Buds, Leaves and Global Warming

John O’Keefe

Harvard Forest

jokeefe@fas.harvard.edu

- www.harvardforest.harvard.edu/schoolyard-lter-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?

- **Fall leaf drop**
  - Temperature and frosts
  - Day length
  - Drought
  - Wind

- **Spring leafout**
  - Cold treatment
  - Cumulative heat sum (growing degree days)
  - Day length

Trees approaching full color at Harvard Forest

As leaves senesce in the fall chlorophyll breaks down and the components are stored for use in the spring. This reveals yellow pigments, carotenoids, which have also been present during the growing season, but masked by chlorophyll.

Many, but not all, trees in our area also have the ability to produce red pigments, called anthocyanins, by using energy from sunlight. These red pigments produce the beautiful orange, red and purple colors that make our forests so beautiful each fall.

Because anthocyanins need sunlight for their production, red leaves tend to develop around the edges of a tree first.

This is not the case for yellow leaves, which are the result of unmasking the already present corotenoids as the chlorophyll breaks down.

For more on fall color see: **www.harvardforest.harvard.edu/autumn-foliage-color**

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 early October in the fall and late April-early May in the spring when events are progressing most rapidly
- I observe and estimate % values (leaf color, leaf drop in fall and leaf emergence, leaf development in spring) over the entire tree (rather than a set number of tagged leaves/buds), which is in fact easier but doesn't work with younger students

NAME: Jok DATE: 9-2-04 AM MID 60S CLR

COM NAME	TREE ID	TAG	LF COLOR	LF FALL	FOPEN	FPAST	COMMENTS
SHADBUSH	AMSP-01	PP003	– ?	–			a couple of orange/yellow lvs
WHITE ASH	FRAM-01	PP004	~15% ?	<1% ?			yellow
BLK. CHERRY	PRSE-01	PP005	<5% ?	~1%			yellow
RED MAPLE	ACRU-01	PP008	~1% ?	– ?			yellowing
SHADBUSH	AMSP-02	PP011	<1%	–			orange/yellow
SUG. MAPLE	ACSA-01	PP012	–	–			
BLK. BIRCH	BELE-01	PP013	~1%	– ?			yellow
YEL. BIRCH	BEAL-01	PP014	~1%	– ?			a few lvs on grd yellow
RED OAK	QURU-01	PP016	– ?	–			poss slight yellowing
WHITE OAK	QUAL-04	PP019A	–	–			
BEECH	FAGR-01	PP020	–	–			Slight yellowing
STR. MAPLE	ACPE-01	PP022	~1%	– ?			a few lvs yellow
BLACK OAK	QUVE-01	PP024	–	–			
PAPER BIRCH	BEPA-01	PP031	<1%	– ?			a few yellowing lvs.
RED MAPLE	ACRU-02	PP033	~5%	~1% ?			yellow/red.
STR. MAPLE	ACRE-02	PP035	~1%	– ?			yellow
BLACK GUM	NYSY-04	PP037A	~1% ?	–			yellow/orange
BEECH	FAGR-05	PP039A	–	–			
STR. MAPLE	ACPE-03	PP040	– ?	–			
YEL. BIRCH	BEAL-02	PP042	–	–			
BLK. BIRCH	BELE-02	PP043	–	–			
BEECH	FAGR-06	PP046A	–	–			
SHADBUSH	AMSP-03	PP056	~1%	– ?			yellow (a few lvs)
BLACK GUM	NYSY-02	PP057	<1%	–			several webworm nests red/orange
YEL. BIRCH	BEAL-03	PP059	– ?	–			
BLACK GUM	NYSY-03	PP059A	~3%	– ?			orange/red.
RED OAK	QURU-02	PP061	–	–			
RED MAPLE	ACRU-03	PP063	<1%	– ?			a few yellowing lvs.
STR. MAPLE	ACPE-04	PP067	– ?	–			some poling
BLACK OAK	QUVE-02	PP069	–	–			
RED MAPLE	ACRU-04	PP074	~1%	– ?			yellow
WHITE OAK	QUAL-02	PP075	<1%	– ?			yellow/red.
BLK. BIRCH	BELE-03	PP079	–	–			
BLACK OAK	QUVE-03	PP081	~3%	– ?			yellow/brown
BLACK OAK	QUVE-04	PP083	–	–			
RED OAK	QURU-03	PP084	–	–			
BLK. CHERRY	PRSE-02	PP086	~10% ?	~1%			Yellow/brown.
PAPER BIRCH	BEPA-02	PP087	–	–			
PAPER BIRCH	BEPA-03	PP088	–	–			
PAPER BIRCH	BEPA-04	PP089	~3% ?	~2% ?			yellow/brown.
WHITE ASH	FRAM-02	PP091	– ?	–			
BEECH	FAGR-04	PP092	–	–			
WHITE OAK	QUAL-03	PP093	–	–			
SUG. MAPLE	ACSA-02	PP095	–	–			
WHITE ASH	FRAM-03	PP096	–	–			
SUG. MAPLE	ACSA-03	PP103	~1%	<1%			orange/yellow
BLK. CHERRY	PRSE-04	PP104A	~1% ?	– ?			yellow – several webworm nests
RED OAK	QURU-04	PP105	– ?	–			a few brown/yellow lvs.
RED MAPLE	ACRU-05	PP106	~2%	– ?			tinged red.
WHITE ASH	FRAM-04	PP108	–	–			

STREAM BY # 10 not flowing a few small puddles.
STREAM BY # 42 not flowing – a few puddles mud dcimp.
STREAM BY # 84 dry / mud dry
STREAM BY # 94 not flowing / no puddles

Clowed lilac N – poling none fallen mid wet.
S – " " "

HEMLOCK HOLLOW small pool of water (2-3M across) <5% fol.
Euonymous – lower ~10% –
" slope N ~5% –
" crest S – –

NAME: JOK DATE: 9-30-03 PM UPPER 53's P/C

acorns falling

COM NAME	TREE ID	TAG	LF COLOR	LF FALL	FOPEN	FPAST	COMMENTS
SHADBUSH	AMSP-01	PP003	~30%?	~3%?			yellow/orange
WHITE ASH	FRAM-01	PP004	~75%?	~12%?			yellow/brown/purple
BLK. CHERRY	PRSE-01	PP005	~20%?	~25%?			yellow
RED MAPLE	ACRU-01	PP008	~30%?	~3%?			yellow/red.
SHADBUSH	AMSP-02	PP011	~10%?	~1%?			yellow/orange
SUG. MAPLE	ACSA-01	PP012	~1%?	-?			yellowing
BLK. BIRCH	BELE-01	PP013	~30%?	~5%?			yellow/gold.
YEL. BIRCH	BEAL-01	PP014	~25%?	~3%?			yellow/gold
RED OAK	QURU-01	PP016	~3%?	-?			yellowing
WHITE OAK	QUAL-04	PP019A	~5%?	-?			yellow
BEECH	FAGR-01	PP020	~1%?	~1%?			yellowing
STR. MAPLE	ACPE-01	PP022	~5%?	~1%			yellow
BLACK OAK	QUVE-01	PP024	~5%?	~3%?			yellow/brown
PAPER BIRCH	BEPA-01	PP031	~20%	~5%?			yellow/brown
RED MAPLE	ACRU-02	PP033	~45%?	~15%?			yellow/red
STR. MAPLE	ACRE-02	PP035	~5%?	~1%			yellow
BLACK GUM	NYSY-04	PP037A	~10%	~1%			orange/yellow
BEECH	FAGR-05	PP039A	~1%	-?			yellowing
STR. MAPLE	ACPE-03	PP040	~7%?	~1%?			yellow
YEL. BIRCH	BEAL-02	PP042	~12%?	~5%?			yellow
BLK. BIRCH	BELE-02	PP043	~10%?	~3%?			yellow/gold.
BEECH	FAGR-03	PP046	~100%	~90%?			brown/gold
SHADBUSH	AMSP-03	PP056	~45%?	~22%?			yellow/brown/orange
BLACK GUM	NYSY-02	PP057	~17%?	~2%?			orange
YEL. BIRCH	BEAL-03	PP059	~65%?	~5%?			yellow
BLACK GUM	NYSY-03	PP059A	~50%?	~5%?			orange/red.
RED OAK	QURU-02	PP061	~3%?	-?			yellowing
RED MAPLE	ACRU-03	PP063	~20%?	~2%?			red/yellow
STR. MAPLE	ACPE-04	PP067	~23%?	~1%?			yellow/brown.
BLACK OAK	QUVE-02	PP069	~3%?	-?			yellow/brown.
RED MAPLE	ACRU-04	PP074	~40%?	~5%?			red/yellow.
WHITE OAK	QUAL-02	PP075	~60%?	~5%?			brown/yellow
BLK. BIRCH	BELE-03	PP079	~27%?	~2%?			yellow/gold
BLACK OAK	QUVE-03	PP081	~35%?	~10%?			brown/yellow
BLACK OAK	QUVE-04	PP083	~3%?	-?			brown/yellow
RED OAK	QURU-03	PP084	~1%?	-?			paling
BLK. CHERRY	PRSE-02	PP086	~33%	~10%??			yellow/brown spots/pink
PAPER BIRCH	BEPA-02	PP087	~8%?	~2%?			yellow/brown.
PAPER BIRCH	BEPA-03	PP088	~10%?	~1%?			yellow
PAPER BIRCH	BEPA-04	PP089	~45%?	~17%?			yellow
WHITE ASH	FRAM-02	PP091	~70%?	~3%?			yellow/purple/brown
BEECH	FAGR-04	PP092	~3%?	-?			gold/brown.
WHITE OAK	QUAL-03	PP093	~3%?	~1%?			red/yellow
SUG. MAPLE	ACSA-02	PP095	~1%?	~1%?			yellowing
WHITE ASH	FRAM-03	PP096	~10%?	~1%?			yellow/brown.
SUG. MAPLE	ACSA-03	PP103	~38%?	~15%?			orange/yellow - seeds just starting to drop.
BLK. CHERRY	PRSE-04	PP104A	~40%?	~30%?			yellow/pink
RED OAK	QURU-04	PP105	~5%?	~1%?			brown/yellow
RED MAPLE	ACRU-05	PP106	~20%?	~2%?			red/yellow
WHITE ASH	FRAM-04	PP108	~12%?	~1%?			purple/yellow

STREAM BY # 10 Flowing well
STREAM BY # 42 flowing - puddles fairly full
STREAM BY # 84 dry - mud dry
STREAM BY # 94 flowing fairly well (made note)

witch hazel #41 first flowers open.
" #60 many flowers open
" #80 dont see flwo

HEMLOCK HOLLOW ~25% full? Enigmous on lawn

color fall
bypass L ~25%? ~3%?
" R ~5%? -?
~3% -?

Cloned lilac color full
N ~65%? -? yellow/brown
" S ~80%? -? "

NAME: JOK DATE: 10/16/04 PM CLOUDY UPPER 50S breezy heavy rain last night

slimy cap mushrooms by #46 up/some going past

Evr larch by #14 just starting to yellow

Lots of WP needles (fresh) on gnd

COM NAME	TREE ID	TAG	LF COLOR	LF FALL	FOPEN	FPAST	COMMENTS
SHADBUSH	AMSP-01	PP003	~99%	~92%?			orange/brown
WHITE ASH	FRAM-01	PP004	100	100			
BLK. CHERRY	PRSE-01	PP005	~65%?	~55%?			yellow/pink/brown spots.
RED MAPLE	ACRU-01	PP008	100%	100%			
SHADBUSH	AMSP-02	PP011	~99%?	~30%?			orange/brown/yellow
SUG. MAPLE	ACSA-01	PP012	~50%?	~3%?			yellow/orange/brown.
BLK. BIRCH	BELE-01	PP013	~98%?	~33%?			gold/yellow
YEL. BIRCH	BEAL-01	PP014	~98%	~98%?			brown/yellow
RED OAK	QURU-01	PP016	~37%?	~3%??			yellow/brown
WHITE OAK	QUAL-04	PP019A	~60%?	~5%??			red/brown/yellow
BEECH	FAGR-01	PP020	~7%?	~1%?			yellow/brown.
STR. MAPLE	ACPE-01	PP022	~75%?	~5%?			yellow
BLACK OAK	QUVE-01	PP024	~60%??	~10%?			brown/yellow
PAPER BIRCH	BEPA-01	PP031	~100%	~78%?			yellow/brown
RED MAPLE	ACRU-02	PP033	100%	~100%			
STR. MAPLE	ACRE-02	PP035	100%	~70%?			yellow/gold/brown.
BLACK GUM	NYSY-04	PP037A	~80%?	~60%?			orange/brown.
BEECH	FAGR-05	PP039A	~33%?	~5%?			yellow/copper
STR. MAPLE	ACPE-03	PP040	~100%	~85%?			yellow/brown
YEL. BIRCH	BEAL-02	PP042	~100%	~97%?			yellow/brown
BLK. BIRCH	BELE-02	PP043	~100%	~78%?			yellow/brown
BEECH	FAGR-06	PP046A	~15%?	~3%?			yellow/brown
SHADBUSH	AMSP-03	PP056	100%	99%			brown/orange
BLACK GUM	NYSY-02	PP057	100%	99%			brown/red.
YEL. BIRCH	BEAL-03	PP059	100%	99%			brown/(curled)
BLACK GUM	NYSY-03	PP059A	100%	~97%?			orange/yellow
RED OAK	QURU-02	PP061	~90%?	~42%?			brown/yellow
RED MAPLE	ACRU-03	PP063	100%	100%			
STR. MAPLE	ACPE-04	PP067	~100%	~78%?			yellow/brown.
BLACK OAK	QUVE-02	PP069	~90%?	~55%?			brown/yellow
RED MAPLE	ACRU-04	PP074	100%	100%			
WHITE OAK	QUAL-02	PP075	~100%	~65%?			brown/red/yellow
BLK. BIRCH	BELE-03	PP079	~99%	~63%?			yellow/gold/brown.
BLACK OAK	QUVE-03	PP081	~85%?	~75%?			brown/yellow
BLACK OAK	QUVE-04	PP083	~70%?	~15%??			brown/red.
RED OAK	QURU-03	PP084	~40%?	~3%??			yellow/brown
BLK. CHERRY	PRSE-02	PP086	~73%?	~62%?			yellow/brown
PAPER BIRCH	BEPA-02	PP087	~90%?	~95%?			yellow/brown
PAPER BIRCH	BEPA-03	PP088	100%	~100%			
PAPER BIRCH	BEPA-04	PP089	~100%	~95%?			yellow/brown
WHITE ASH	FRAM-02	PP091	100	100			
BEECH	FAGR-04	PP092	~10%?	~5%??			yellow/brown.
WHITE OAK	QUAL-03	PP093	~50%?	~3%??			brown/yellow/red. (pure 5% fall??)
SUG. MAPLE	ACSA-02	PP095	~67%?	~3%?			orange/yellow
WHITE ASH	FRAM-03	PP096	~100%	98%?			brown
SUG. MAPLE	ACSA-03	PP103	~97%?	~42%?			orange/yellow/red
BLK. CHERRY	PRSE-04	PP104A	~80%?	~55%??			pink/yellow
RED OAK	QURU-04	PP105	~50%?	~5%?			yellow/brown. (rec ~7% fall?)
RED MAPLE	ACRU-05	PP106	~100%	~90%?			red/yellow
WHITE ASH	FRAM-04	PP108	~80%?	~55%?			yellow/brown/purple

STREAM BY # 10 flowing very well

STREAM BY # 42 flowing gently. puddles ~full

STREAM BY # 84 dry/mud start damp (almost dry)

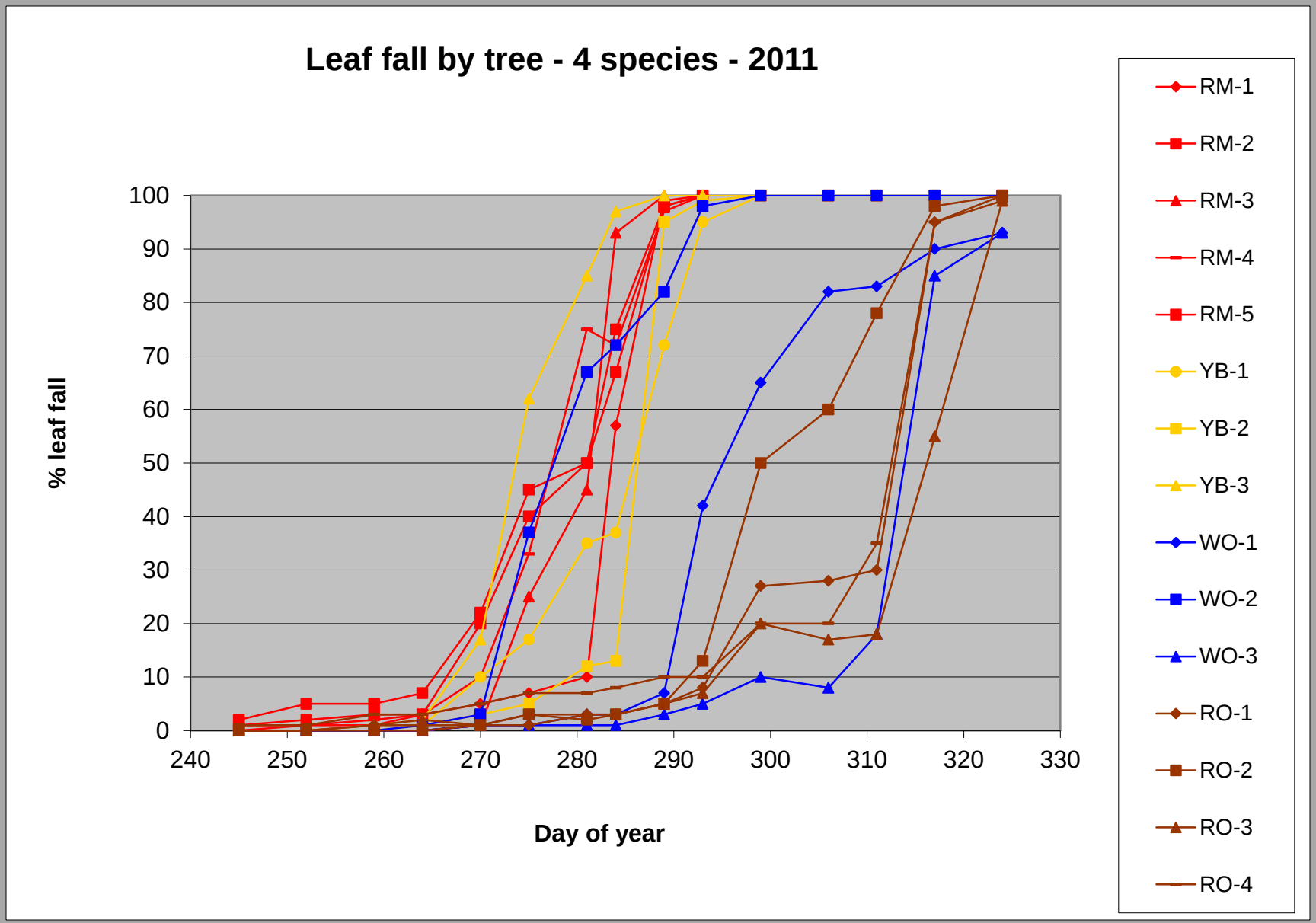
STREAM BY # 94 flowing well

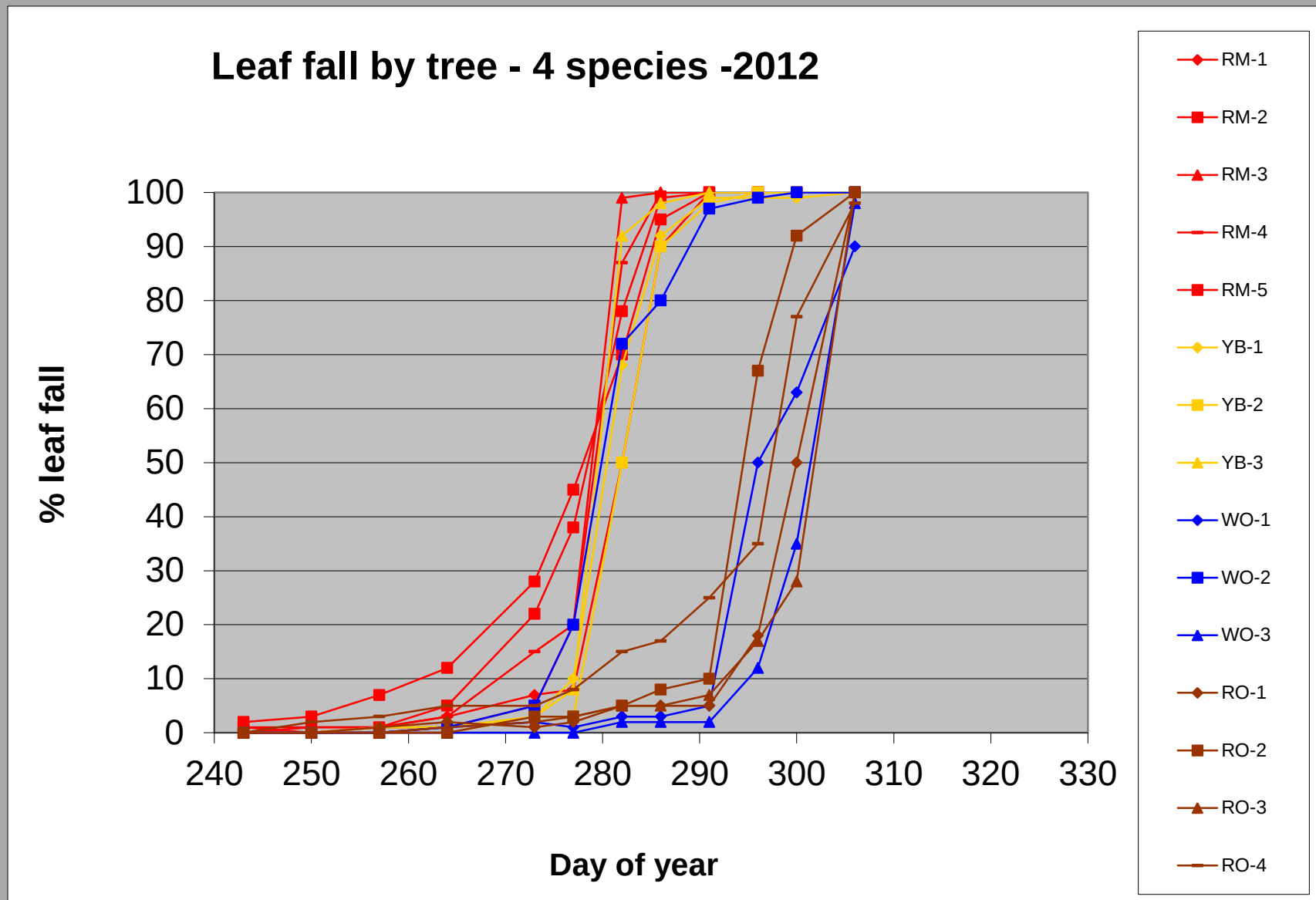
HEMLOCK HOLLOW ~full

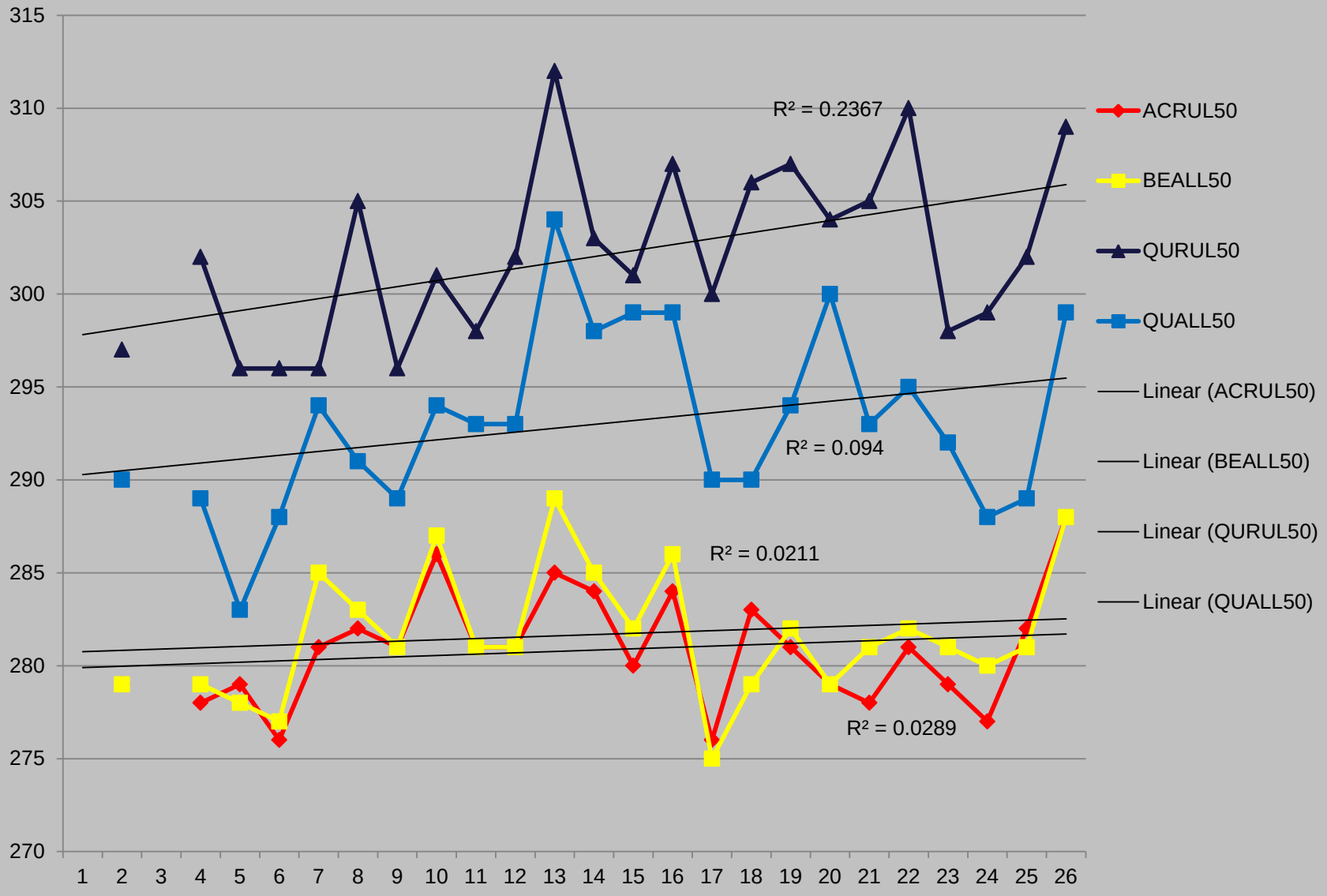
		color	full	bloom
witch hazel #	47	~100%	~25%? going past?	
"	66	100%	~50%? some going past	
"	80	~80%?	< 5%?	~full ...?

	color	fall
Euonymous lawn	~85%?	~15%?
" Nve L	~65%?	~1%?
" " R	~40%?	- ?
Clover lilac N	~75%?	~5%? yellow/brown spots
" S	~90%?	~15%?

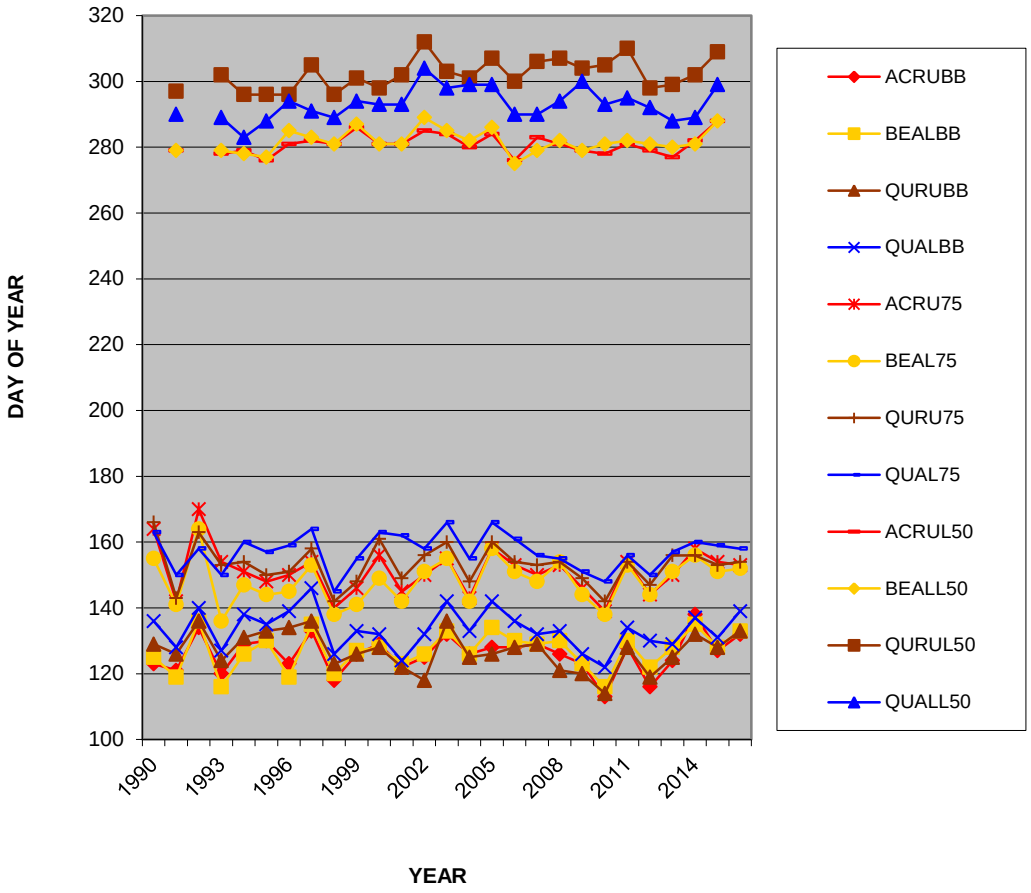
DATE	TREE ID	TAG	LF COLOR	LF FALL	FOPEN	FPAST	COMMENTS	CIRCUIT
9/2/2004	AMSP-01	PP003	0	0				1
9/7/2004	AMSP-01	PP003	1	0				1
9/16/2004	AMSP-01	PP003	3	1				1
9/23/2004	AMSP-01	PP003	5	1				1
9/30/2004	AMSP-01	PP003	23	2				1
10/7/2004	AMSP-01	PP003	45	5				1
10/12/2004	AMSP-01	PP003	95	35				1
10/16/2004	AMSP-01	PP003	99	92				1
10/22/2004	AMSP-01	PP003	100	100				1
10/28/2004	AMSP-01	PP003	100	100				1
11/4/2004	AMSP-01	PP003	100	100				1
11/16/2004	AMSP-01	PP003	100	100				1
9/2/2004	FRAM-01	PP004	15	0				2
9/7/2004	FRAM-01	PP004	18	1				2
9/16/2004	FRAM-01	PP004	50	5				2
9/23/2004	FRAM-01	PP004	65	8				2
9/30/2004	FRAM-01	PP004	95	70				2
10/7/2004	FRAM-01	PP004	100	98				2
10/12/2004	FRAM-01	PP004	100	100				2
10/16/2004	FRAM-01	PP004	100	100				2
10/22/2004	FRAM-01	PP004	100	100				2
10/28/2004	FRAM-01	PP004	100	100				2
11/4/2004	FRAM-01	PP004	100	100				2
11/16/2004	FRAM-01	PP004	100	100				2
9/2/2004	PRSE-01	PP005	3	1				3
9/7/2004	PRSE-01	PP005	3	1				3
9/16/2004	PRSE-01	PP005	18	5				3
9/23/2004	PRSE-01	PP005	18	15				3
9/30/2004	PRSE-01	PP005	15	17				3
10/7/2004	PRSE-01	PP005	17	27				3
10/12/2004	PRSE-01	PP005	40	50				3
10/16/2004	PRSE-01	PP005	65	55				3
10/22/2004	PRSE-01	PP005	80	73				3
10/28/2004	PRSE-01	PP005	95	85				3
11/4/2004	PRSE-01	PP005	100	100				3
11/16/2004	PRSE-01	PP005	100	100				3
9/2/2004	ACRU-01	PP008	1	0				4
9/7/2004	ACRU-01	PP008	1	0				4
9/16/2004	ACRU-01	PP008	7	1				4
9/23/2004	ACRU-01	PP008	10	2				4
9/30/2004	ACRU-01	PP008	22	8				4
10/7/2004	ACRU-01	PP008	80	15				4
10/12/2004	ACRU-01	PP008	100	90				4
10/16/2004	ACRU-01	PP008	100	100				4
10/22/2004	ACRU-01	PP008	100	100				4
10/28/2004	ACRU-01	PP008	100	100				4
11/4/2004	ACRU-01	PP008	100	100				4
11/16/2004	ACRU-01	PP008	100	100				4
9/2/2004	AMSP-02	PP011	0	0				5
9/7/2004	AMSP-02	PP011	0	0				5
9/16/2004	AMSP-02	PP011	3	0				5
9/23/2004	AMSP-02	PP011	3	0				5
9/30/2004	AMSP-02	PP011	7	1				5
10/7/2004	AMSP-02	PP011	20	2				5
10/12/2004	AMSP-02	PP011	90	10				5
10/16/2004	AMSP-02	PP011	99	30				5
10/22/2004	AMSP-02	PP011	100	82				5

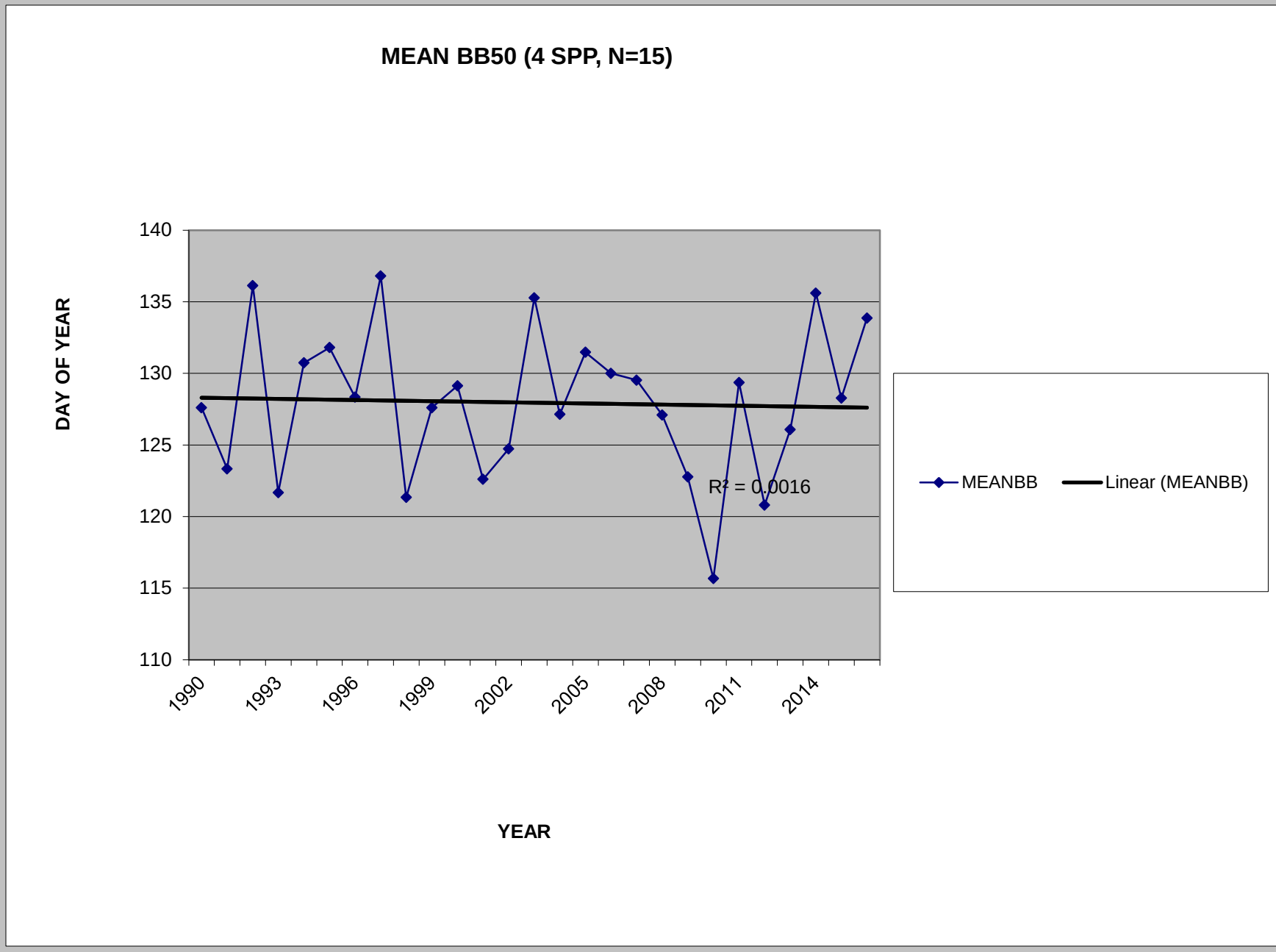

Leaf fall by tree - 4 species - 2011
% leaf fall
Day of year
0
10
20
30
40
50
60
70
80
90
100
240
250
260
270
280
290
300
310
320
330
RM-1
RM-2
RM-3
RM-4
RM-5
YB-1
YB-2
YB-3
WO-1
WO-2
WO-3
RO-1
RO-2
RO-3
RO-4

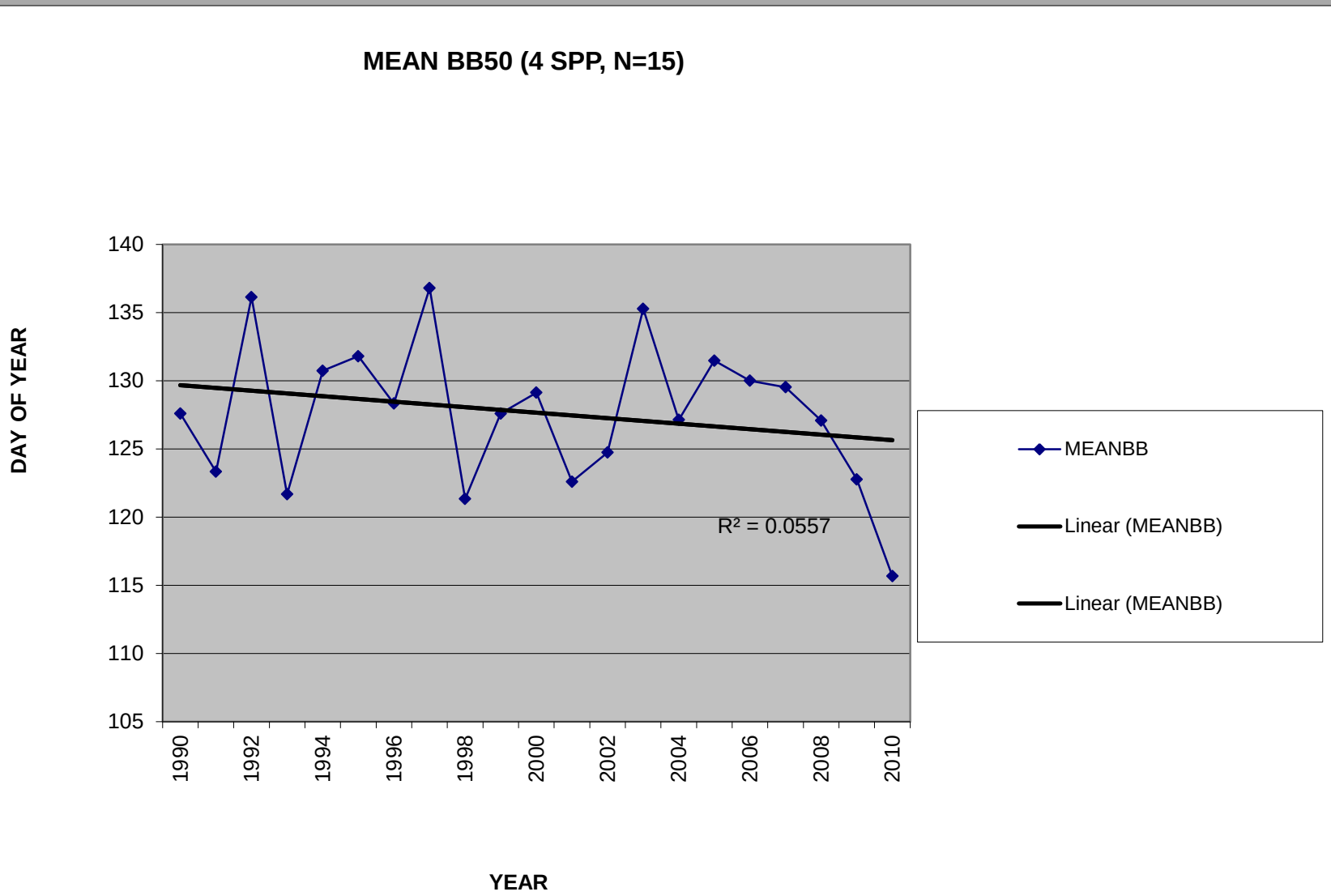

Leaf fall by tree - 4 species -2012
% leaf fall
100
90
80
70
60
50
40
30
20
10
0
240
250
260
270
280
290
300
310
320
330
Day of year
RM-1
RM-2
RM-3
RM-4
RM-5
YB-1
YB-2
YB-3
WO-1
WO-2
WO-3
RO-1
RO-2
RO-3
RO-4

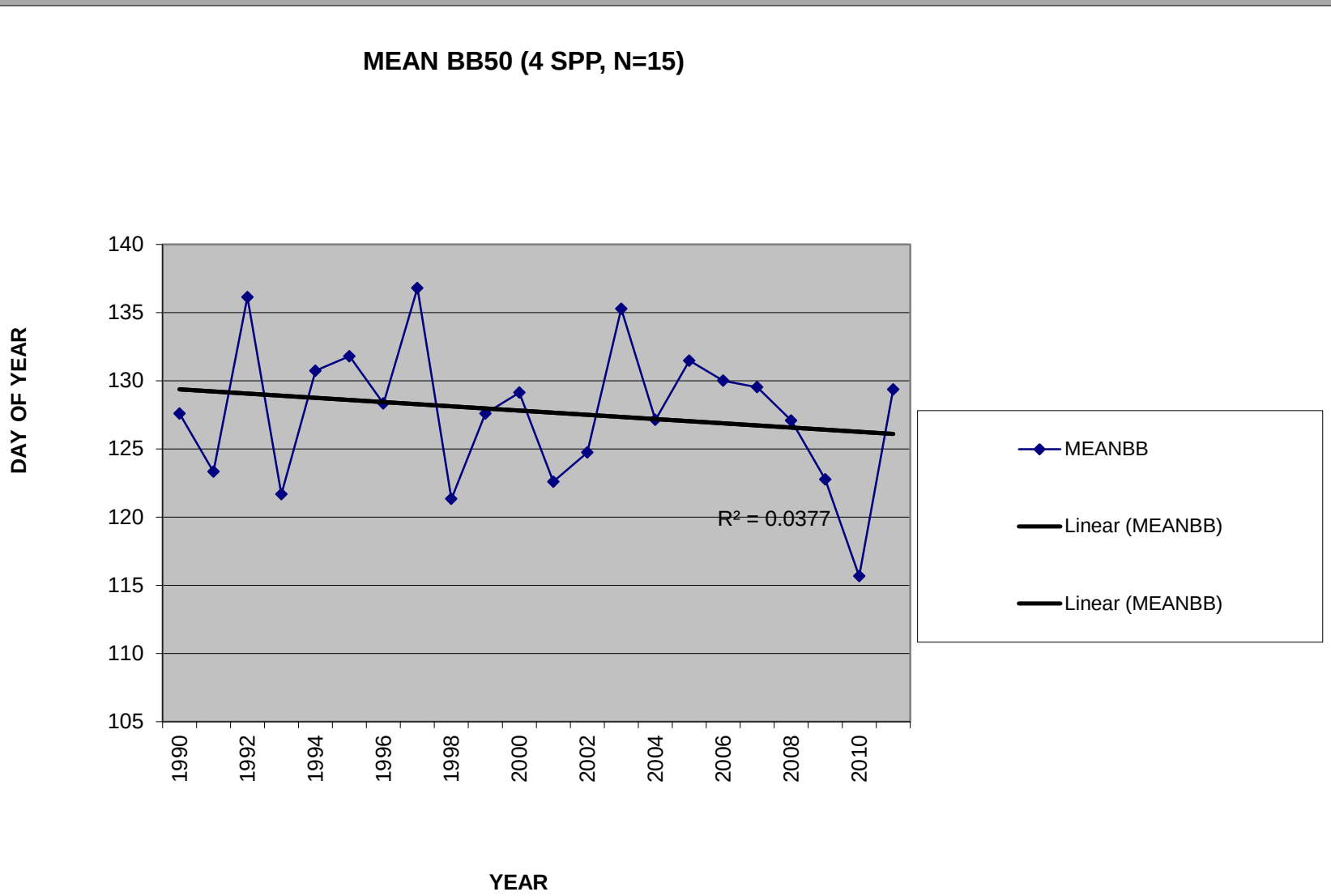

315
310
305
300
295
290
285
280
275
270
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
R² = 0.2367
R² = 0.094
R² = 0.0211
R² = 0.0289
ACRUL50
BEALL50
QURUL50
QUALL50
Linear (ACRUL50)
Linear (BEALL50)
Linear (QURUL50)
Linear (QUALL50)

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)

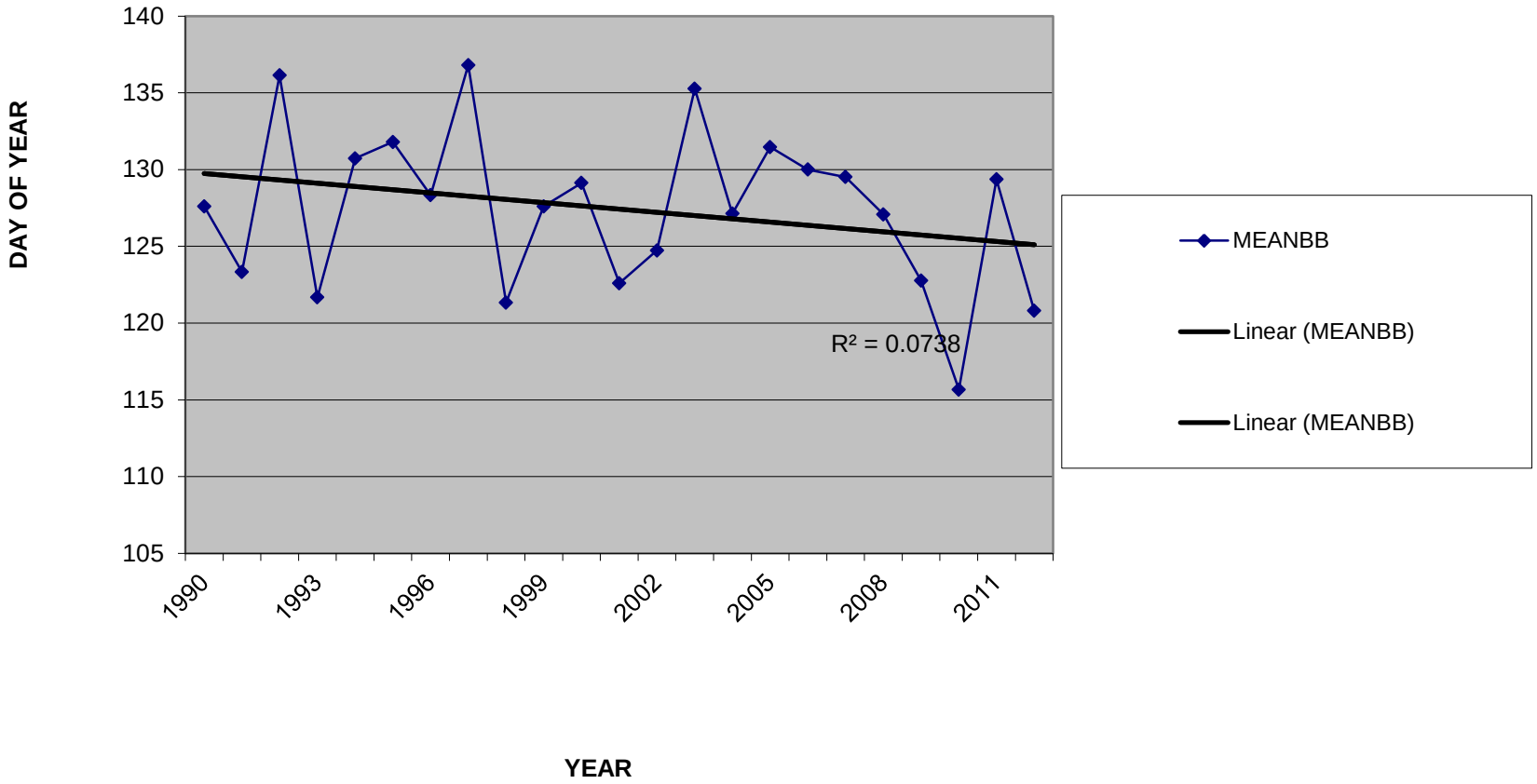


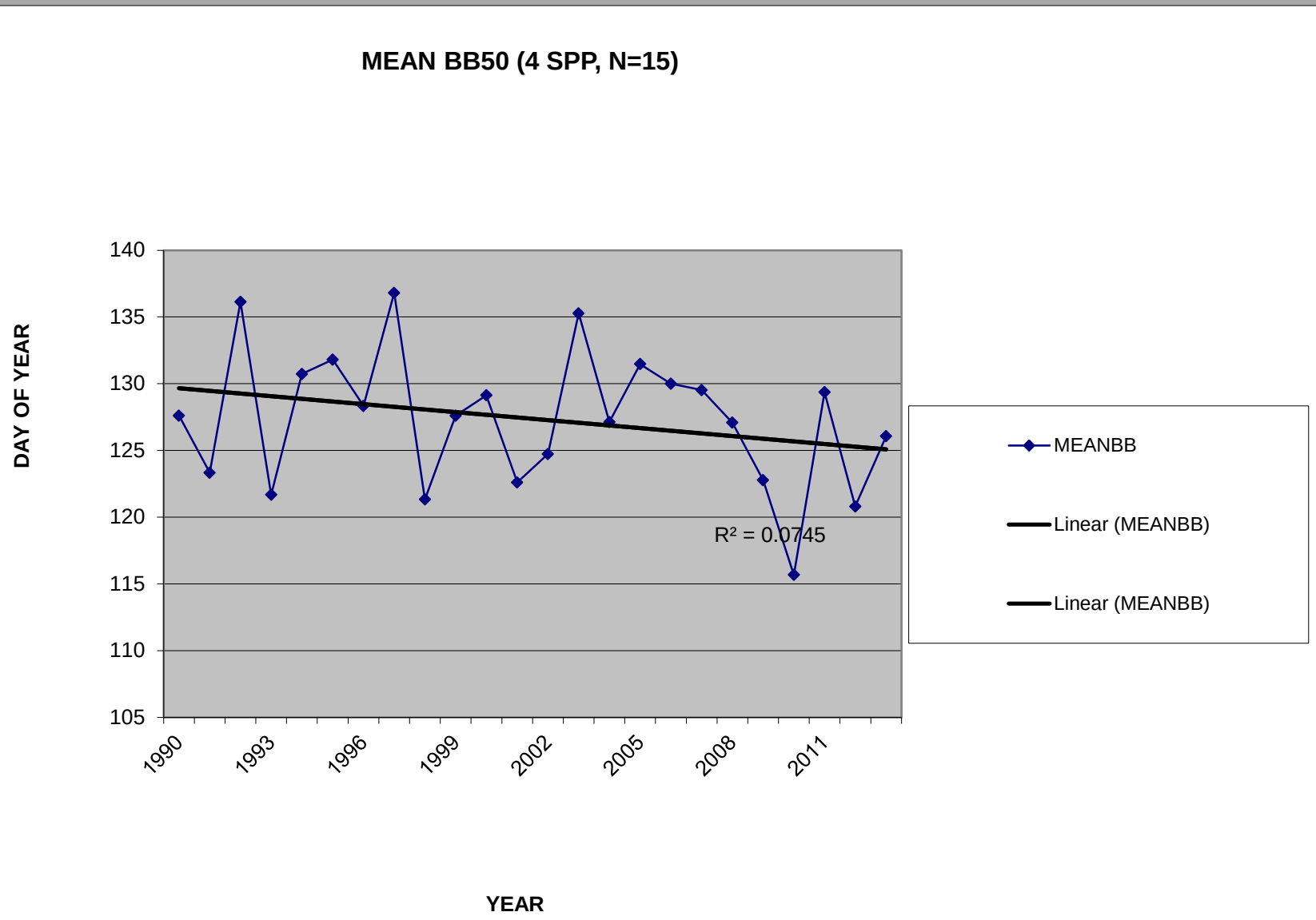

MEAN BB50 (4 SPP, N=15)
DAY OF YEAR
140
135
130
125
120
115
110
1990
1993
1996
1999
2002
2005
2008
2011
2014
R² = 0.0016
MEANBB
Linear (MEANBB)
YEAR


MEAN BB50 (4 SPP, N=15)
DAY OF YEAR
140
135
130
125
120
115
110
105
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
R² = 0.0557
YEAR
MEANBB
Linear (MEANBB)
Linear (MEANBB)

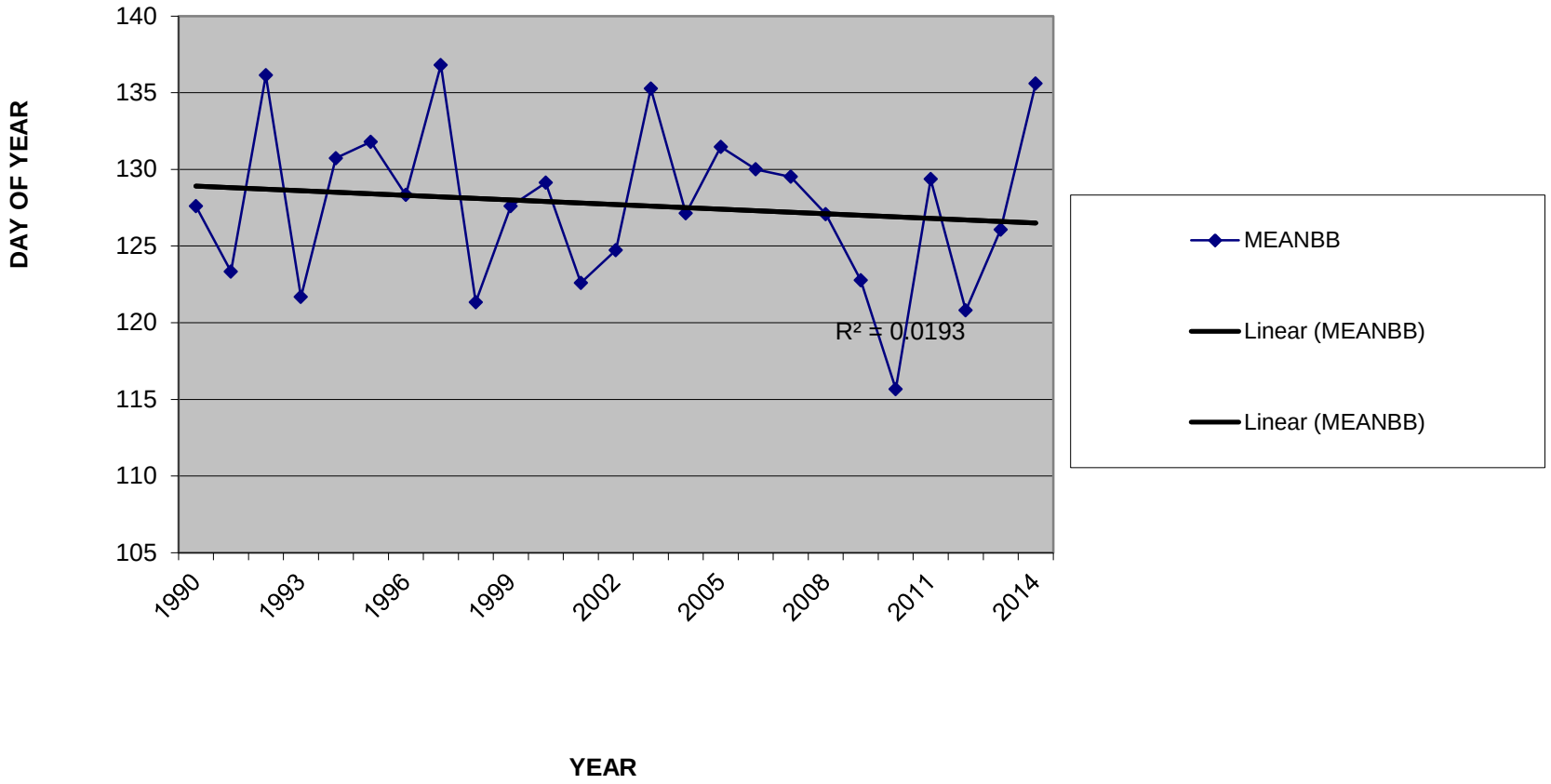

MEAN BB50 (4 SPP, N=15)
DAY OF YEAR
140
135
130
125
120
115
110
105
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
YEAR
R² = 0.0377
MEANBB
Linear (MEANBB)
Linear (MEANBB)

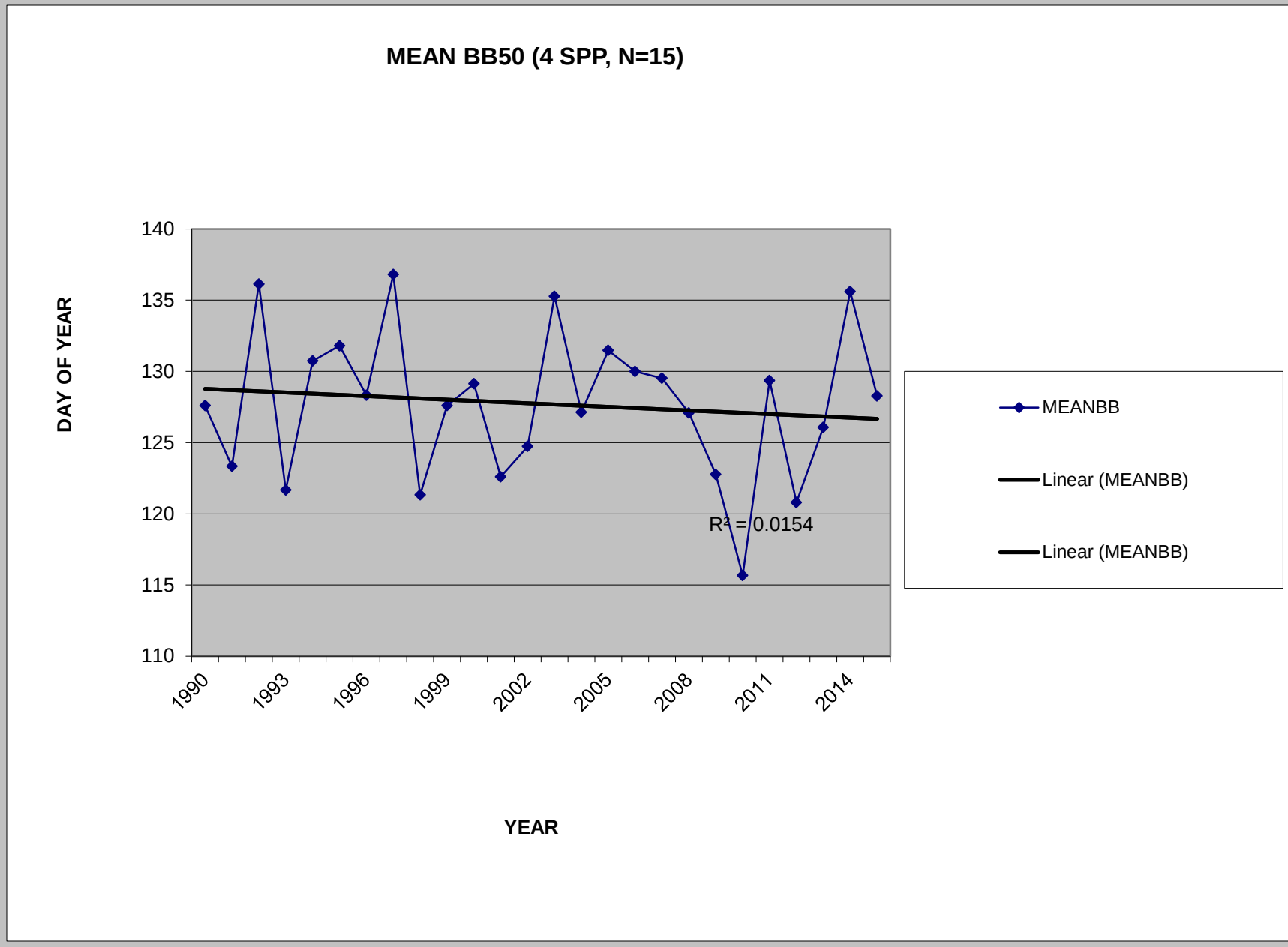
MEAN BB50 (4 SPP, N=15)

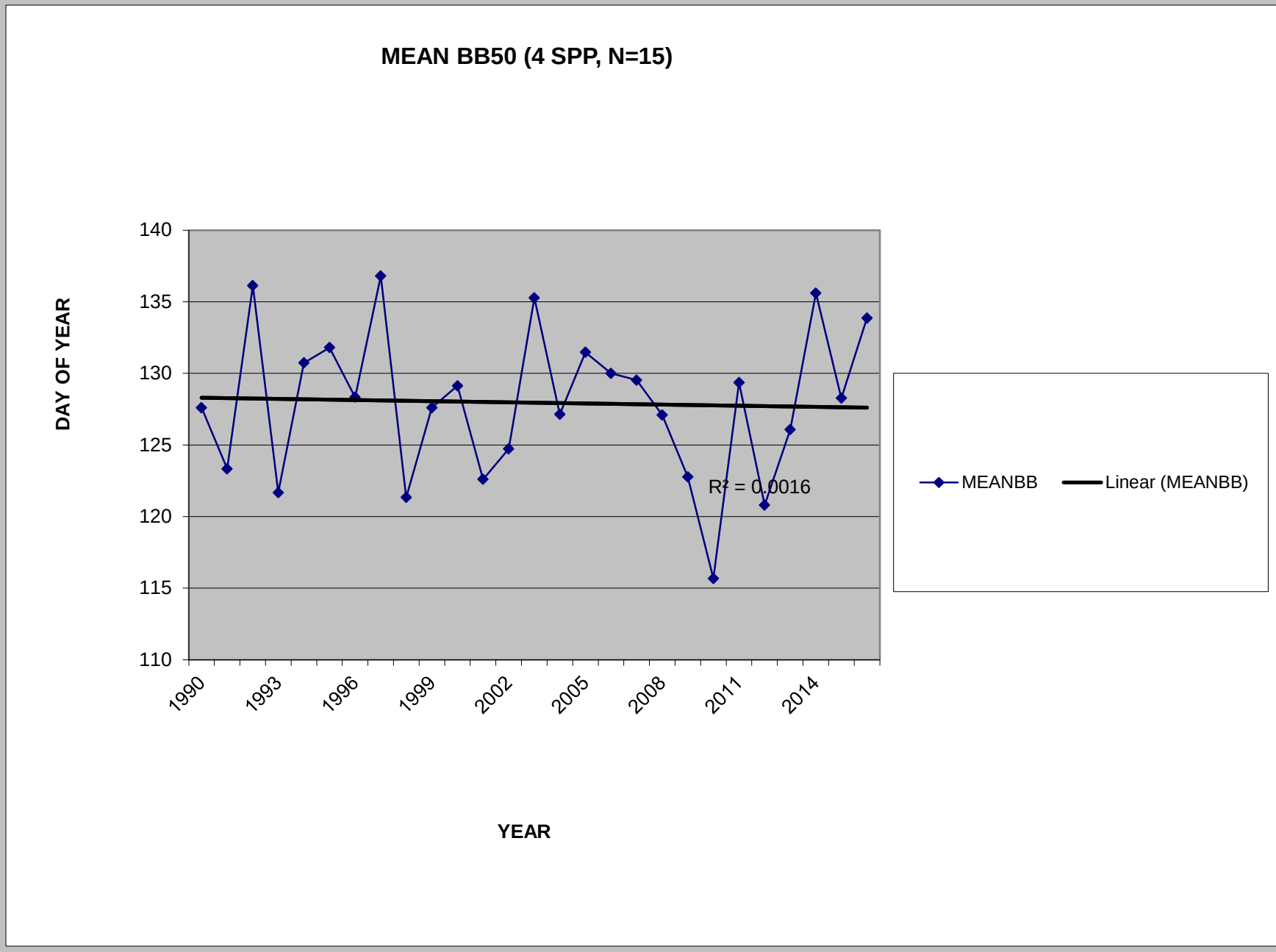



MEAN BB50 (4 SPP, N=15)
DAY OF YEAR
140
135
130
125
120
115
110
105
1990
1993
1996
1999
2002
2005
2008
2011
R² = 0.0745
YEAR
MEANBB
Linear (MEANBB)
Linear (MEANBB)

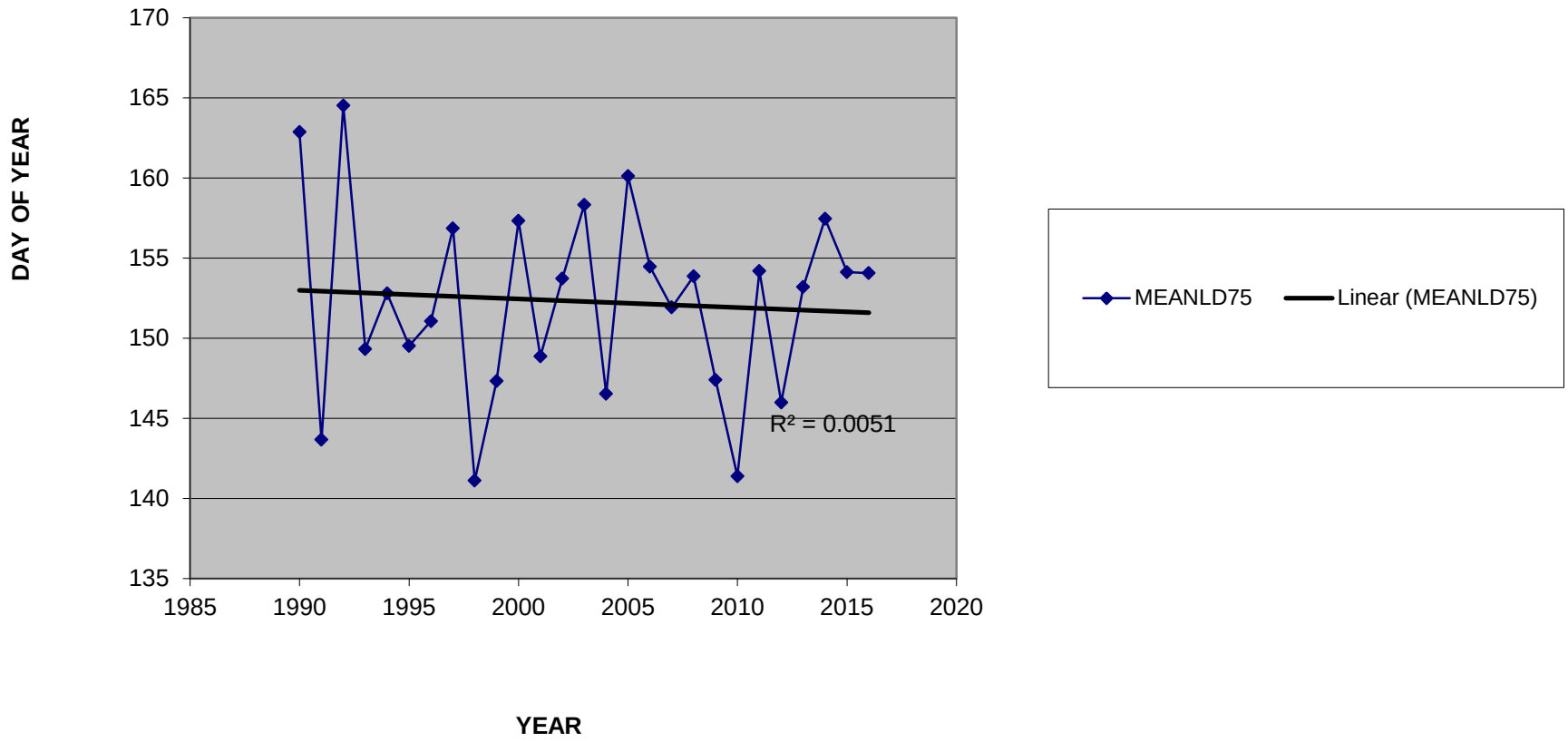
MEAN BB50 (4 SPP, N=15)



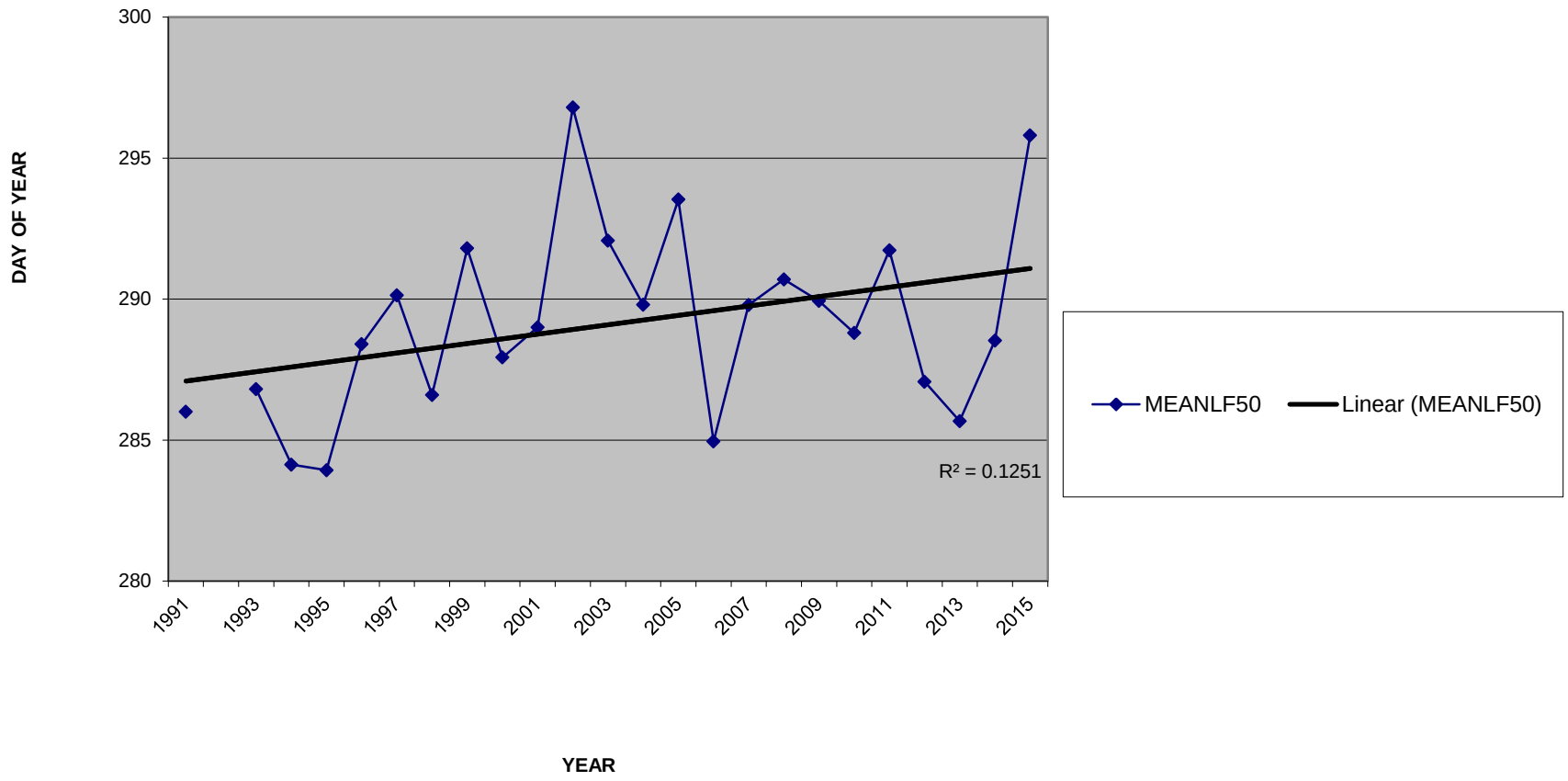

MEAN BB50 (4 SPP, N=15)
DAY OF YEAR
140
135
130
125
120
115
110
1990
1993
1996
1999
2002
2005
2008
2011
2014
R² = 0.0154
YEAR
MEANBB
Linear (MEANBB)
Linear (MEANBB)


MEAN BB50 (4 SPP, N=15)
DAY OF YEAR
140
135
130
125
120
115
110
1990
1993
1996
1999
2002
2005
2008
2011
2014
R² = 0.0016
MEANBB
Linear (MEANBB)
YEAR

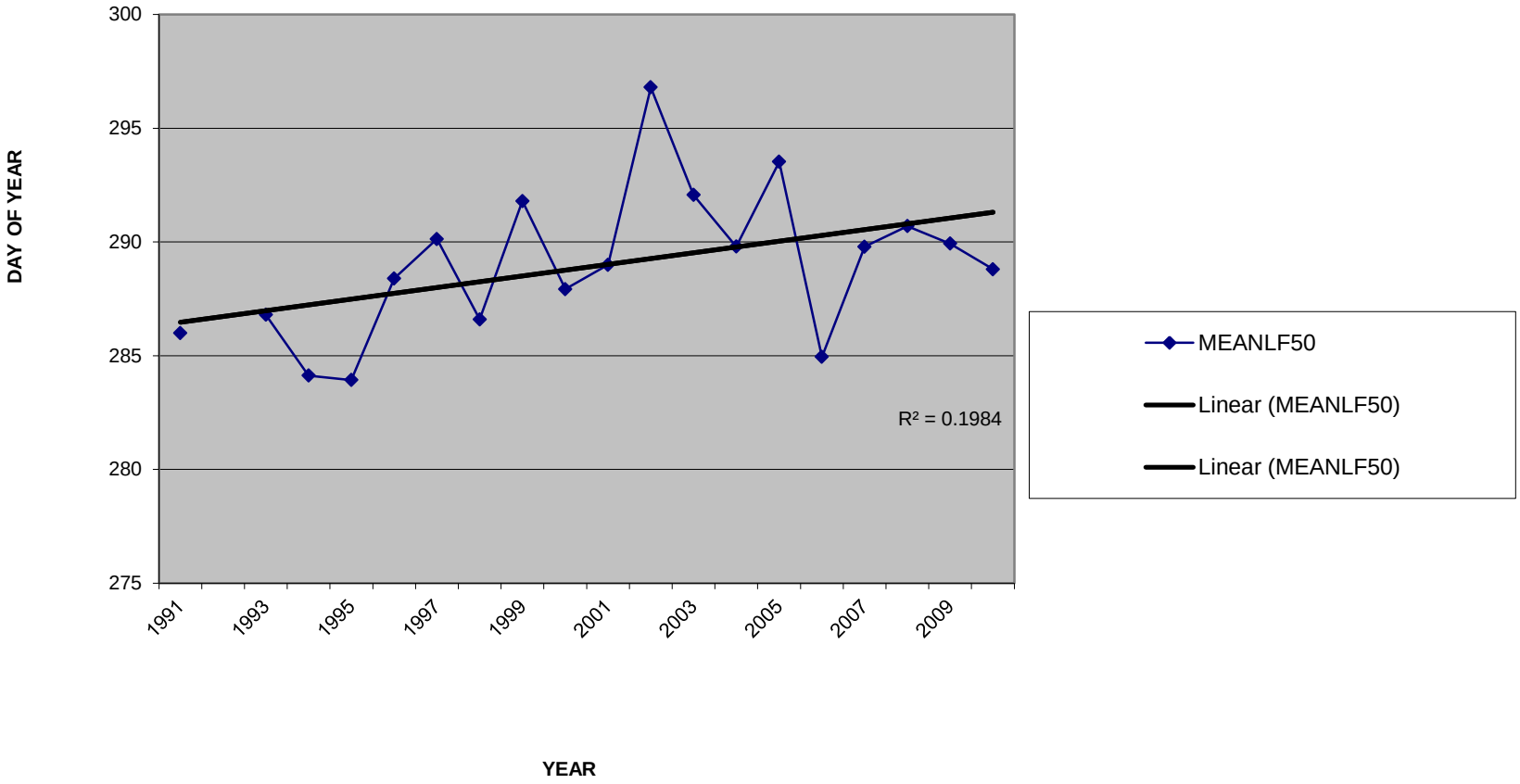
MEAN LD75 (4 SPP, N=15)



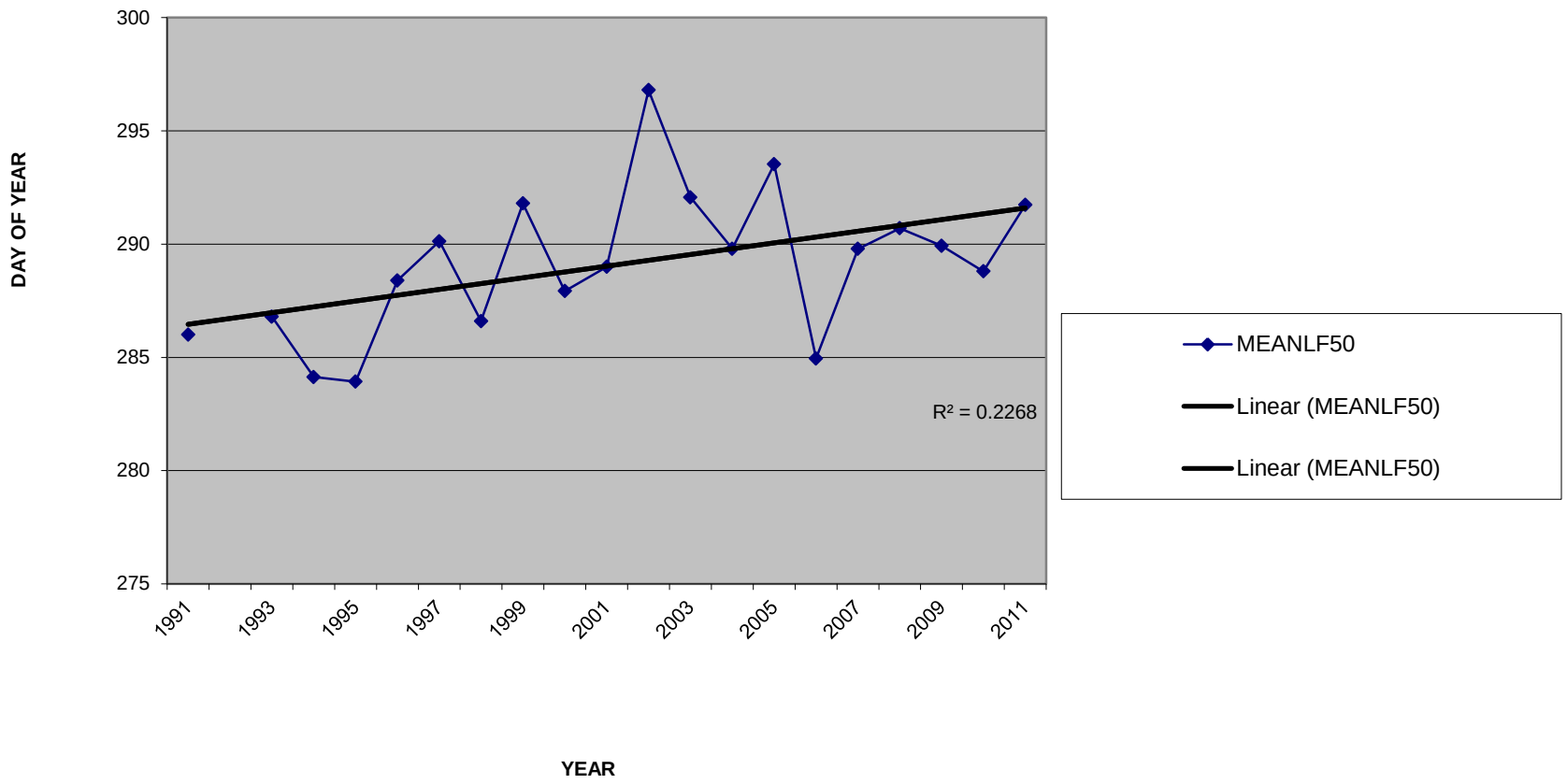
MEAN LF50 (4 SPP, N=15)



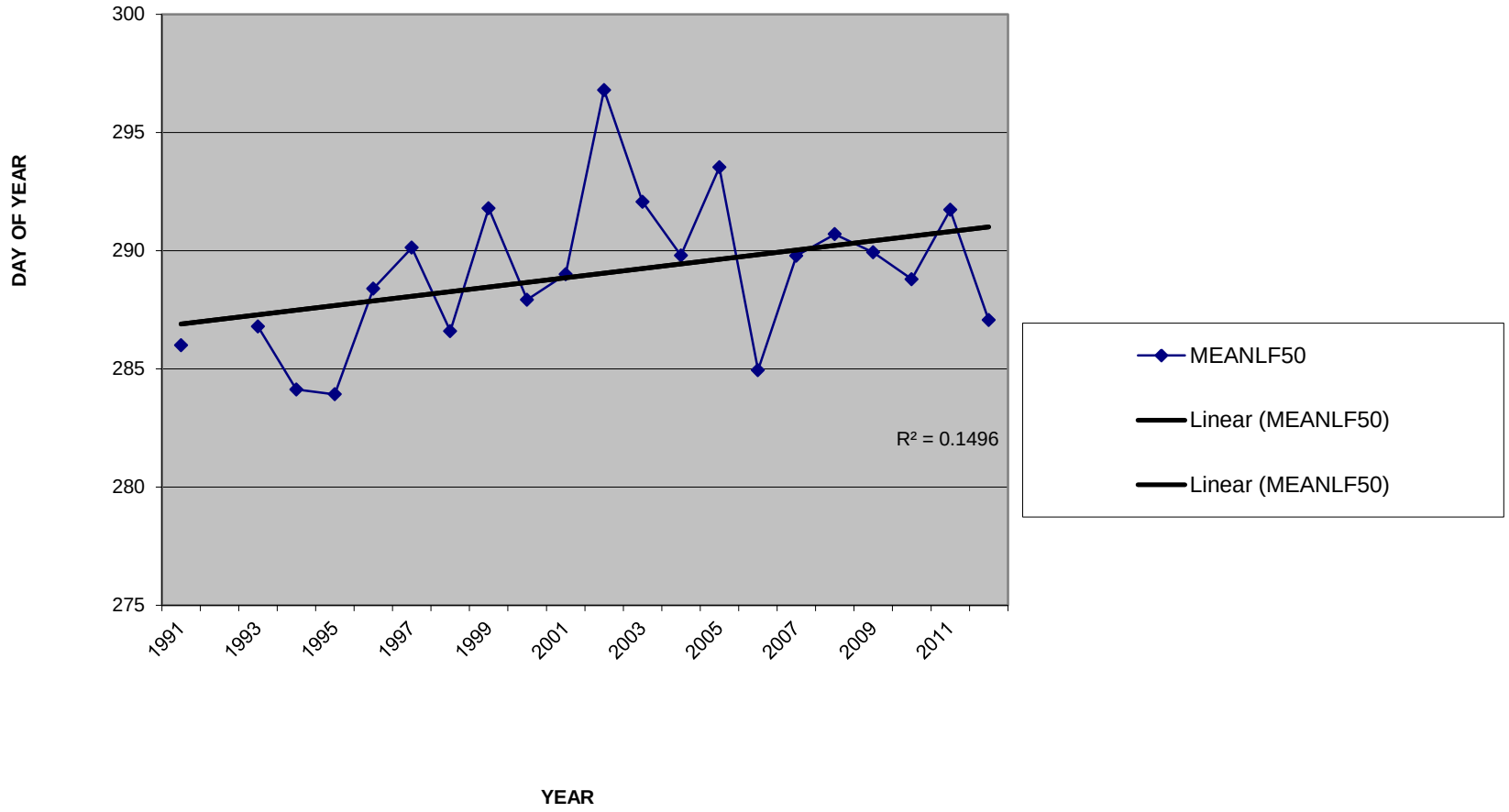
MEAN LF50 (4 SPP, N=15)



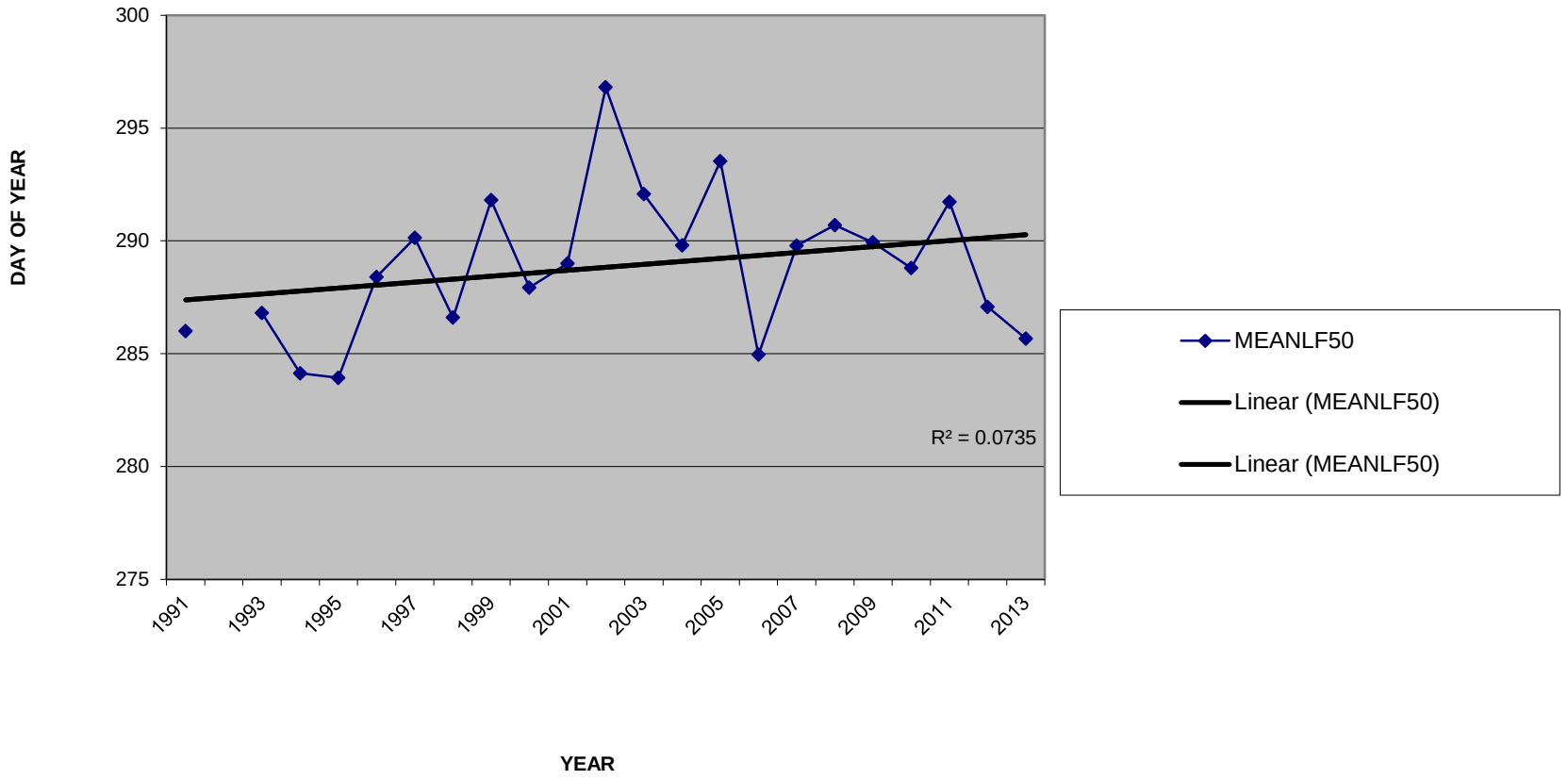
MEAN LF50 (4 SPP, N=15)



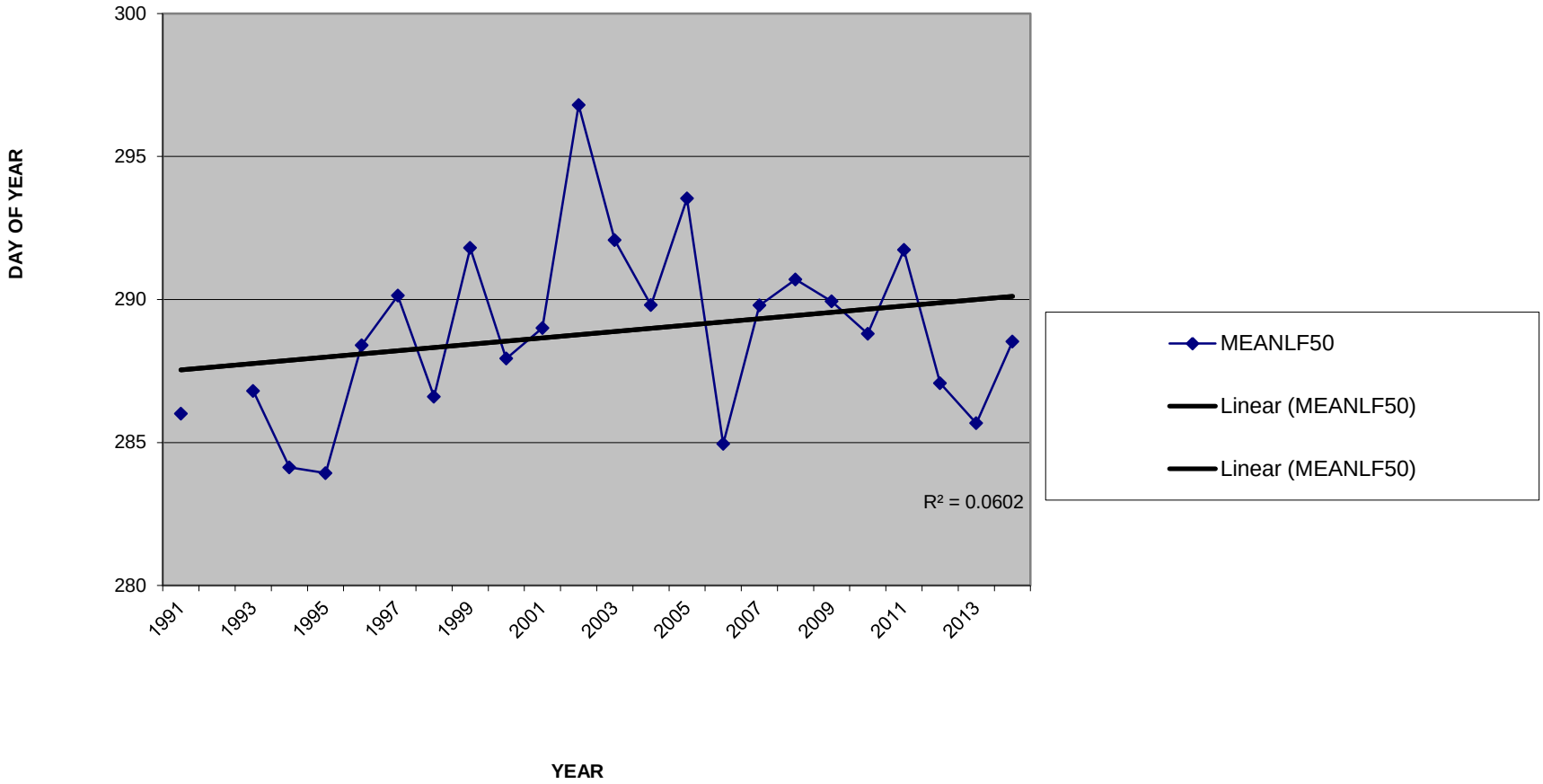
MEAN LF50 (4 SPP, N=15)



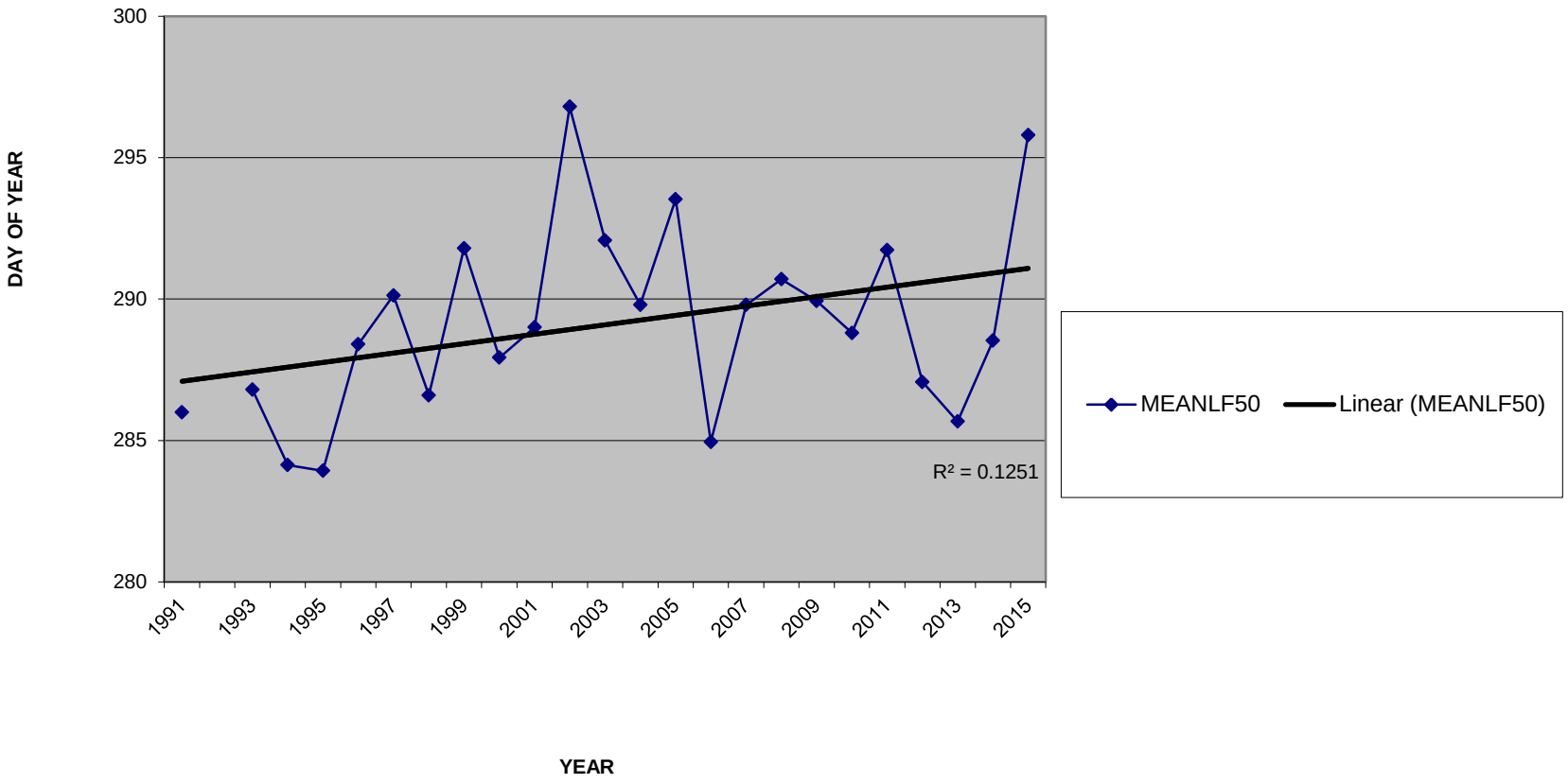
MEAN LF50 (4 SPP, N=15)



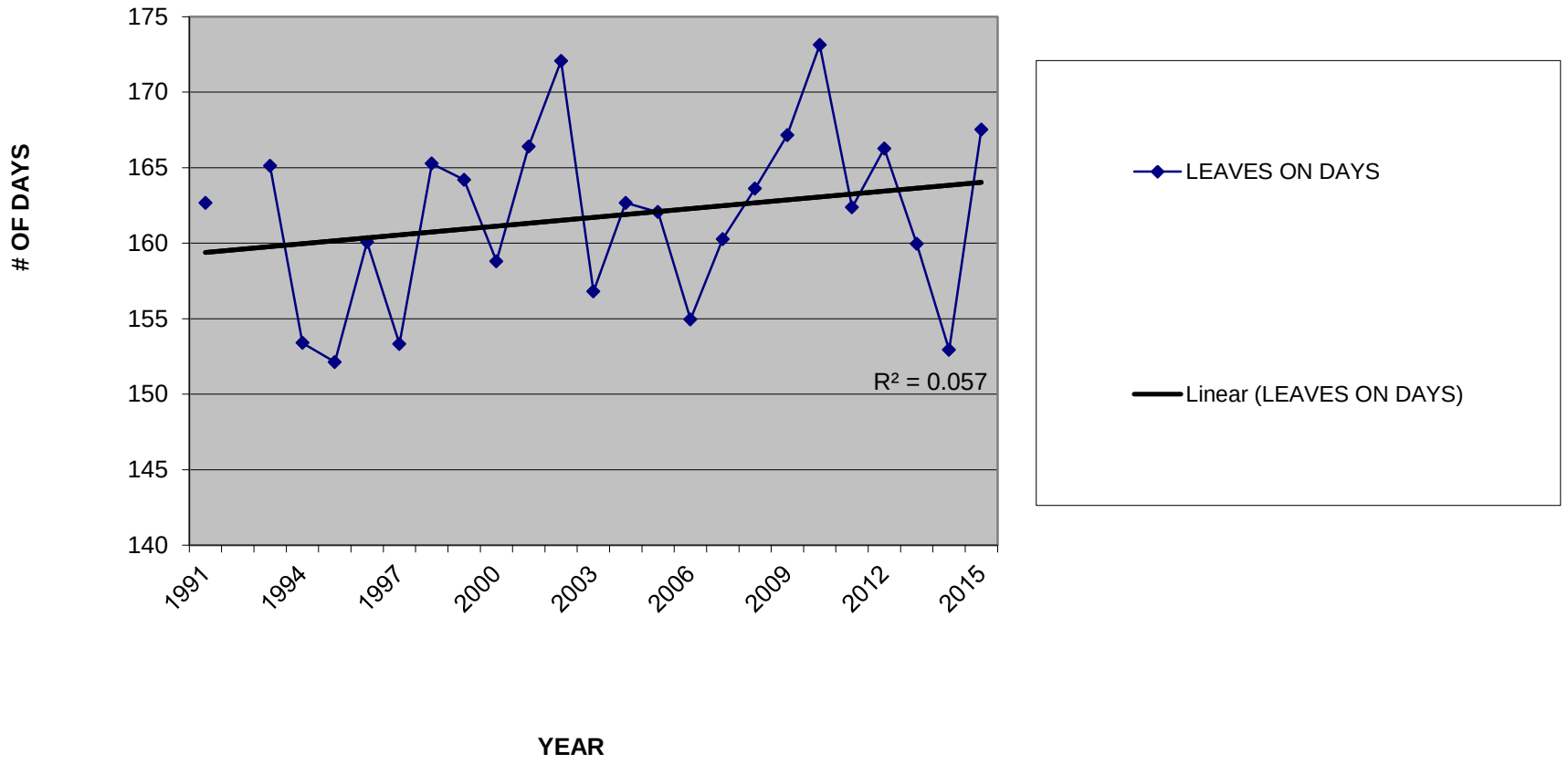
MEAN LF50 (4 SPP, N=15)



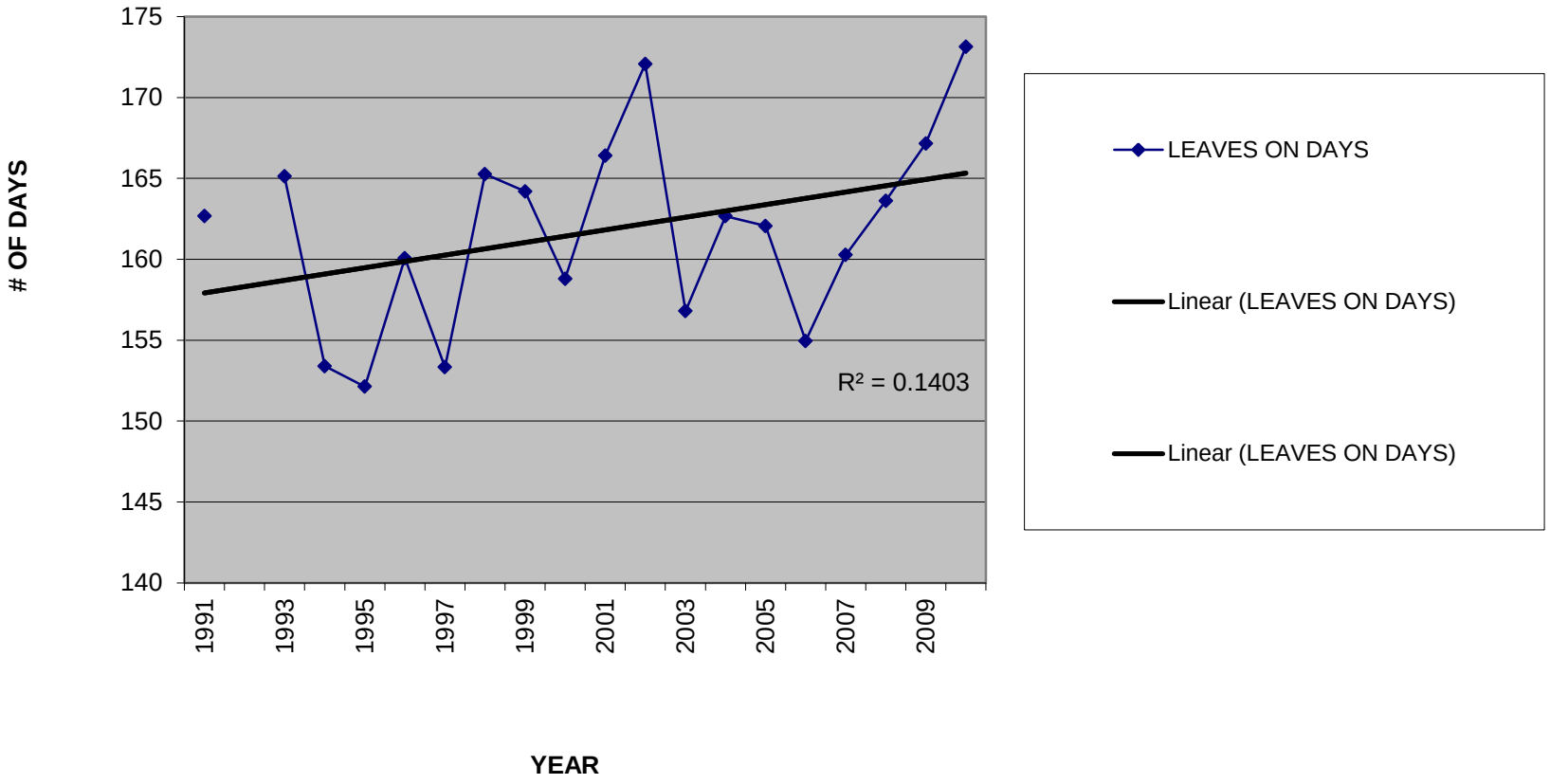
MEAN LF50 (4 SPP, N=15)



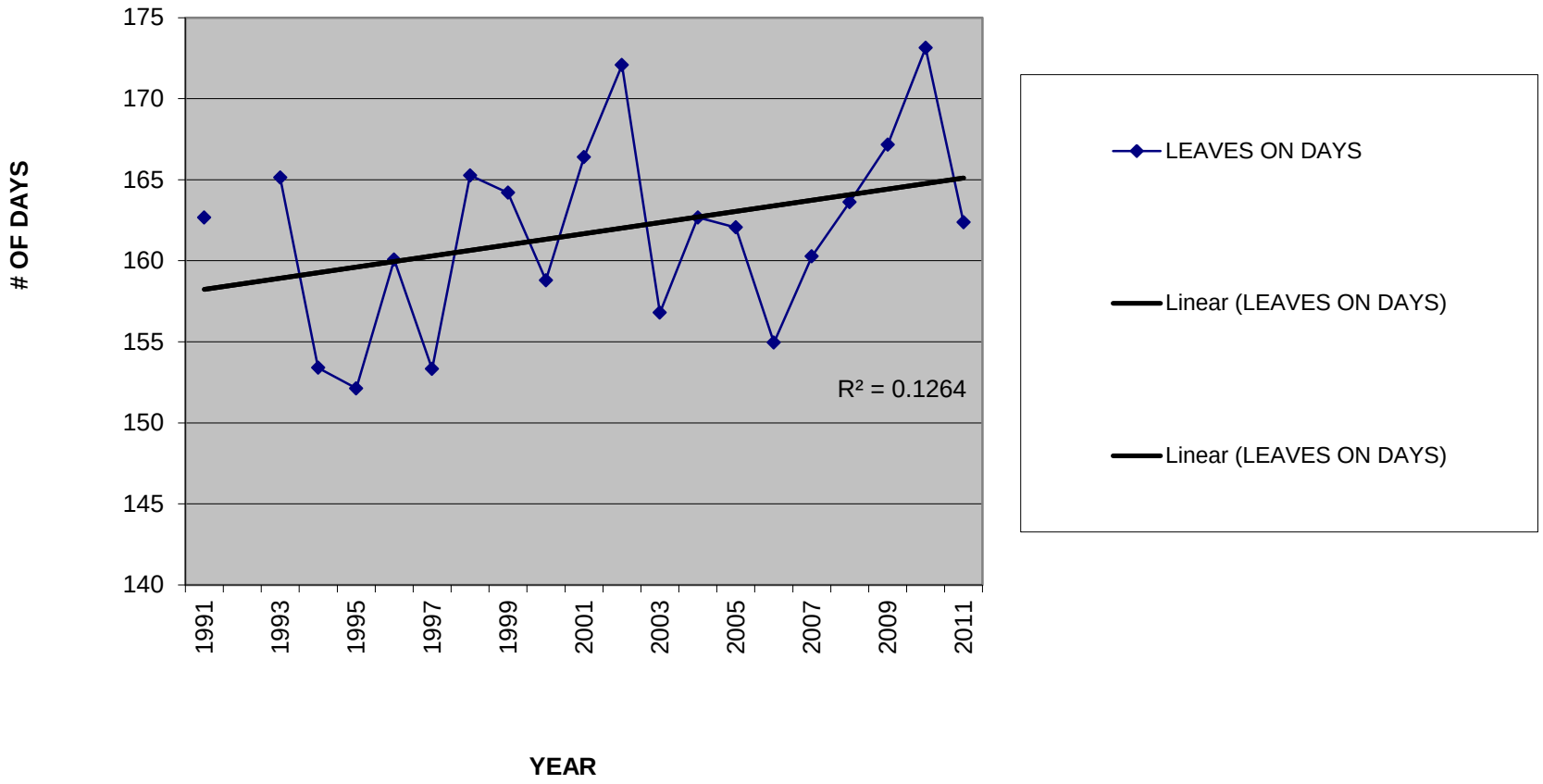
LEAVES ON DAYS (4 SPP, N=15)

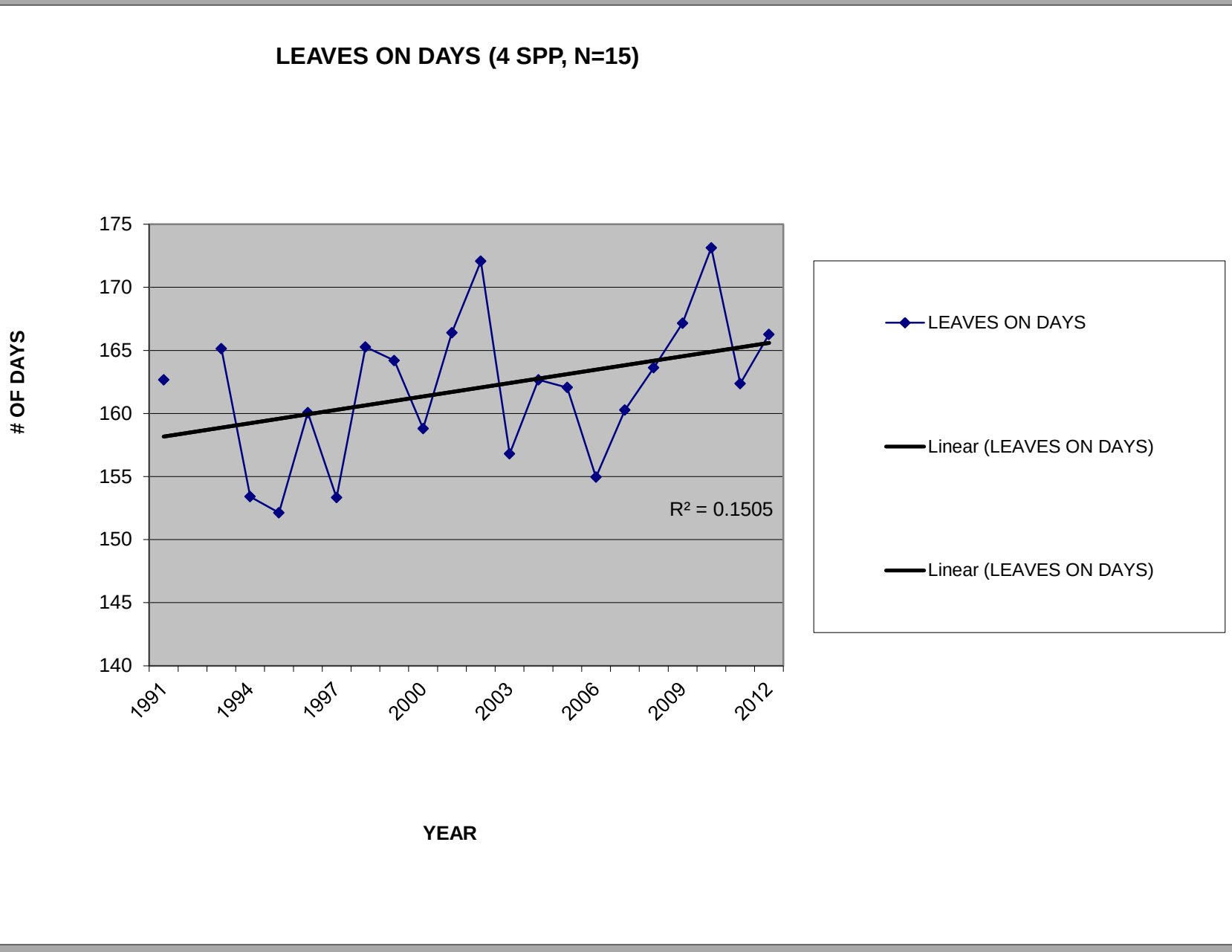


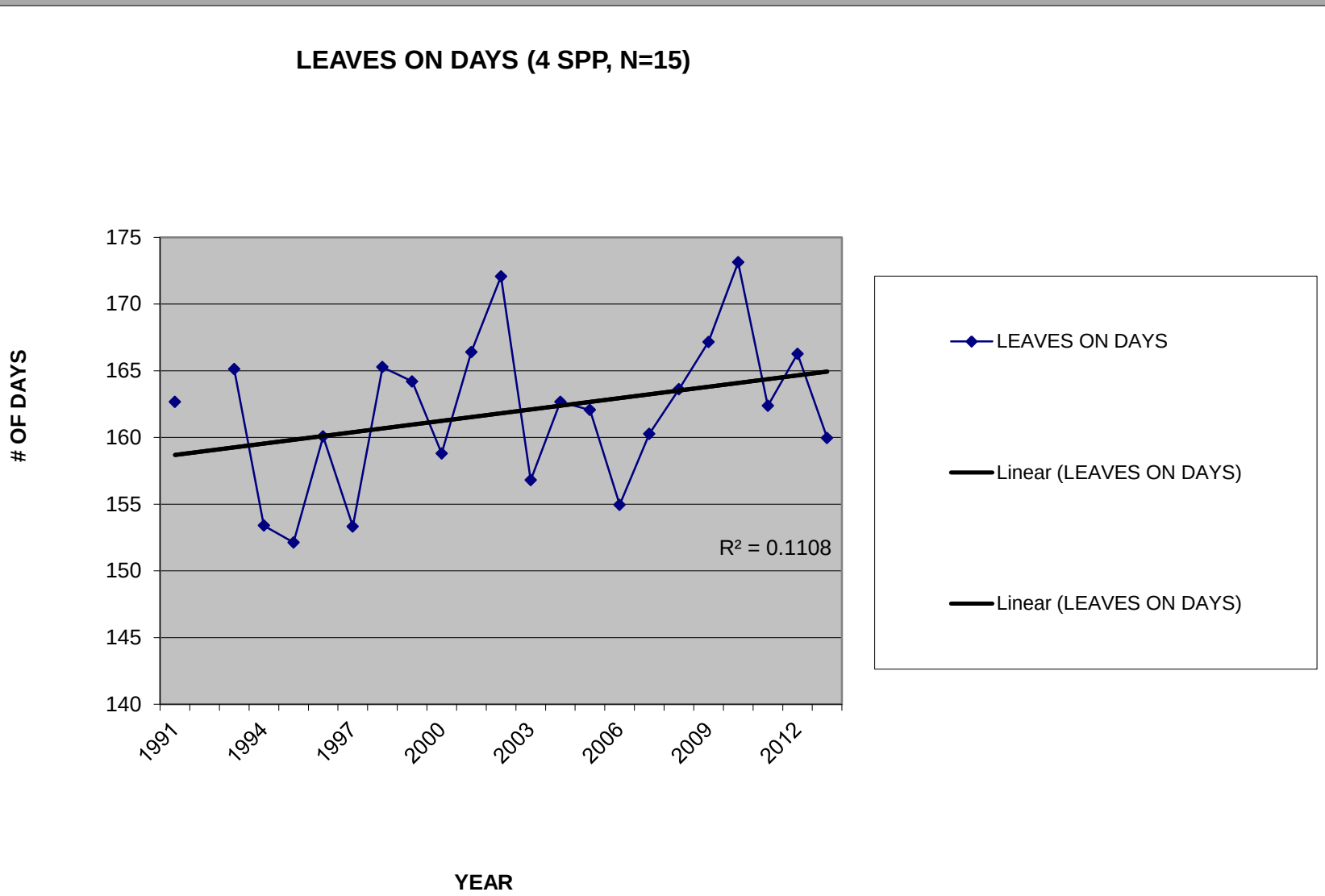
LEAVES ON DAYS (4 SPP, N=15)



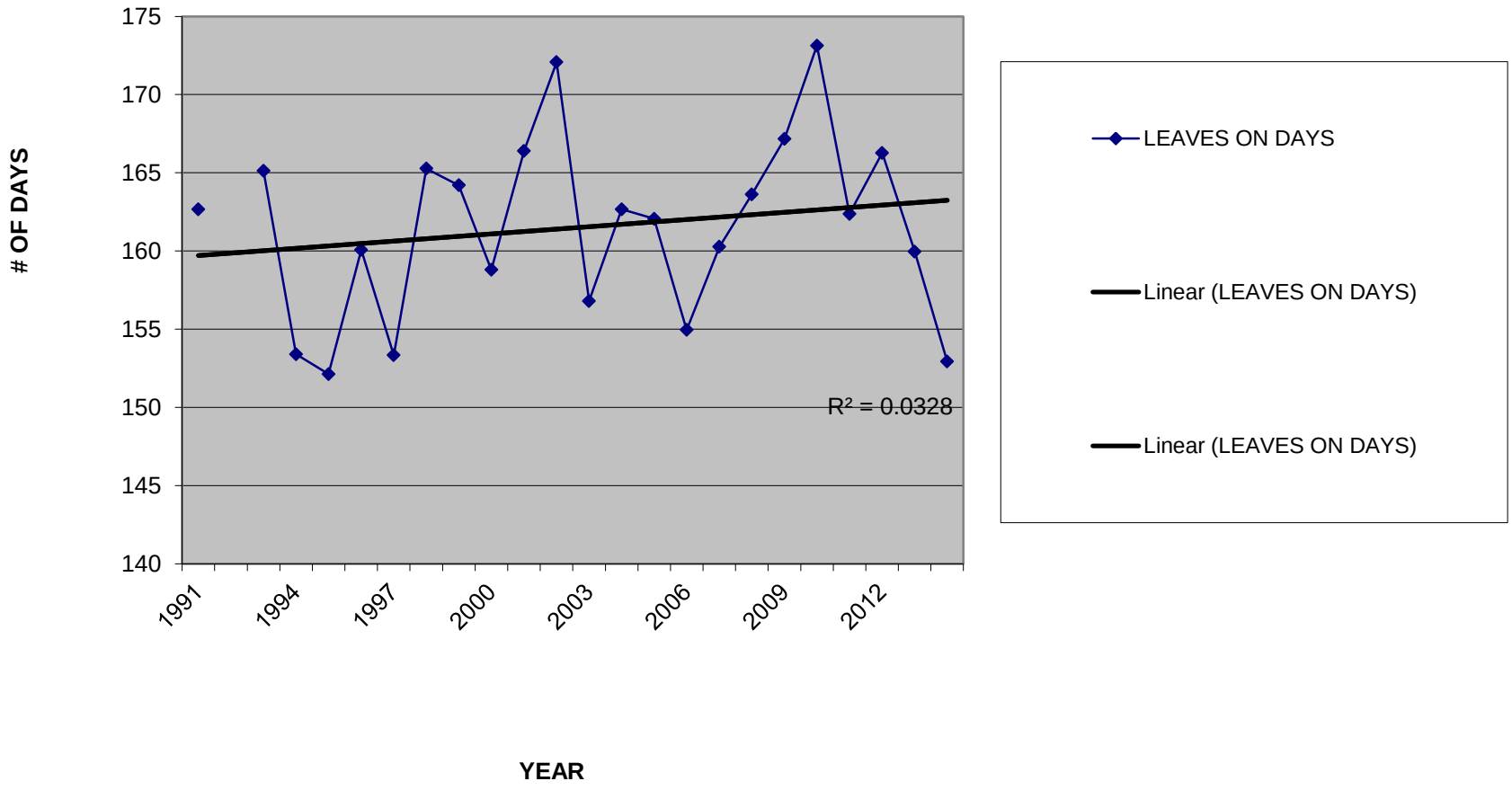
LEAVES ON DAYS (4 SPP, N=15)



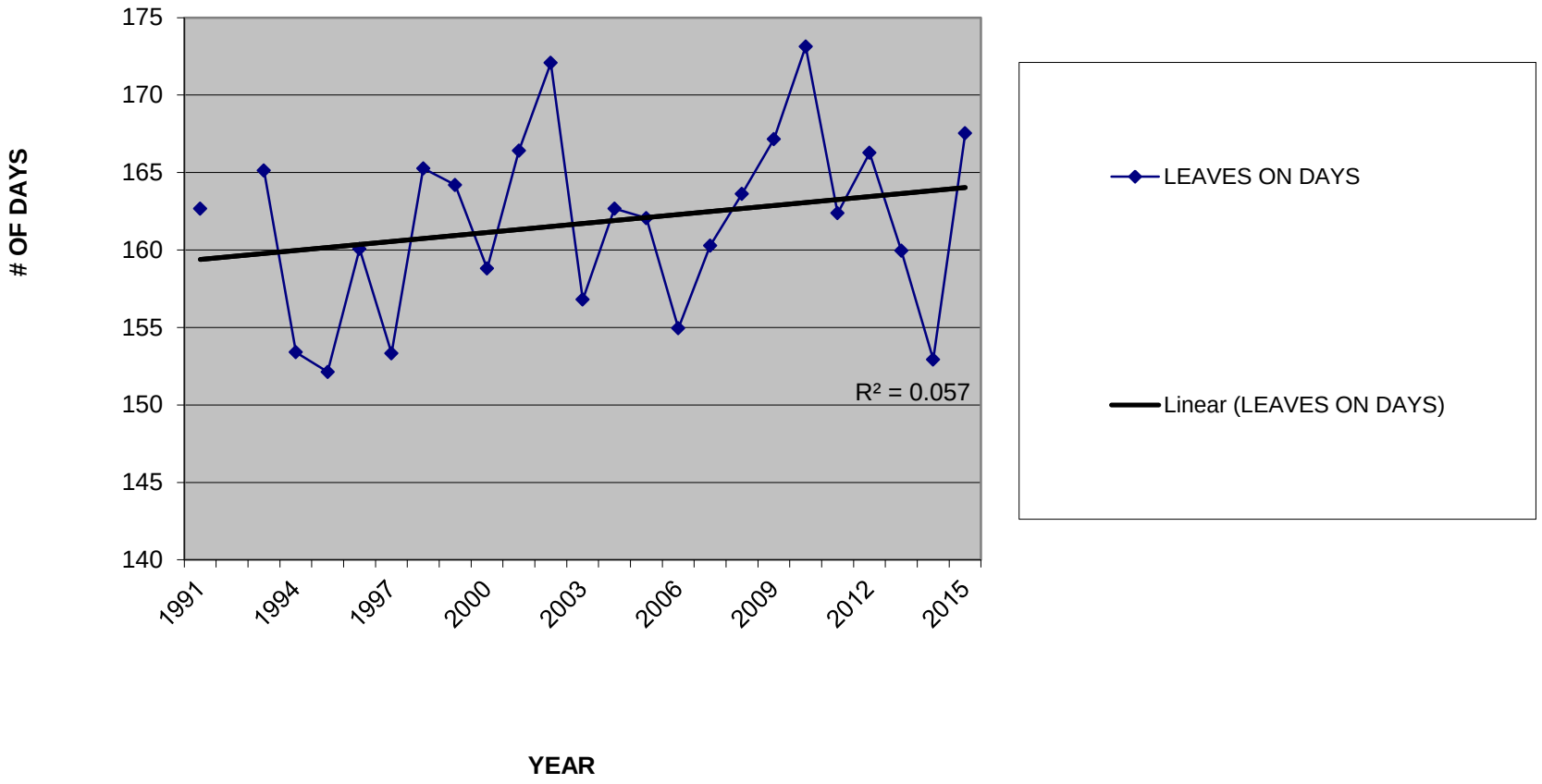

LEAVES ON DAYS (4 SPP, N=15)
OF DAYS
175
170
165
160
155
150
145
140
1991
1994
1997
2000
2003
2006
2009
2012
R² = 0.1505
YEAR
LEAVES ON DAYS
Linear (LEAVES ON DAYS)
Linear (LEAVES ON DAYS)


LEAVES ON DAYS (4 SPP, N=15)
OF DAYS
175
170
165
160
155
150
145
140
1991
1994
1997
2000
2003
2006
2009
2012
R² = 0.1108
YEAR
LEAVES ON DAYS
Linear (LEAVES ON DAYS)
Linear (LEAVES ON DAYS)

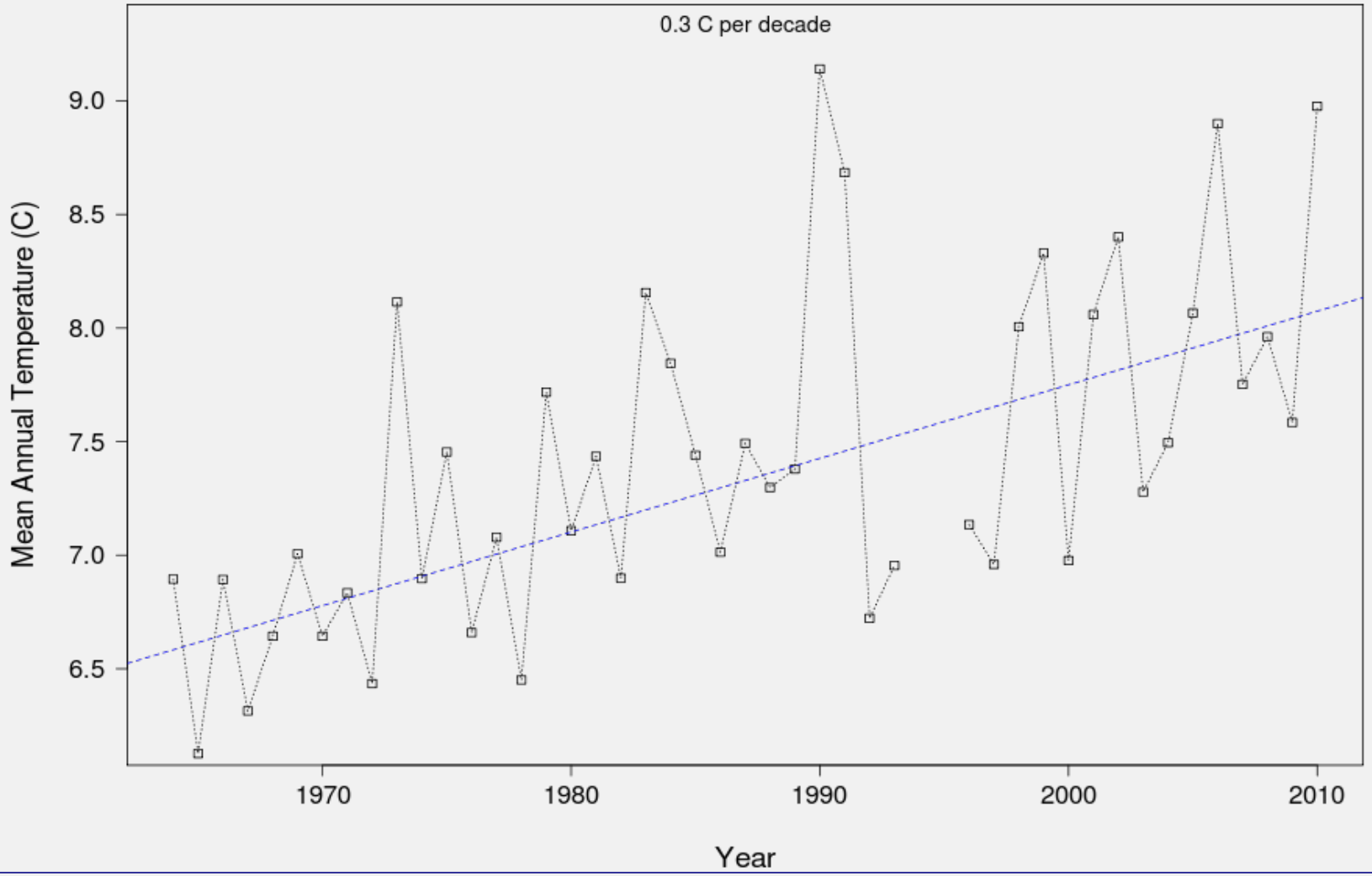
LEAVES ON DAYS (4 SPP, N=15)



LEAVES ON DAYS (4 SPP, N=15)

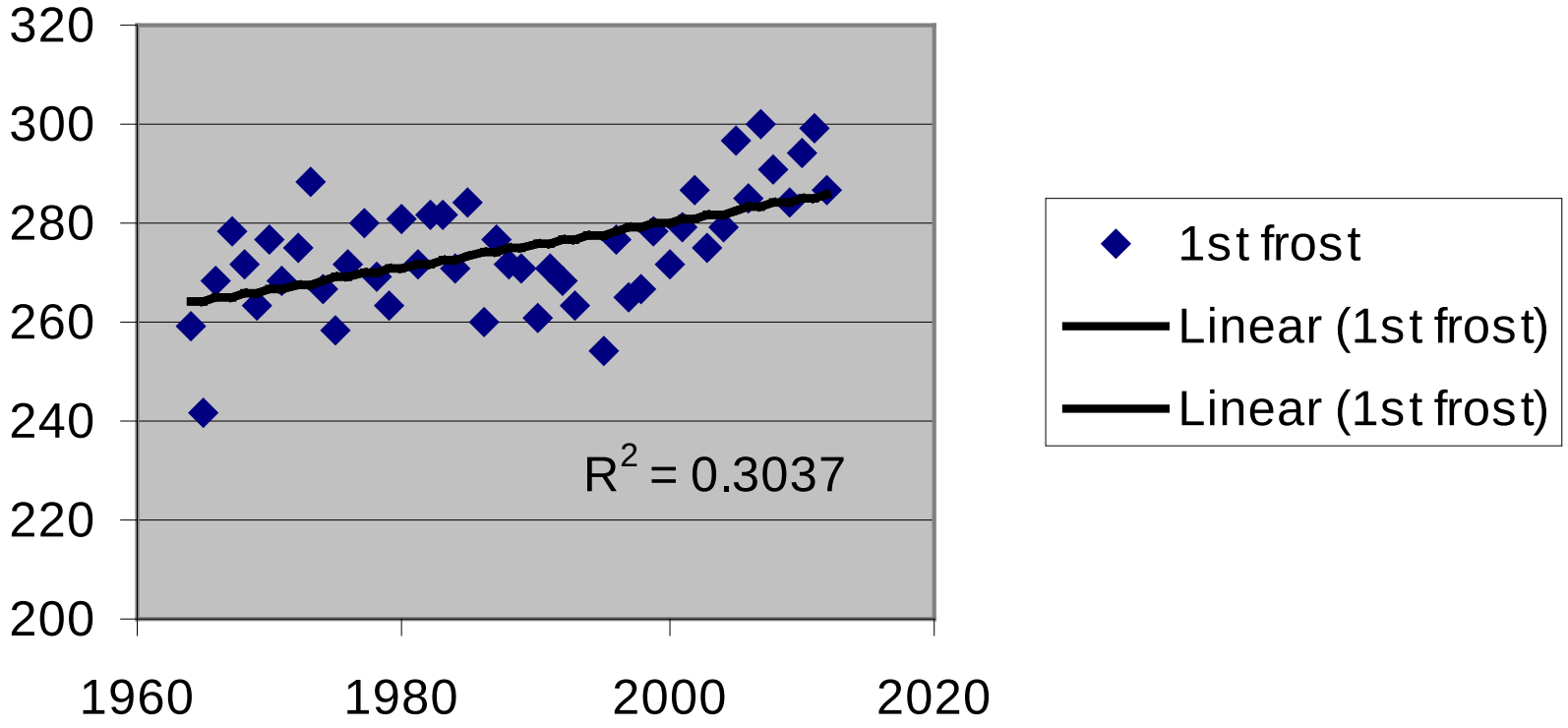


Mean Annual Temperature at Harvard Forest Meteorological Station



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

1st frost (day of year) 1964-2012



NOAA's top ten warmest global monthly departures from average

1] 0.90°C, Mar 2015
1] 0.90°C, Feb 2015
3] 0.89°C, Jan 2007
4] 0.88°C, June 2015
5] 0.87°C, Feb 1998
6] 0.86°C, May 2015
7] 0.85°C, Mar 2010
8] 0.84°C, Dec 2014
9] 0.83°C, Nov 2013
9] 0.83°C, Apr 2010

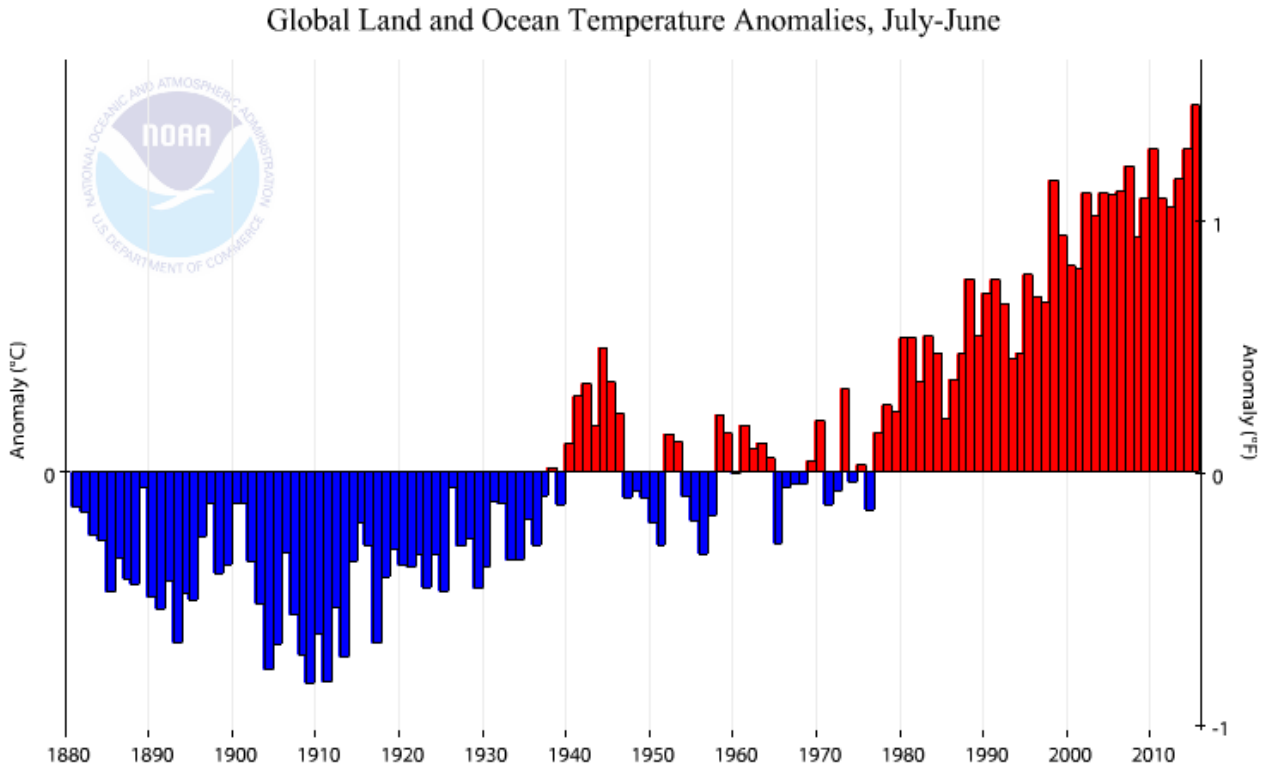
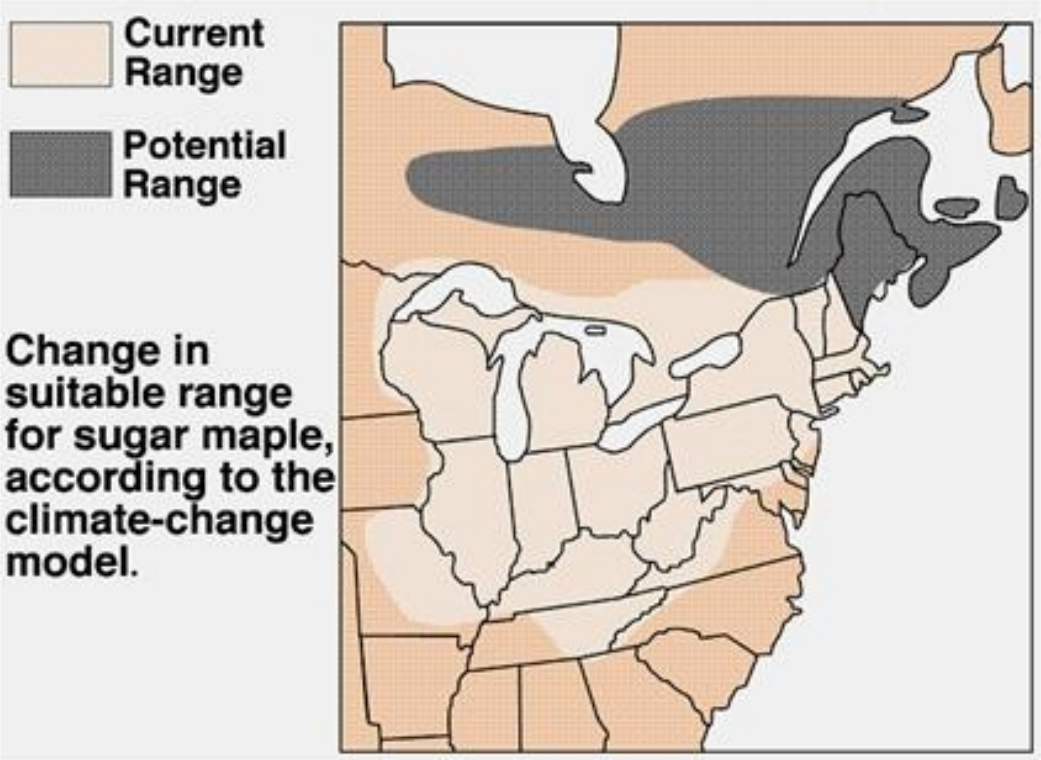


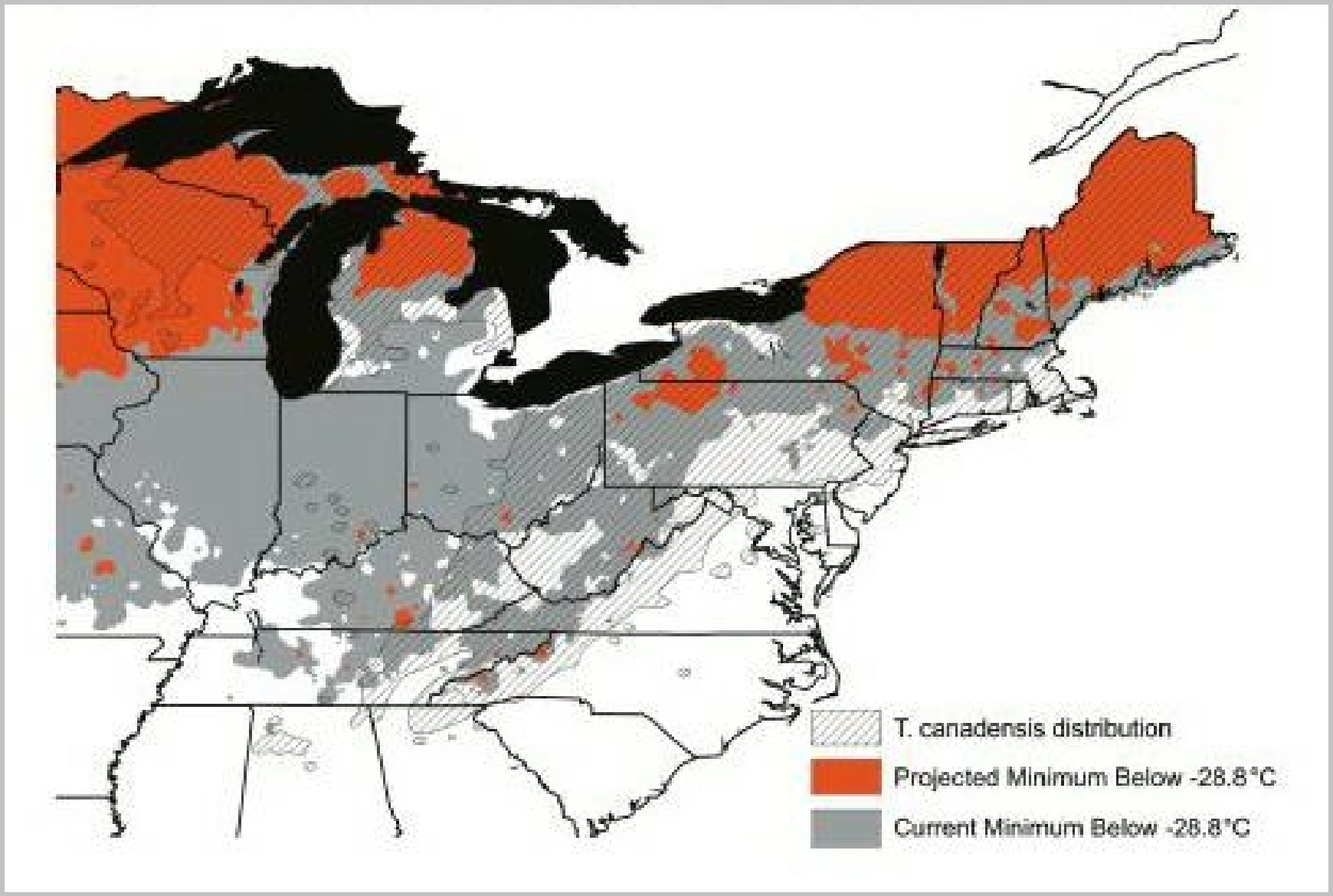
Figure 1. Departure of temperature from average for the globe for 12-month periods ending in June each year, starting in 1880 and ending in 2015. There is no evidence of a long term slow-down in global warming. Image credit: NOAA.

Impacts of Climate Warming

Some climate models predict that most of New England will be outside the range of sugar maple by the end of this century



The occurrence of temperatures cold enough to limit the survival of hemlock woolly adelgid will be greatly reduced in central New England



Choosing a Site and Trees

- **Sites** with a variety of native trees (when possible) 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.

A site with maples and birches having many branches within easy reach for this study.

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, boxelder(ashleaf maple), 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 for that tree, 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 or tape (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.

Tagging a gray birch branch

Tag placed below the sixth leaf/bud (not counting the terminal leaf/bud).

Fall Data Collection

- Start data collection about the second week in Sept. and continue until all leaves have fallen or turned brown (many oaks and beech), in late Oct. or early Nov.
- Try to collect data once a week.
- Each student team will observe the 6 leaves closest to the branch tip (skipping the terminal leaf if there is one) that have been previously labeled.
- On the first visit they will also measure the length (not including the petiole or stem) and width of the leaves for comparison in the spring, being careful not to pull any leaves off.
- On the first visit it is also very helpful to have the students sketch the branch and leaves. This makes them look closely and helps them identify the study leaves on future visits.
- They will record approximately what fraction (see data sheet) of each leaf is not green or if the leaf has fallen.
- They will record what fraction of the leaves on the whole tree are not green.
- 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

Autumn Student Data Sheet

March 2016

Name: _____ **Date:** _____

Teacher: _____ **School:** _____

Tree Species: _____ **Tree ID Number:** _____

Total Number of Leaves Observed per branch: _____

Total Number of Leaves Fallen per branch: _____

Teacher Note: Remember that the branch totals above must be added with the branch totals from all branches of the same tree to get the total number of leaves dropped per tree to submit to Harvard Forest database.

Fraction/ Percent Color Key

Color Code	Fraction of Tree that has Changed Color
1	0 – 25%
2	26-50%
3	51-75%
4	76-100%

Whole Tree Color: Look at the entire tree canopy and estimate how much of the tree has changed color.

Whole Tree Color Code: _____

Individual Leaf Color: What percent of each leaf on your study branch has changed color?

Leaf Color Codes:

Leaf #	Color Code
1	
2	
3	
4	
5	
6	

See Reverse for Leaf Measurement Table and Optional Field Notes…

Leaf Length: Measure Leaf Length only once in the beginning of the fall season

	Leaf 1	Leaf 2	Leaf 3	Leaf 4	Leaf 5	Leaf 6
Leaf Length(cm.)						
Leaf Width (cm.)						

Teacher Note: Leaf Length data will not be entered onto Harvard Forest Database. We recommend that students measure leaves in order to have an opportunity to practice measurement skills and to get a benchmark for leaf length that will serve as a guideline when leaf measurement is required in the spring protocol.

Optional Field Notes: Sometimes observations about weather, animal sign, or plant flowering times, herbaceous plant presence, etc. are helpful in understanding phenology and/or natural areas more fully. If you have time, jot down some field notes here.

Weather Notes:

Animal Notes:

Plant Notes:

Other:

Buds, Leaves and Global Warming

John O’Keefe

Harvard Forest

jokeefe@fas.harvard.edu

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