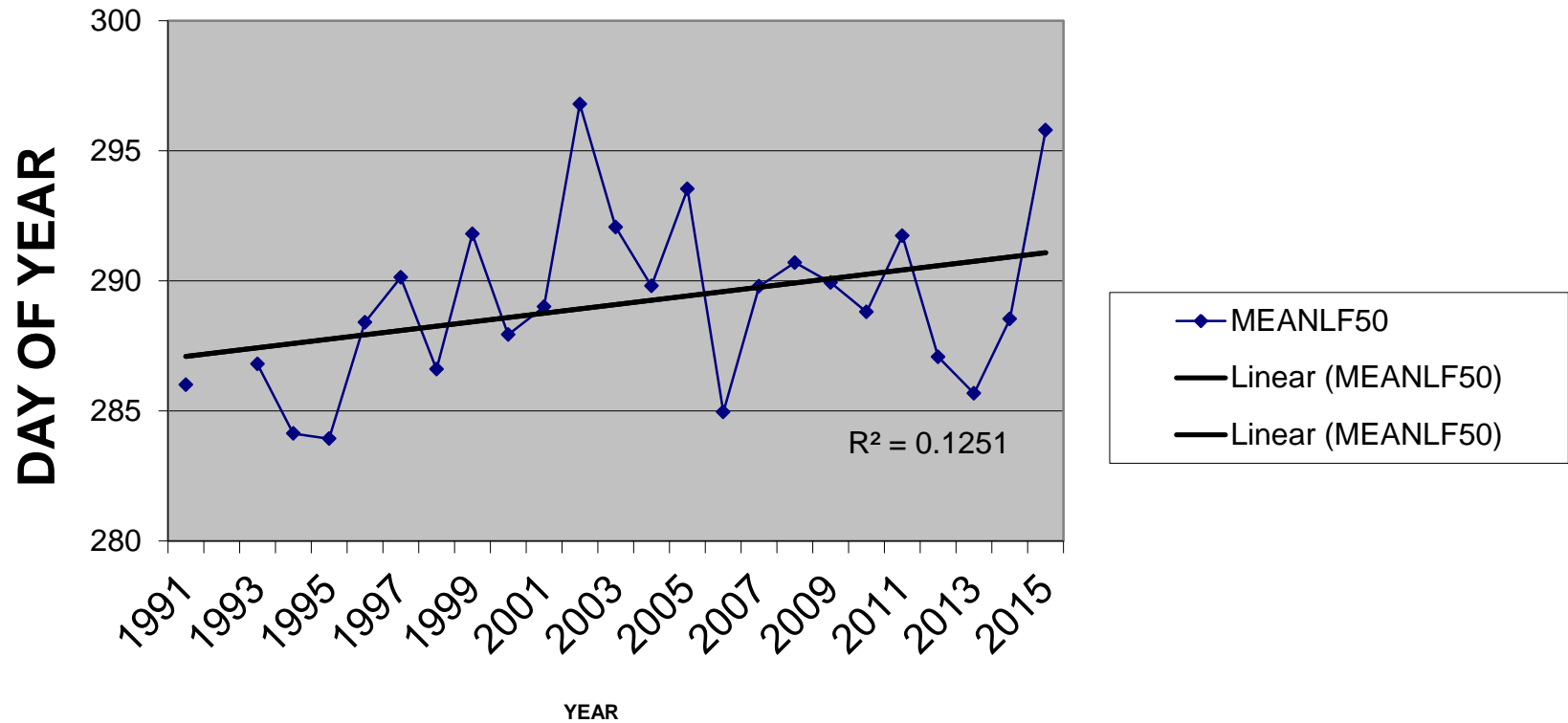
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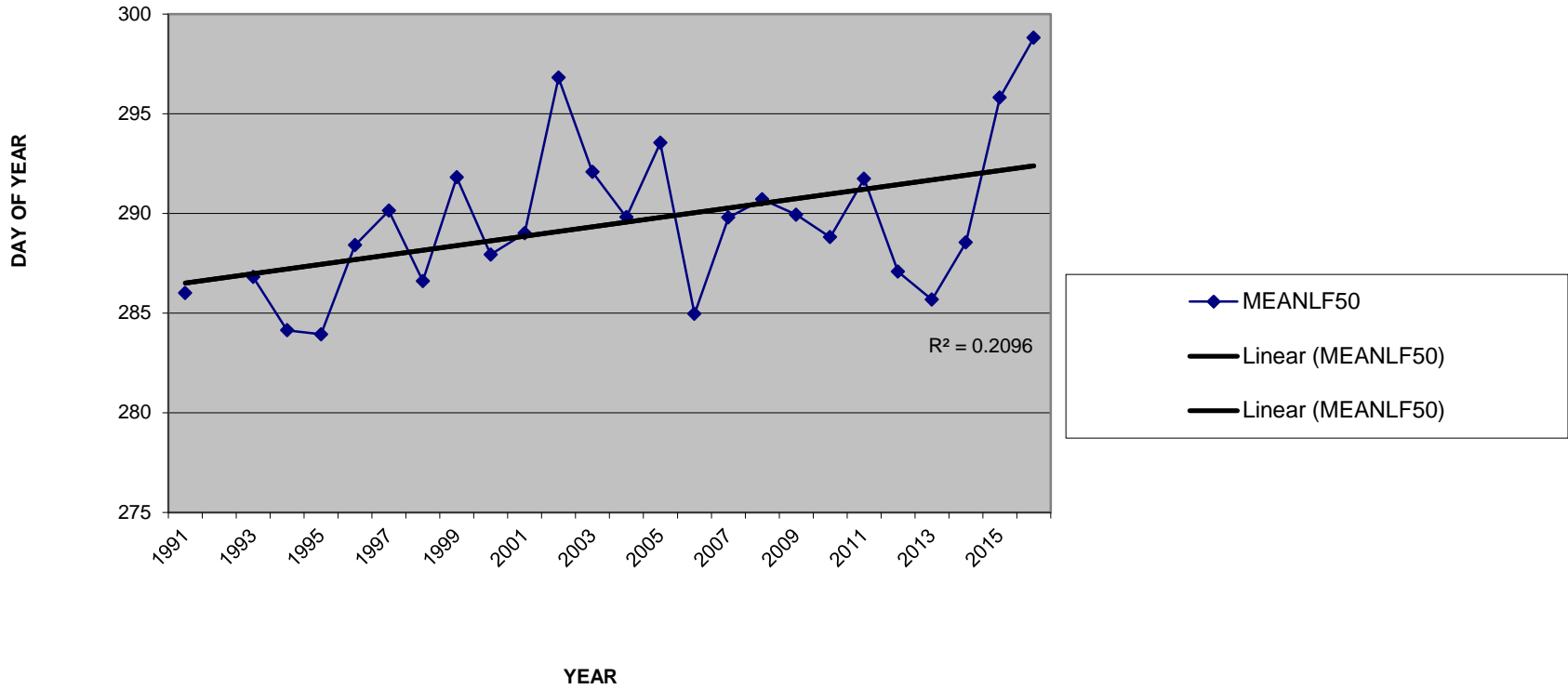
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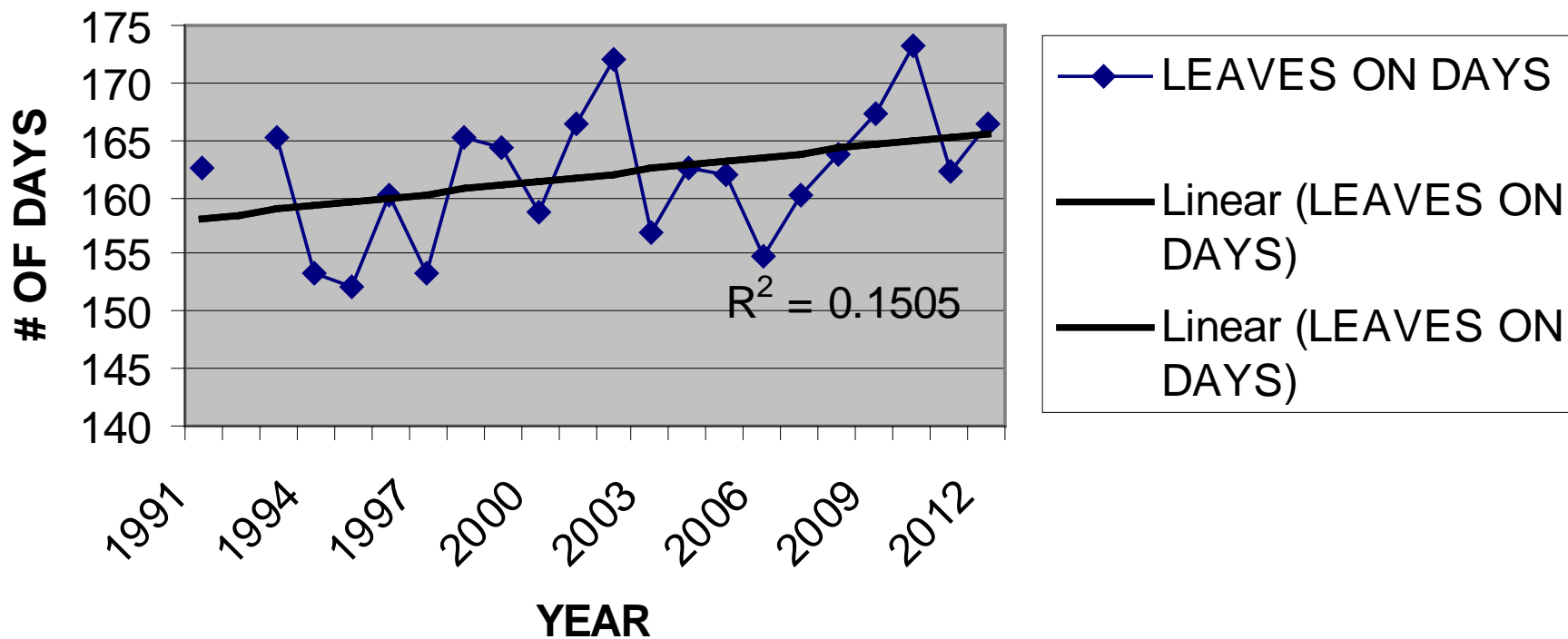
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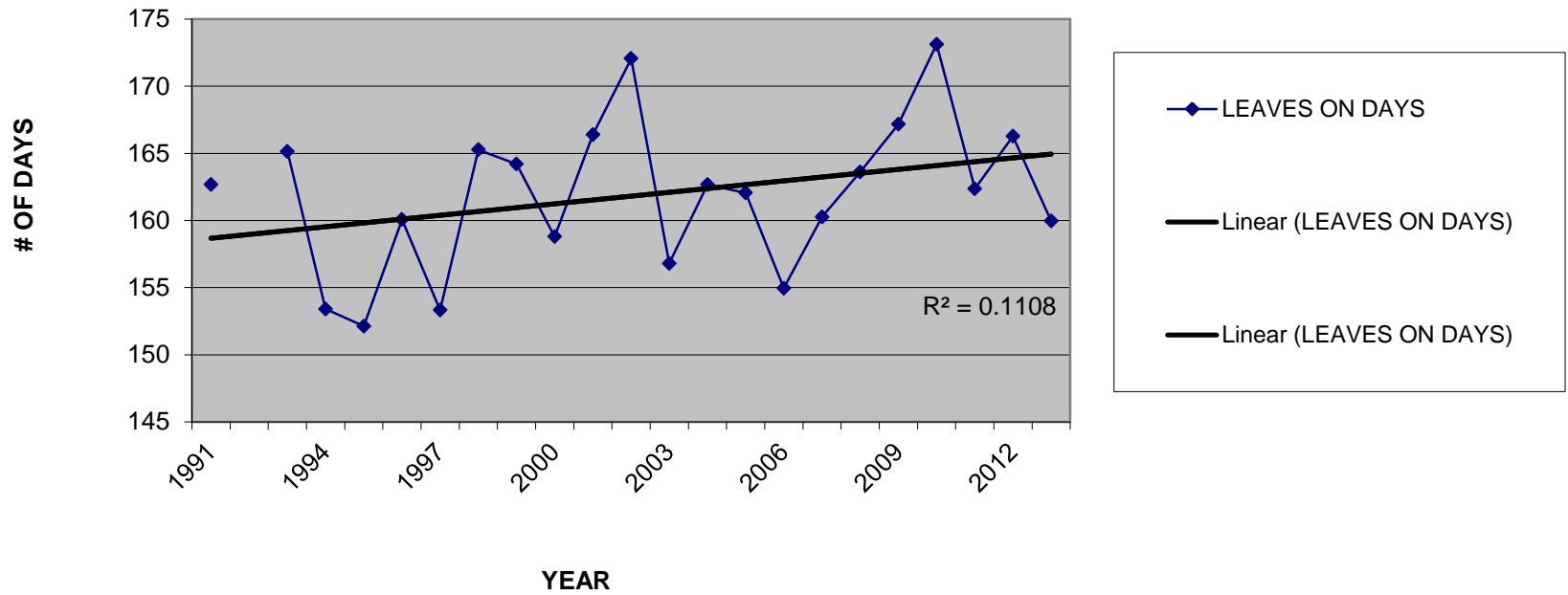
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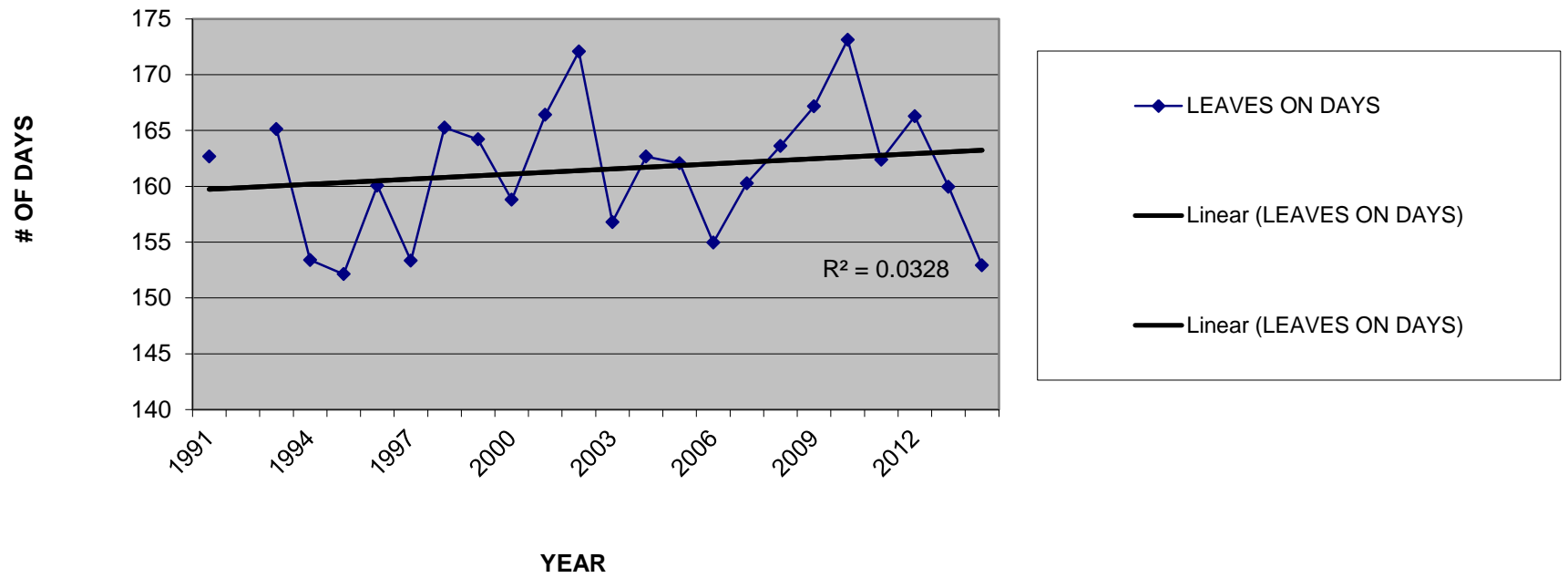
LEAVES ON DAYS (4 SPP, N=15)



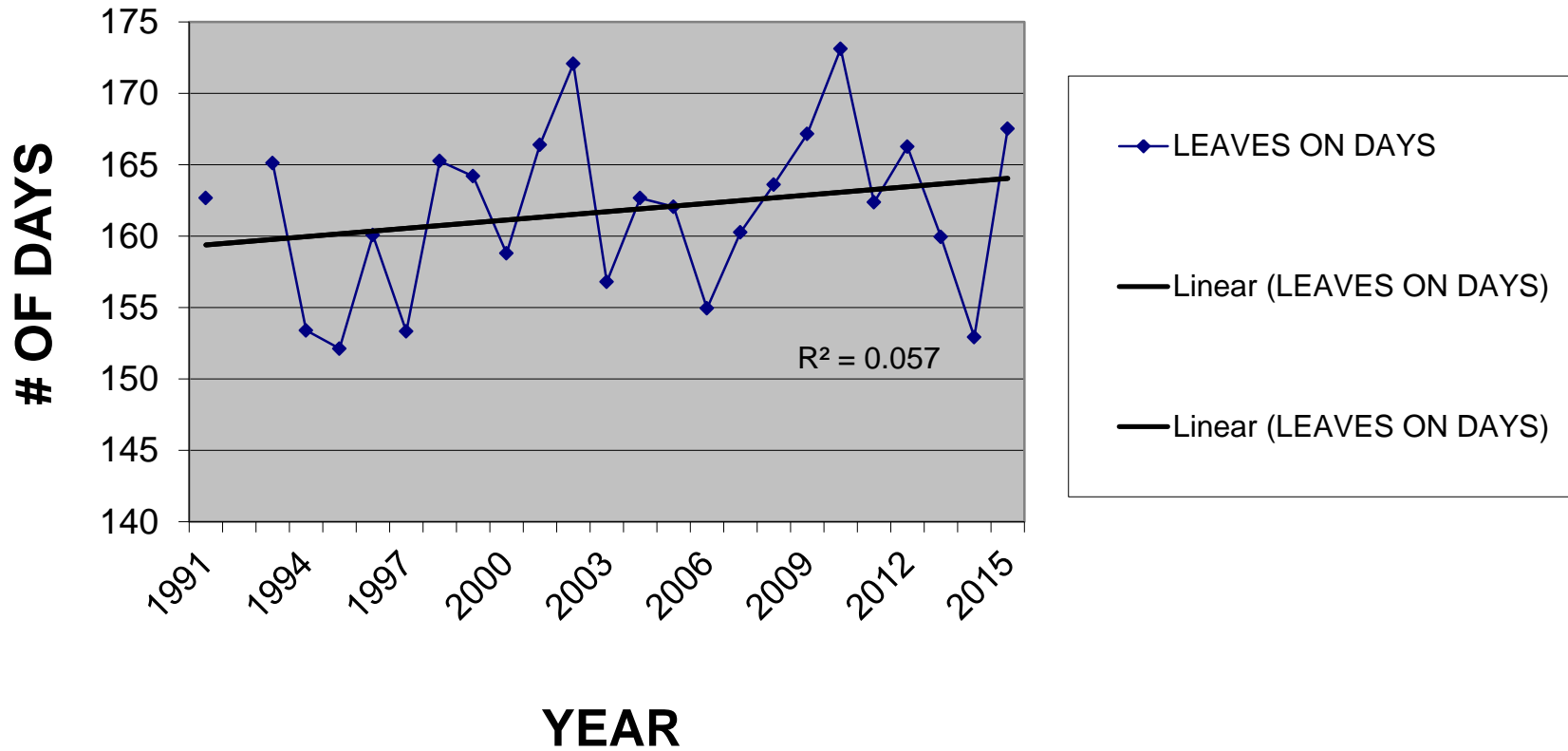
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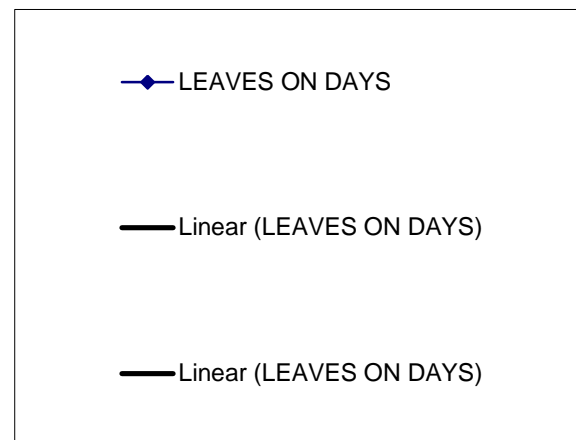
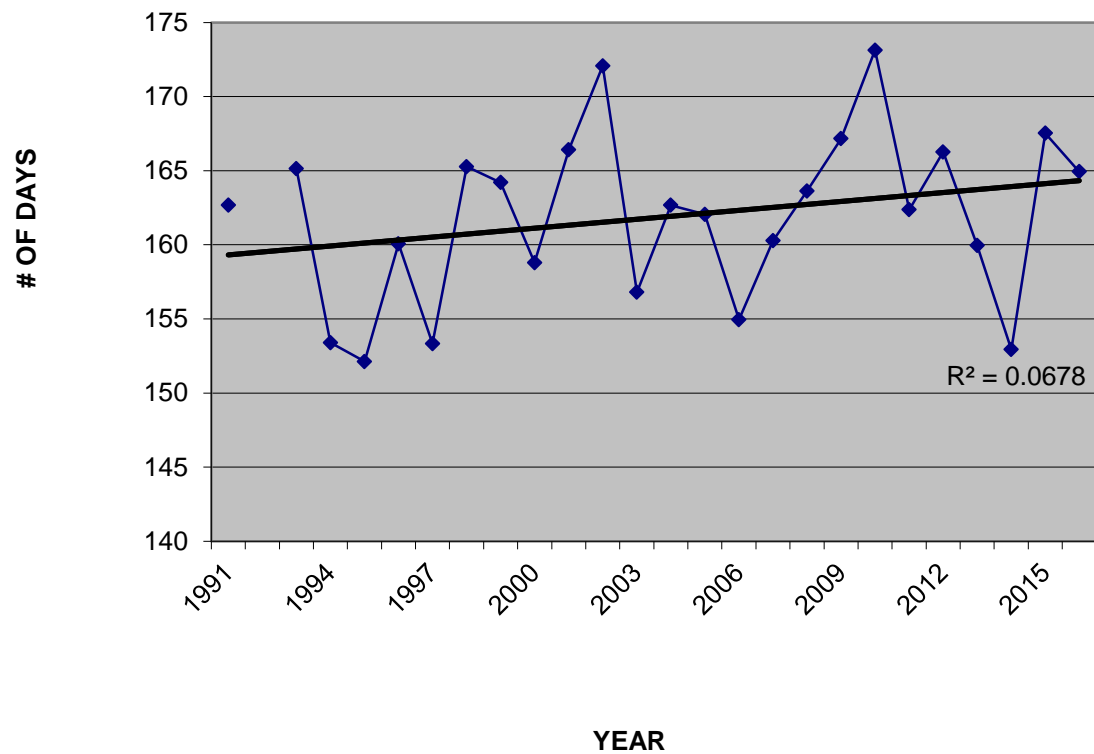
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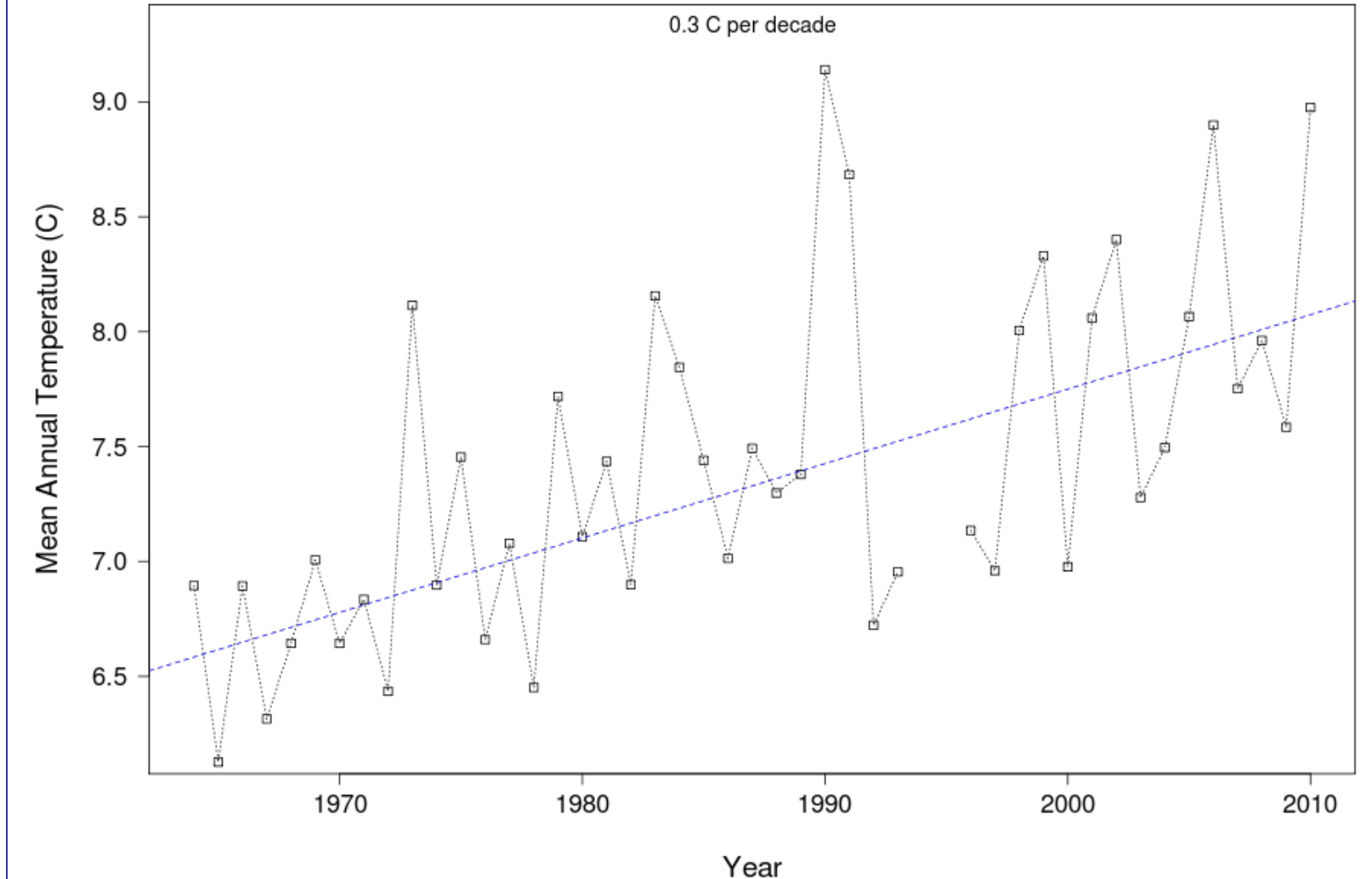
LEAVES ON DAYS (4 SPP, N=15)



LEAVES ON DAYS (4 SPP, N=15)



Mean Annual Temperature at Harvard Forest Meteorological Station



Mean annual temperature has increased **0.3C** per decade, though with large interannual variability, and seasons independently of annual mean

Choosing a Site and Trees

- **Sites** with a variety of native trees with branches in easy reach of students, located in an easily monitored area, are best.
- **Trees in reach**-each study tree should have two or more branches on which students can reach and monitor 6 leaves.
- **Trees that will last**-try to pick trees that will have a low chance of being cut for maintenance or vandalized. This can be a challenge/
- **Tree variety**-a variety of native tree species is best, especially for comparing results across the region.
- **Tree branches**-try to use two or more branches on each tree (for replication), with one branch for each student research team.

Tree ID tips

- The first thing to look at is the arrangement of leaves, buds and branches. Are they opposite each other or staggered alternately along the branch or stem.
- Only a few native trees (maples, ashes, dogwoods – **MAD**) have opposite leaves/branches. The rest are alternate.
- Are the leaves simple (each leaf has a bud at the base of its stem or petiole) or compound (the leaf stem that is attached to the woody twig next to the bud has many leaflets along it)? The ashes, hickories, walnut, butternut and sumacs are the main compound leaf species in this region.
- Then look at leaf shape, edges and vein pattern, bud shape and check for twig smell and bark characteristics.

Site preparation

- You will need one branch with 6 leaves/buds for each student team participating in the study.
- Label (with flagging) each tree in your study, 1 through X (X= total number of trees) and record the species of each tree. Plan to observe at least two branches on each study tree.
- Label (with flagging) each branch being studied on each tree with a letter, A, B, C,...etc. So each study branch will be identified with a tree number and branch letter (i.e. 1A, 1B, 1C, 2A etc.)
- If a branch (or tree) dies, not that unusual, try to pick another branch on that tree and use the next letter, pick a branch on another study tree of the same species and use the next letter, or try to find another tree of that species and add it to your study with new tree and branch labels.

Labeling leaves/buds

- This is probably the hardest part of this study, but it is necessary to ensure consistency in data collection. The teacher should choose and label trees and branches (6 leaves/buds per branch) before bringing students to the site.
- Branches are labeled by tying a piece of flagging (with the tree and branch number/letter) just behind the 6 study leaves/buds on the branch.
- When choosing and labeling leaves/buds do not use the terminal/tip leaf/bud, but start counting at the next leaf from the tip as #1, then the next as #2, etc. On opposite leaved trees #1 and #2 will be paired across from each other. If there is a side branch on your main branch before you reach #6, use the tip bud on the side branch as the next # and continue using buds down the side branch until you reach #6 or, if necessary, return to leaves on the main branch. Note, you do use the tip bud on side branches, just not on the main branch.

Spring Data Collection

- Typically start data collection in late March, but this may vary depending on March weather. I strongly recommend bringing shoots of study species inside in mid-March to force.
- Try to collect data once a week.
- Each student team will observe the 6 live buds closest to the branch tip (skipping the terminal bud if there is one) that have been previously labeled.
- On the first visit it is a good idea to have them sketch the branch and study buds and bring the sketch on later visits to help identify the study buds.
- They will record how many buds have recognizable leaves, not just leaf tips, emerged from them.
- Once leaves have emerged, record the length (not including stem) of the largest leaf.
- The teacher will combine all data for each tree and submit to Harvard Forest.

Field Notes/Observations

- These notes are optional and not submitted, but represent the type of observations scientists make when they are collecting their data.
- Typical observations might include temperature, cloud cover, precipitation, wildlife observations, any unusual conditions or recent events/changes such as a strong windstorm or frost/freeze.



Harvard Forest Schoolyard Ecology Buds, Leaves, and Global Warming

Spring Protocol: Budburst

Objective: Students will record the progression of bud swelling and budburst to monitor the start of the local growing season. The end of the growing season is monitored in the fall for this project. This means if you do this annually, one class will pass on data to be used by next year's class.

What is Budburst exactly? We are defining budburst as the point where the bud scales have opened AND leaves are fully visible. Leaves may be tiny but the entire leaf can be seen. Budburst indicates when the growing season begins and leaves begin making food for the tree.

Data Collection:

- 1. Begin and end dates:** Spring data collection should begin in early to mid April (before the buds have become very swollen), and continue until all or most buds have burst, and leaves are fully emerged. Ideally, continue until June 1st or as close to the end of the school-year as is feasible for your schedule. Dr. O'Keefe completes his study when all trees in his field site have 75% leaf development (leaves are 75% of their expected final size estimated from measurements taken the previous fall). This is generally in mid to late June.
- 2. How often to collect data:** Collect data at least once a week during study time. We recommend going out twice a week if possible when the buds are very swollen and budburst appears imminent, as that would pin point budburst more accurately.
- 3. Observe the specific branch(s) and buds assigned and labeled.** These will be the six buds nearest the branch tip, not counting the terminal (tip) bud. See Section VIII (Site Preparation) in the Study Overview.
- 4. Budburst:** Observe and record whether each bud is completely closed (not puffy), or almost ready (puffy or opening with a green leaf tip visible but not unfolded yet), or open (budburst - the emerging leaf is unfolded/whole leaf is visible) by putting a check in the proper category on the data sheet.

"Student Data Sheet-Spring"

Observe and record whether each bud is completely closed (not puffy), or almost ready (puffy or opening with a green leaf tip visible but not unfolded yet), or open (budburst - the emerging leaf is unfolded/whole leaf is visible) by putting a check in the proper category on the data sheet.

1. Number of buds open: Record on the data sheet how many of the labeled and observed buds (0-6) are closed, puffy, and open. Please refer to photos of buds enclosed in teacher notebook and posted online at:

<http://harvardforest.fas.harvard.edu/museum/data/sy001/budburst-chart.pdf>

to clarify the differences between "puffy", "open" and "closed".

2. "Bud fallen off"-Please note if the bud is no longer on the branch. Place a check mark in appropriate box. If no buds remain on a branch, replace the branch with another branch with live buds. Data from earlier branch should be reported to HF as "NA" (missing).

3. Leaf measurement: If the leaves are fully open, select the largest leaf and record its length. Measure the blade of the leaf only, not including the stem (also called the petiole). Note: If there is more than one leaf growing from each bud, measure the largest leaf only. If the leaf is compound (multiple leaflets are attached to a main leaf stem/petiole), measure from the tip of the entire leaf down to the base of the lowest leaflets where they meet the leaf stem for the leaf length. For width, measure the widest part of the whole leaf-as in the widest pair of leaflets.

4. Field Notes/Observations: This part of data collection is **optional**. Scientists usually take field notes when collecting data. If you choose to include it, record any notes about field conditions – climate (temperature, cloud cover, precipitation), wildlife, what is happening with other plants, moisture, snow, or human activity - that you notice while collecting data. As time allows you may discuss these optional data with students.

5. Teacher Note: In order to prepare data for submission to Harvard Forest, you must combine data from all branches on the same tree to create tree-level data to enter into Excel and email to Harvard Forest.

Red Oak

Moderately
Puffy Buds



Moderately Puffy



White Ash



Slightly puffy buds



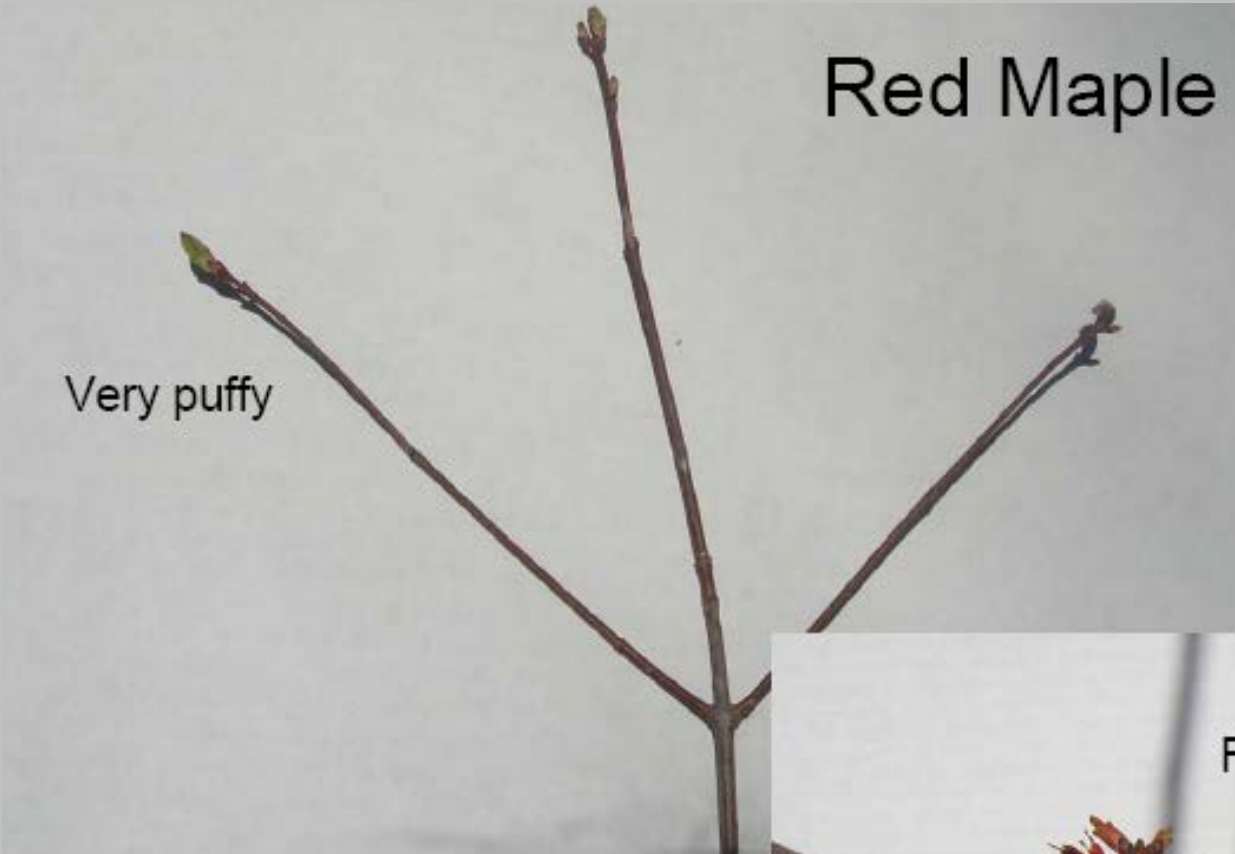
Very puffy



Yellow Birch-Mixed-some open and some puffy

Red Maple

Very puffy

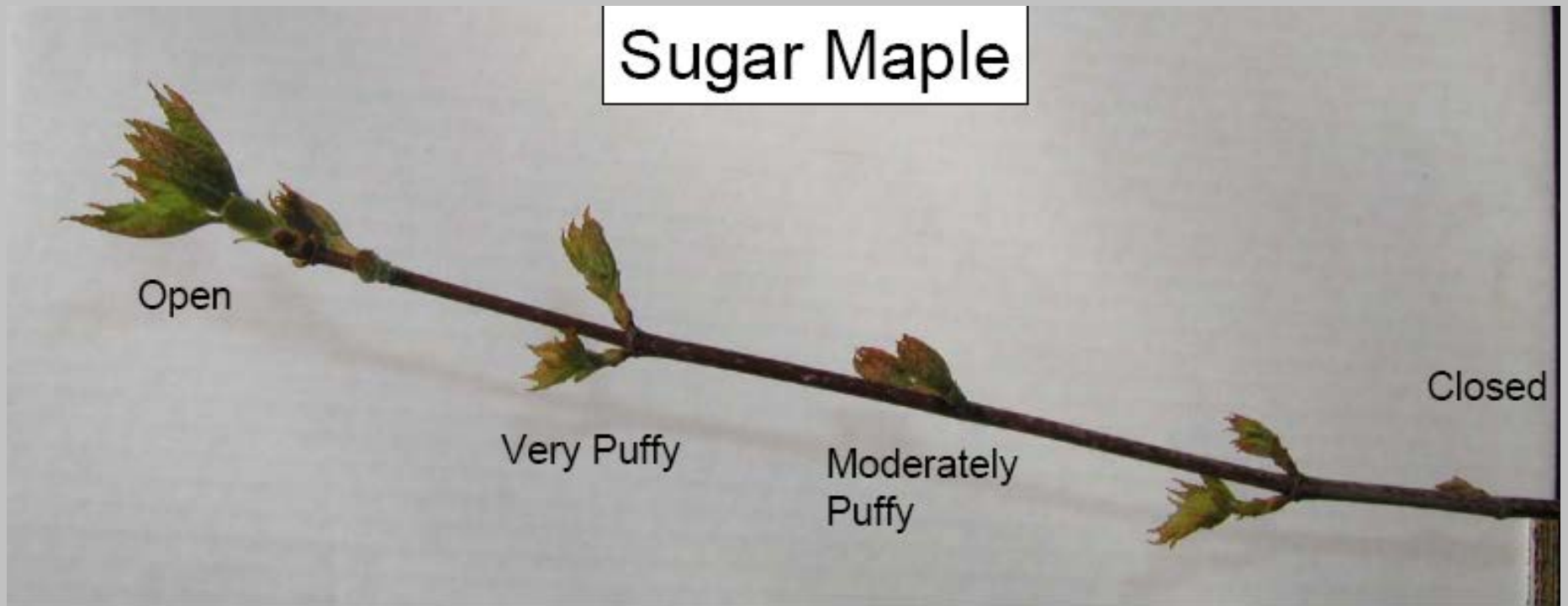


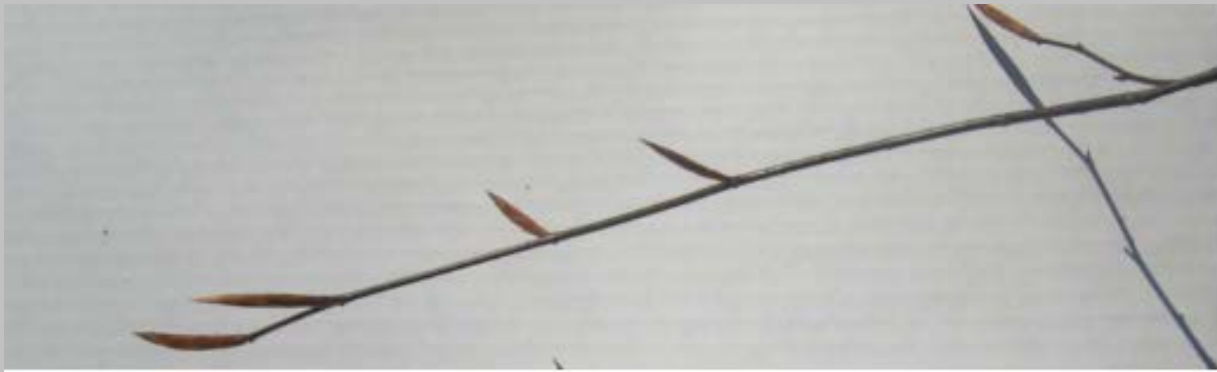
Flowers

Very puffy



Sugar Maple





American Beech-Slightly-moderately puffy buds



Beech-Some buds are open,
Others very puffy



Harvard Forest LTER Schoolyard Program
Buds, Leaves and Global Warming

Student Data Sheet – Spring

Revised March 2010 by JOK and PS

Names: _____

School: _____ **Date:** _____

Tree Species: _____

Tree ID (number): _____ **Branch ID (letter):** _____

1. Put a check mark in the correct column below to show the stage of each bud.

	Bud 1	Bud 2	Bud 3	Bud 4	Bud 5	Bud 6
Closed: Bud is closed and not puffy						
Puffy: Bud is swollen or opening with no unfolded leaf						
Open: Bud has opened and whole leaf is visible (budburst)						
Bud Fallen Off						

2. How many buds were observed in all? _____
Of these, how many were Closed? _____ **Puffy?** _____ **Open?** _____

3. Look for the open bud with the largest leaf.
Measure the leaf length in centimeters: _____

4. Field notes:
Temperature (degrees Celsius): _____
Humidity(%): _____
Circle one: Sunny Cloudy Rainy
Other observations and Notes: _____

Teacher Note: Please combine data from all branches on the same tree to create tree-level data for submission to Harvard Forest.

Buds, Leaves and Global Warming

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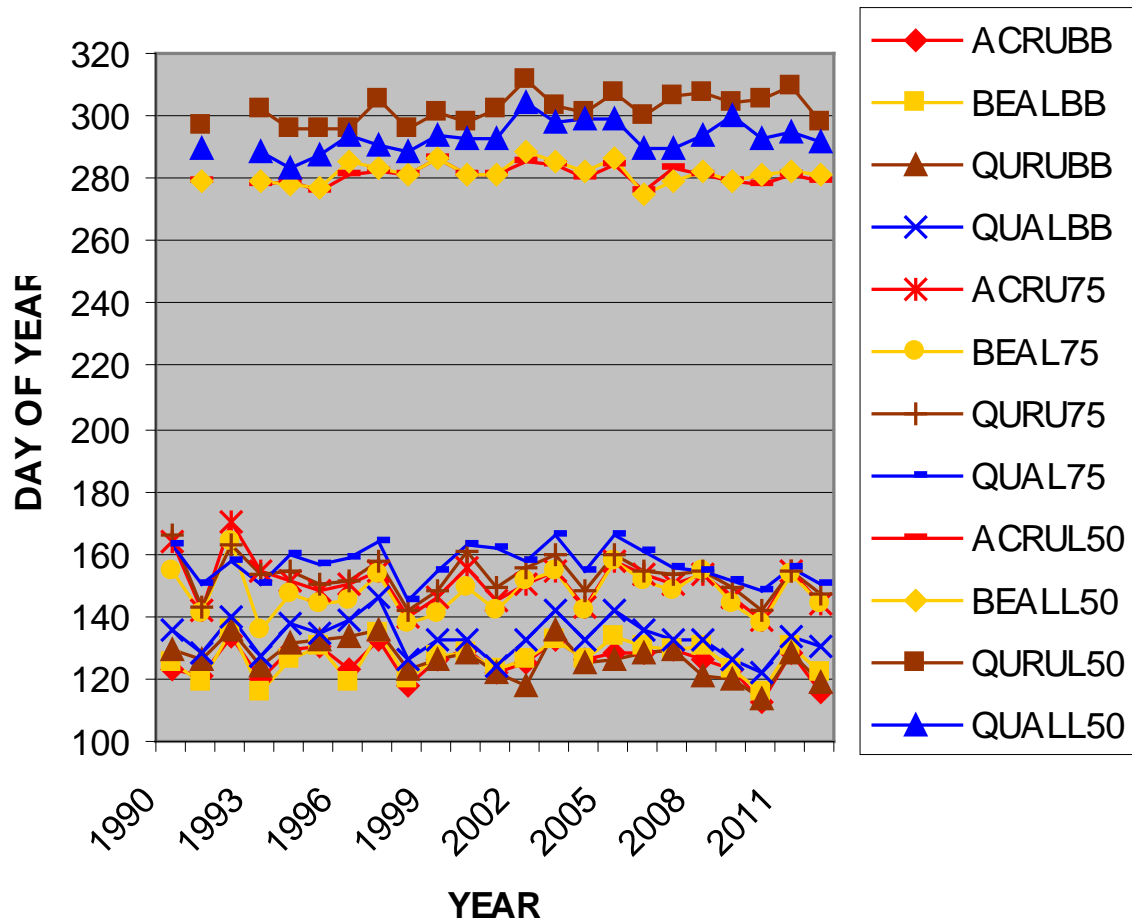
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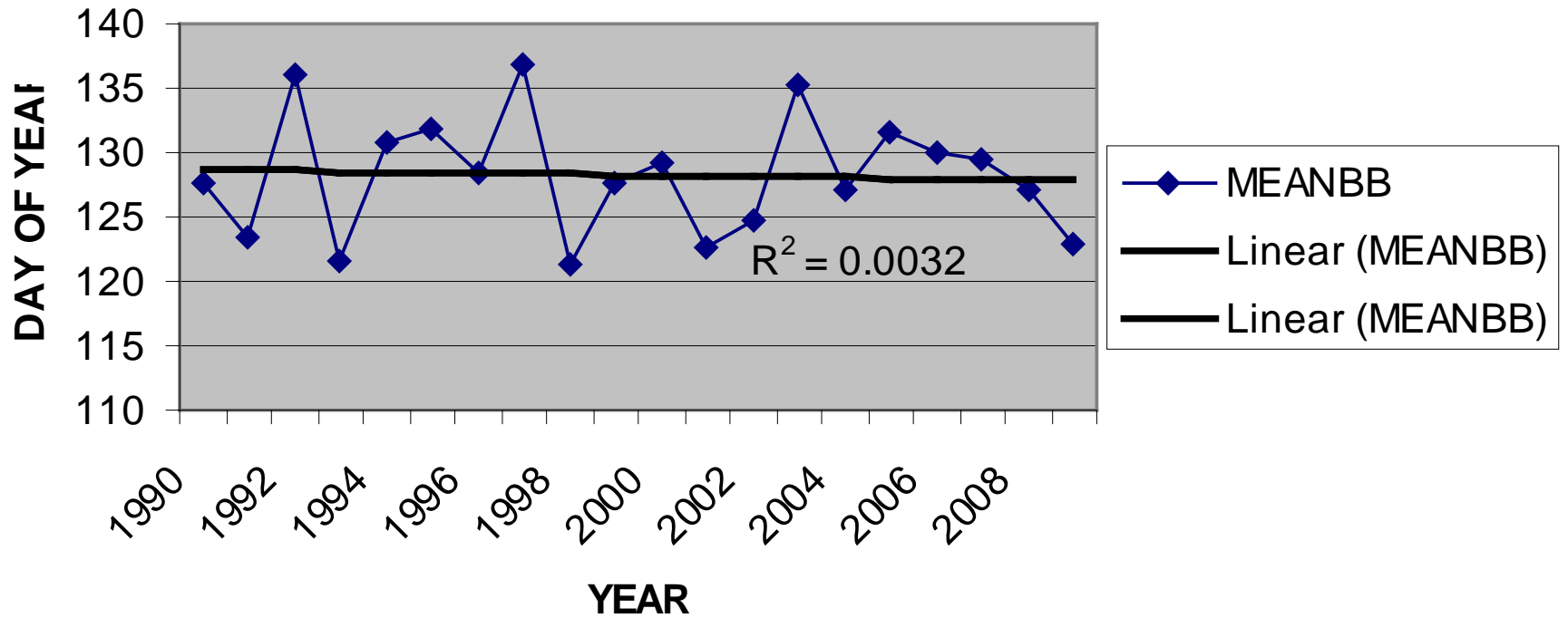
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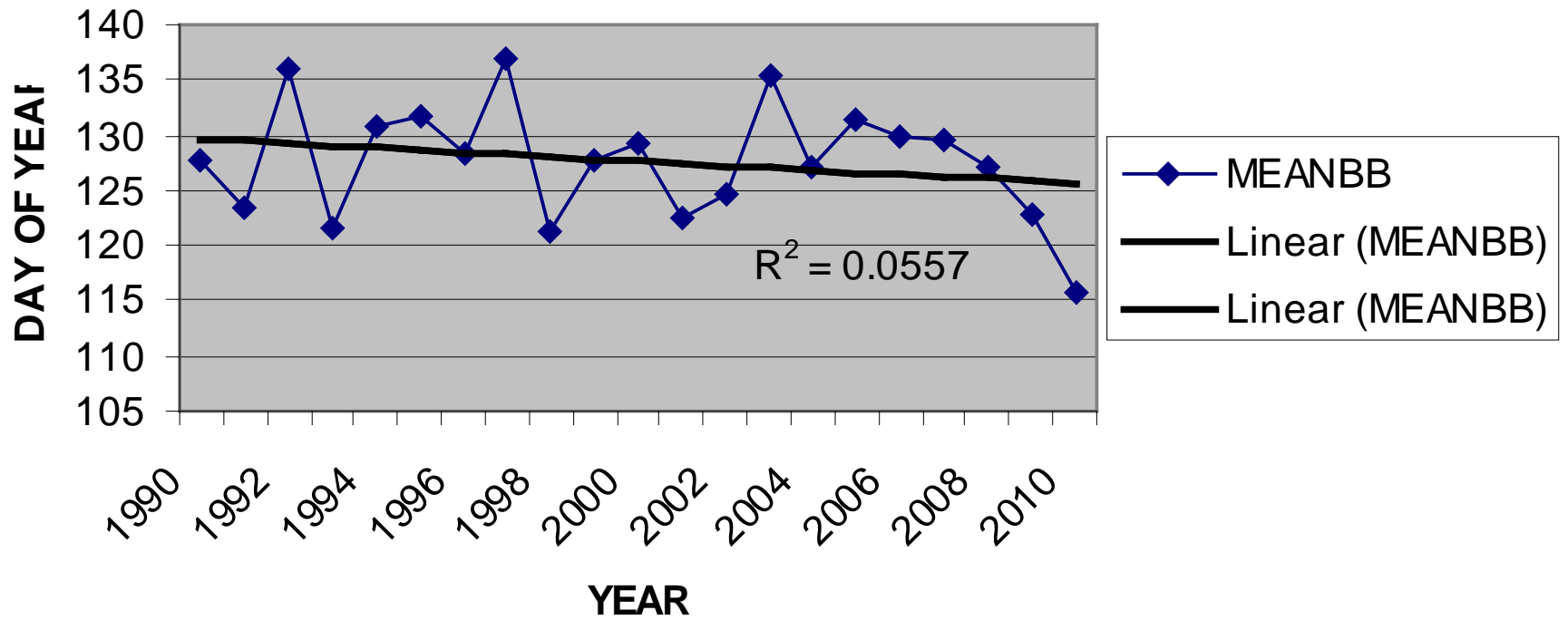
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**Contact Pamela Snow, Schoolyard Coordinator,
at psnow@fas.harvard.edu or (978) 724-3302 x246
to begin your schoolyard research project.**

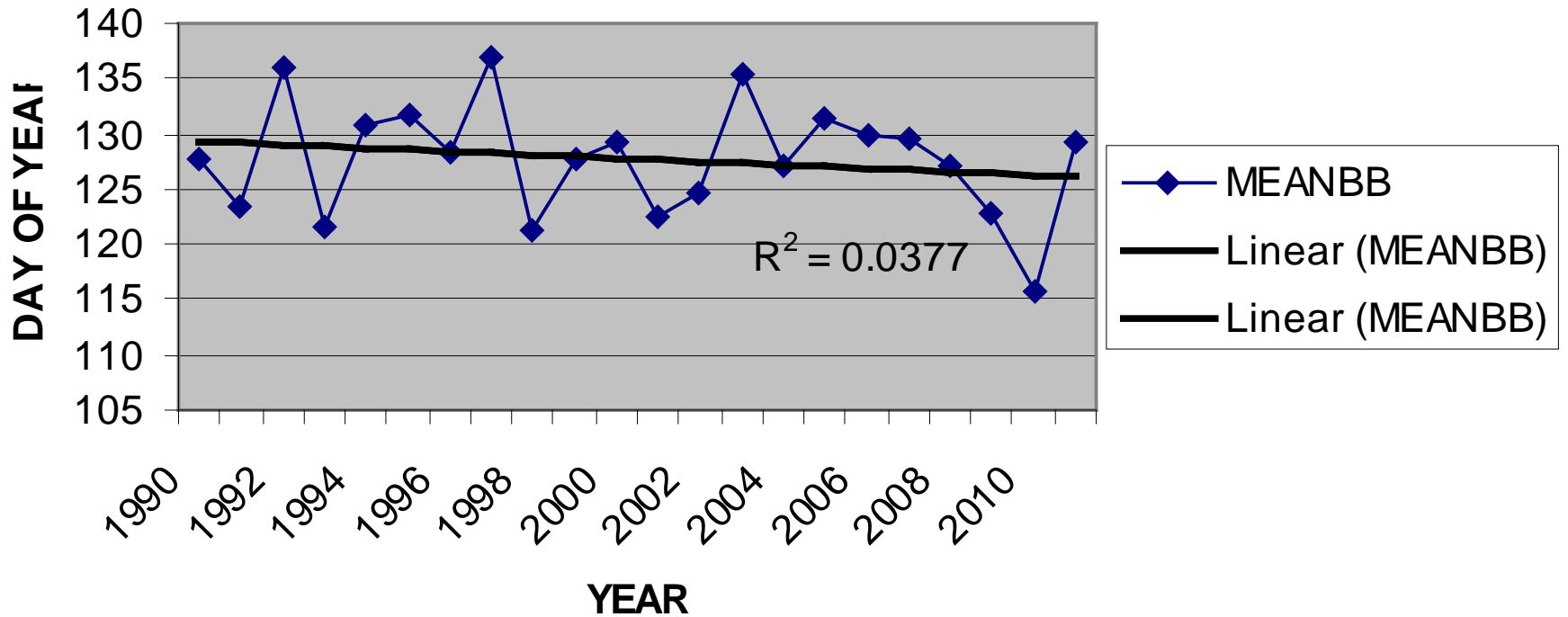
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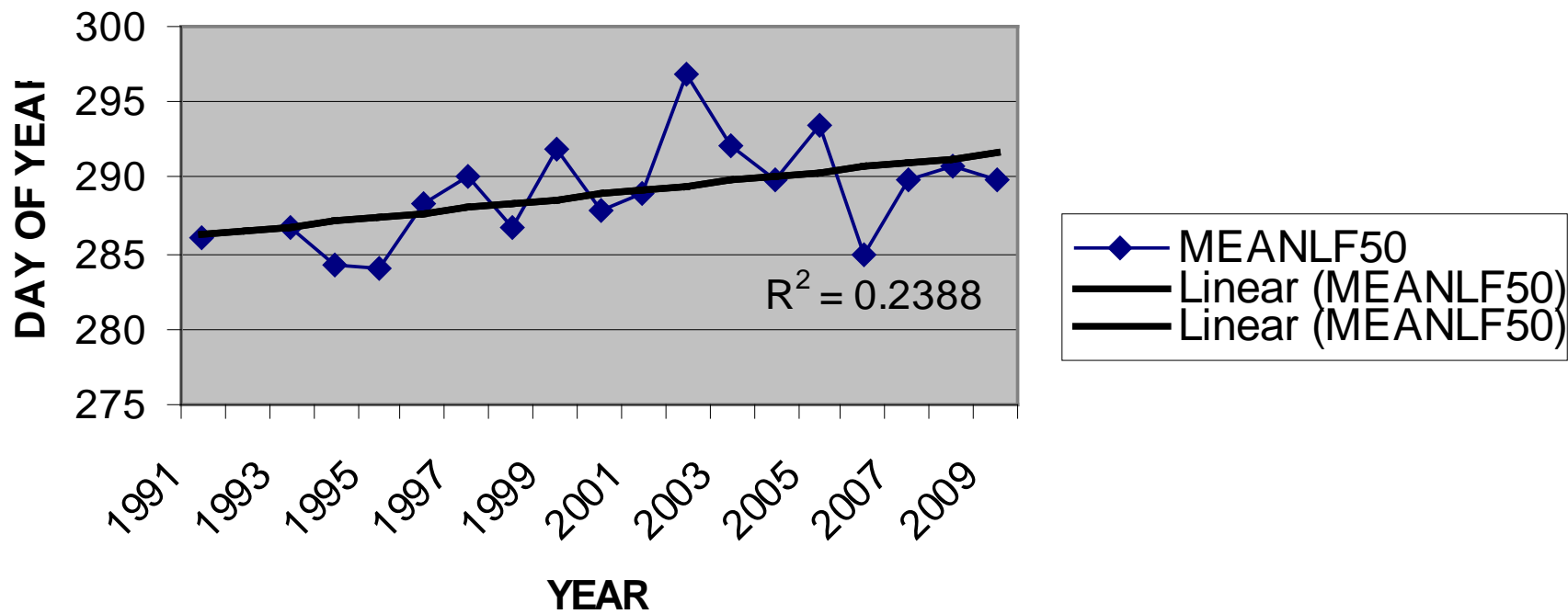
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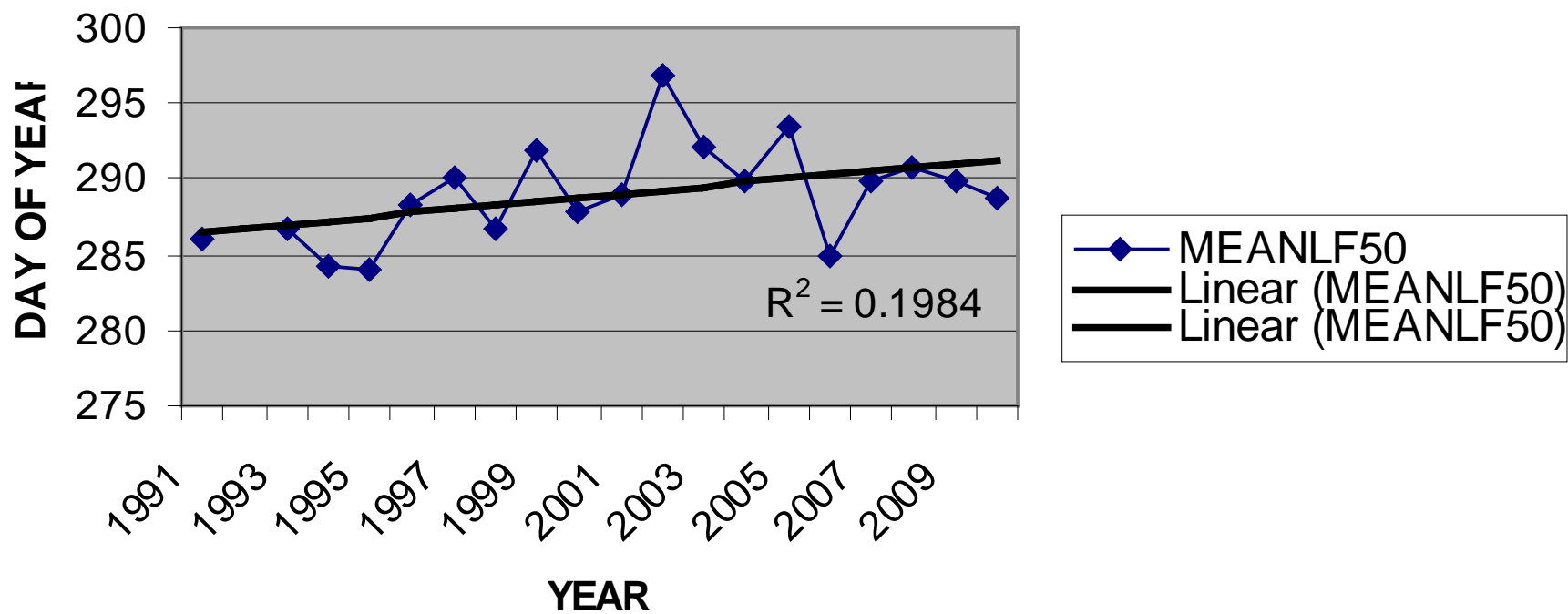
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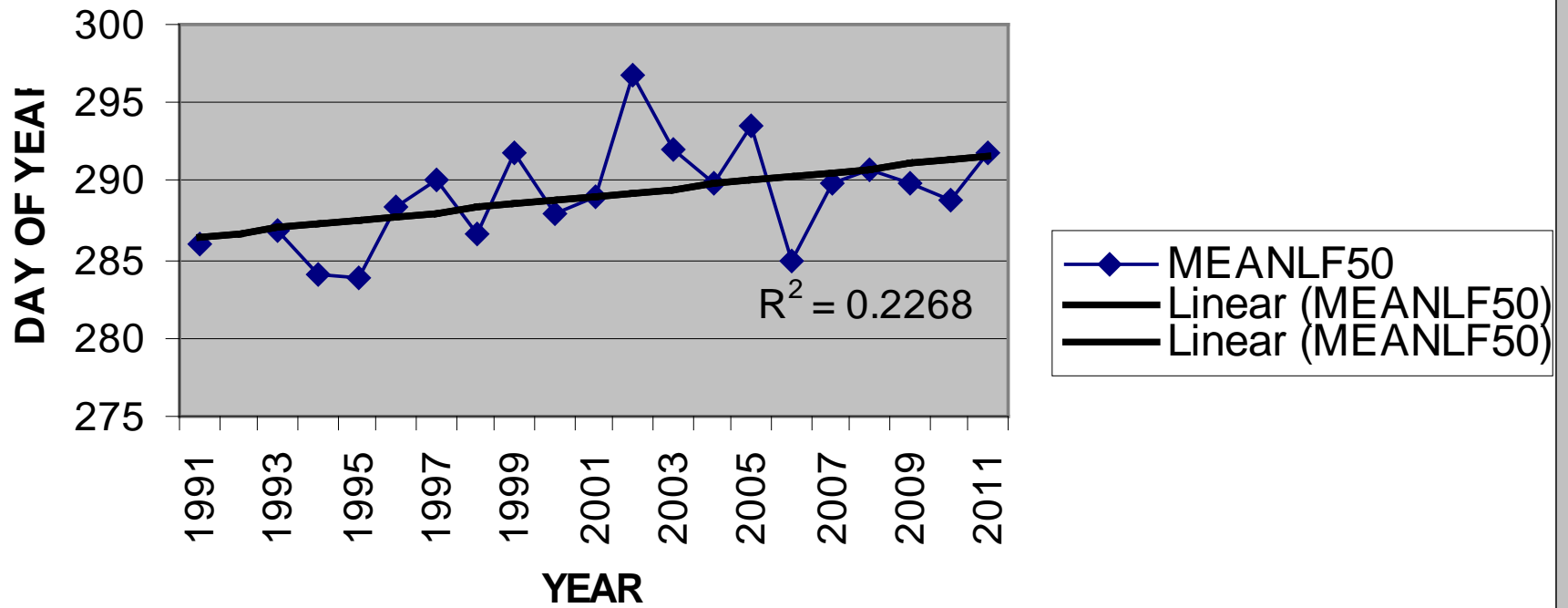
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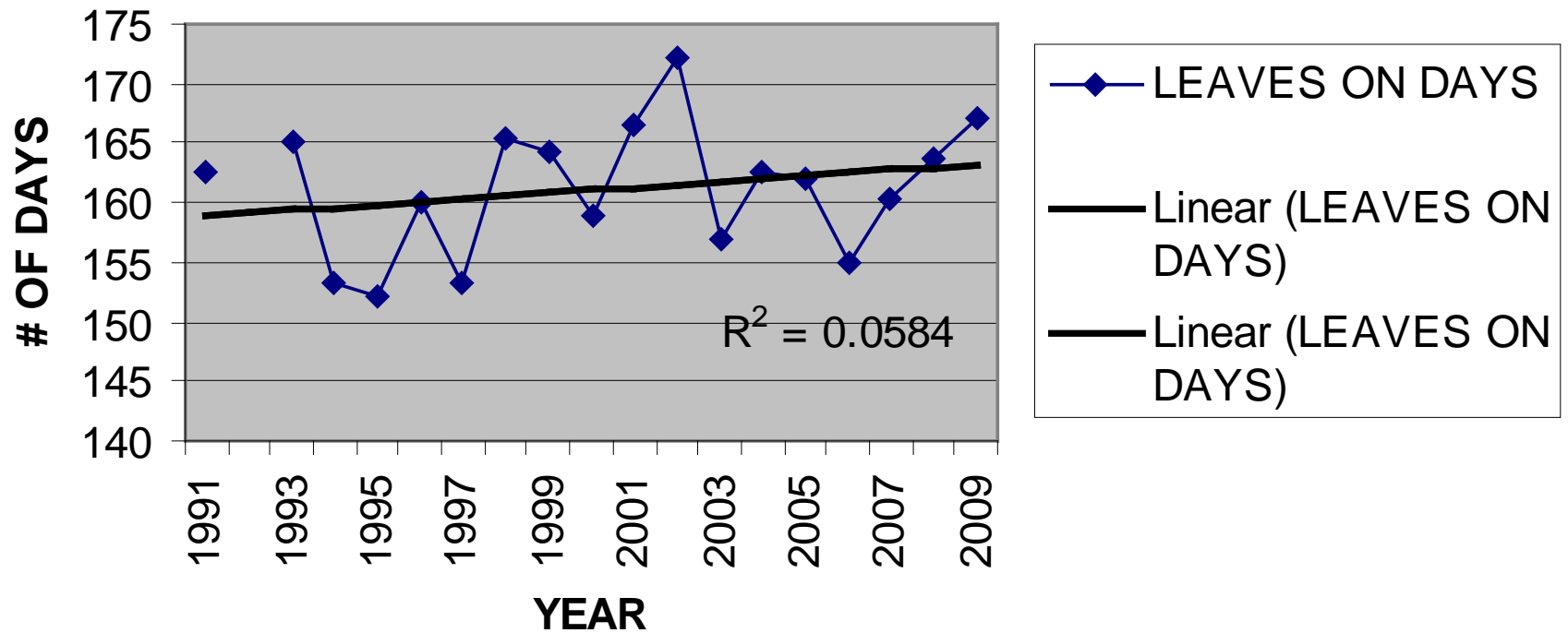
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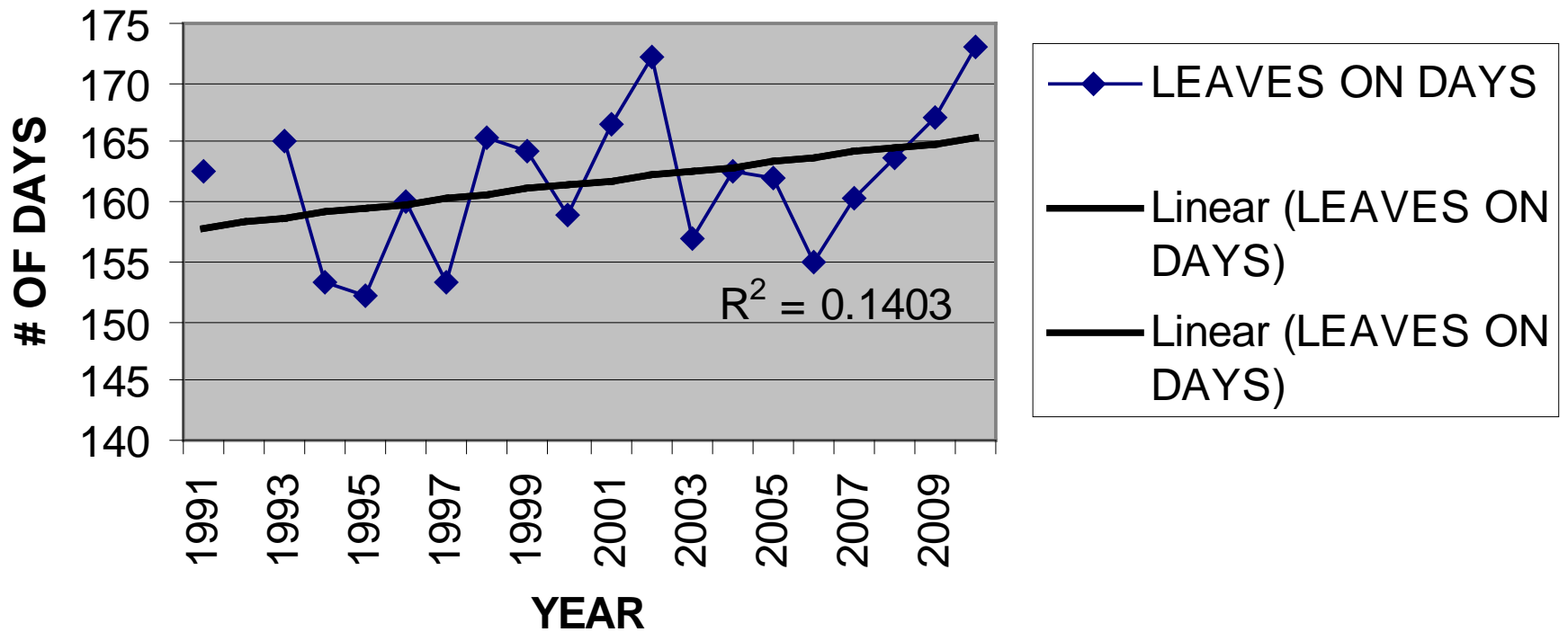
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LEAVES ON DAYS (4 SPP, N=15)



LEAVES ON DAYS (4 SPP, N=15)



LEAVES ON DAYS (4 SPP, N=15)

