An Ecological Study of American Ginseng (*Panax quinquefolius* L.) in the Missouri Ozark Highlands:

Effects of Herbivory and Harvest and Wild Simulated Cultivation

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Presentation outline:

Part I: Seed germination trials

Part II: Effects of herbivory by white-tailed deer

Part III: Effects of harvest

Part IV: Time for seedling to mature

Part V: Distribution of stages in 18 ginseng populations

Part I – Determining optimal sowing depth

McGraw (2000) found best sowing depth in West Virginia to be 2 cm.

Seeds sown in four subsections of the Ozark Highlands in Franklin County, Osage County, Boone County and Maries County.

Sites chosen were northeast facing slopes (20% to 40%) with canopy closure of 80% or more.

Seeds were sown in Nov 2003 and Nov 2004.

Plots were monitored weekly from mid April to late May in 2004 and 2005.

Five quarter meter plots were established at each location.

Stratified seeds were sown at 7 treatment depths: 0 cm to 6 cm.

Treatment depth was assigned using a randomized Latin square.

2	1	5	3	4	0	6
6	5	2	0	1	4	3
0	6	3	1	2	5	4
5	4	1	6	0	3	2
4	3	0	5	6	2	1
1	0	4	2	3	6	5
3	2	6	4	5	1	0

49 seeds were sown in each quarter meter square (= 245 per location and 980 total).

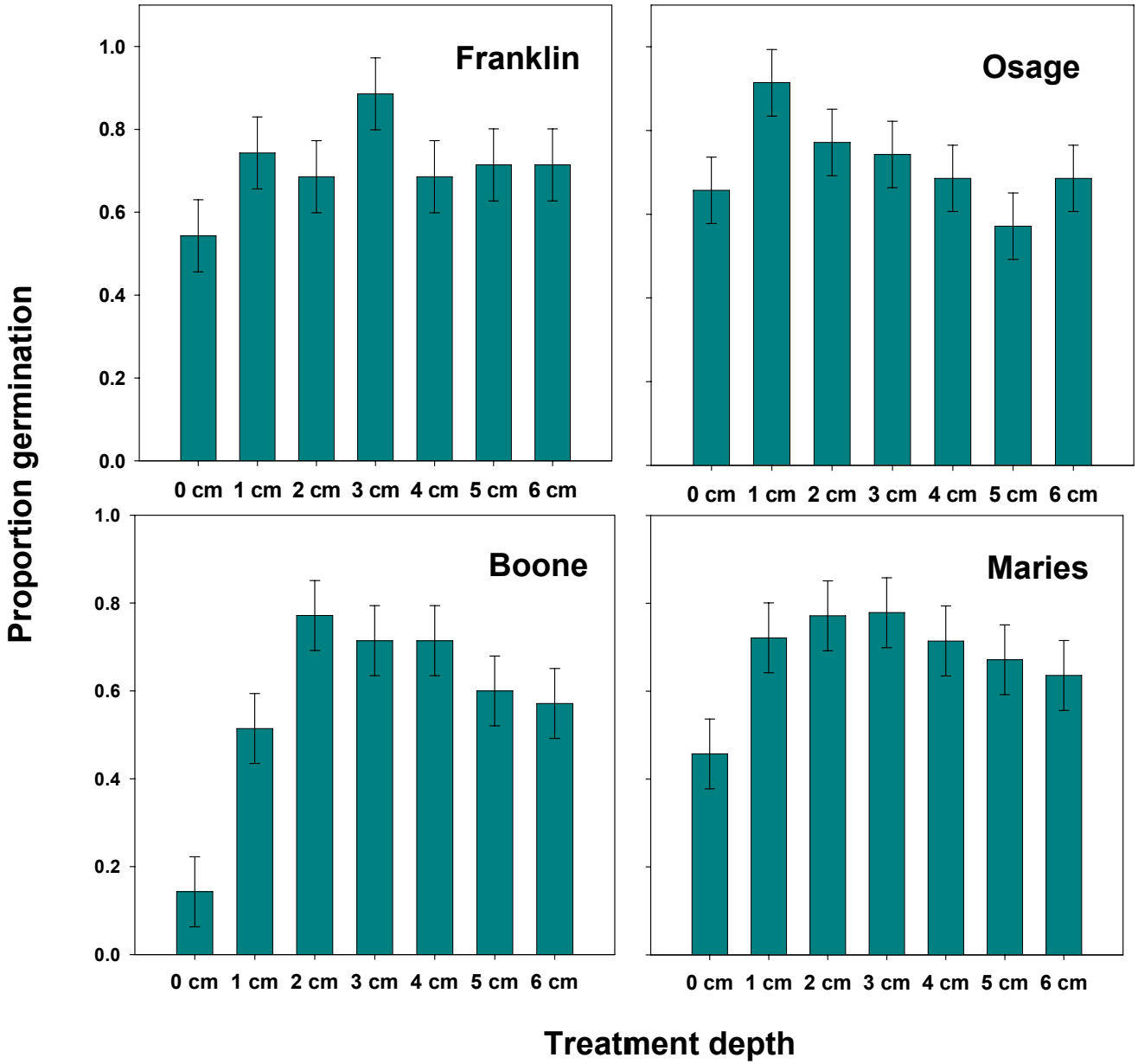
Seeds were spaced 8 cm apart in each direction.

Results of ANOVA*
2003 Cohort

Source	*df*	*SS*	*MS*	*F*	*p*
Location	3	1.29	0.431	5.61	**0.00012**
Depth	6	3.84	0.639	8.33	**<.0001**
Loc * Depth	18	2.97	0.165	2.15	**0.0077**
Column	24	1.57	0.066	0.85	0.6624
Row	24	1.72	0.072	0.93	0.5562
Error	120	20.6			

*Germination proportions were arcsine square-root transformed

Mean germination of 2003 cohort at 4 locations

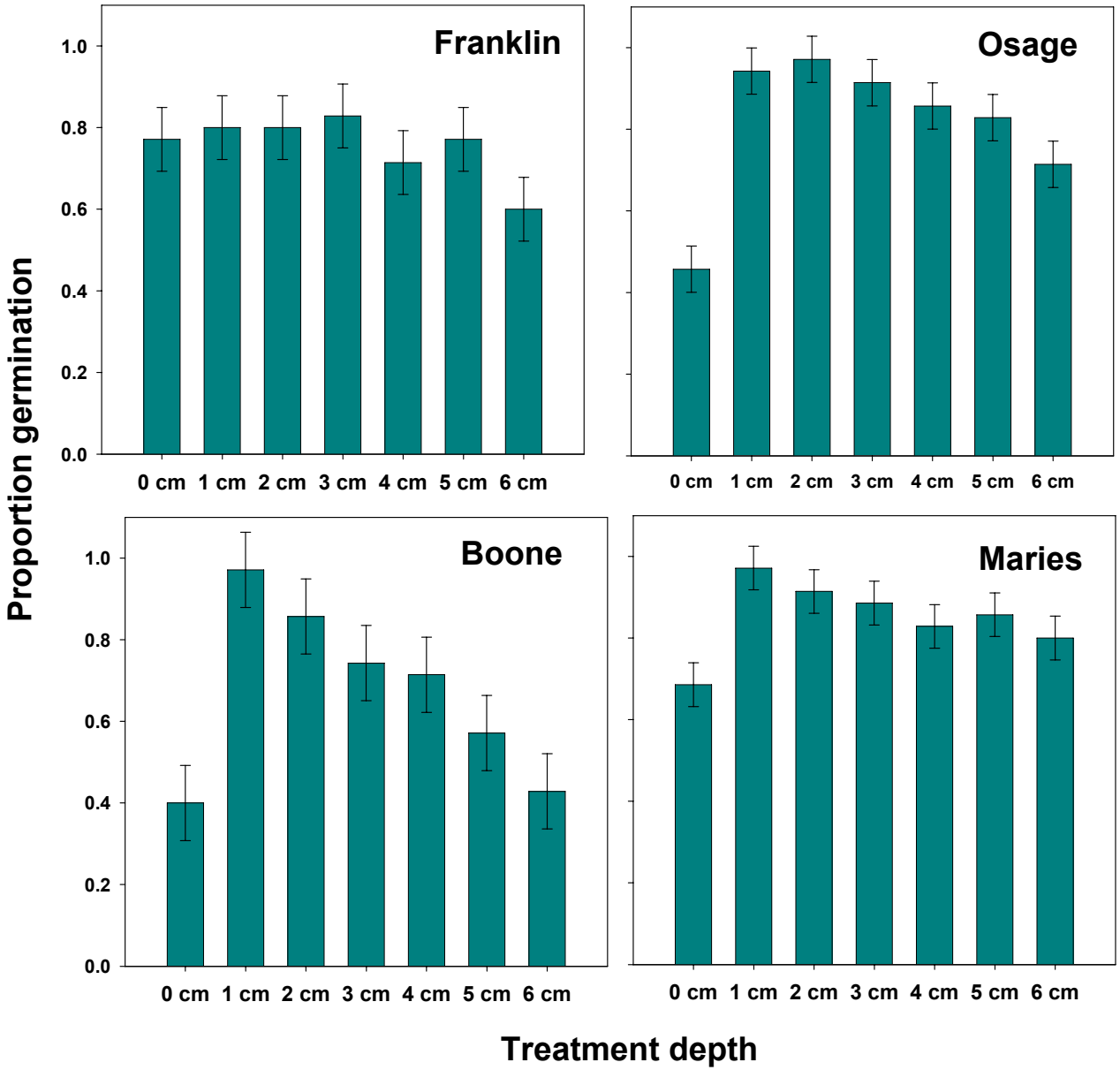


Results of ANOVA*
2004 Cohort

Source	*df*	*SS*	*MS*	*F*	*p*
Location	3	1.77	0.593	7.10	**0.0002**
Depth	6	6.25	1.042	12.5	**<.0001**
Loc * Depth	18	2.36	0.131	1.57	0.0776
Column	24	2.71	0.112	1.36	0.1446
Row	24	2.30	0.096	1.15	0.3031
Error	120	25.4			

*Germination proportions were arcsine square-root transformed

Mean germination of 2004 cohort at 4 locations



Average total germination at different depths

Depth	Missouri	West Virginia*
0 cm	51.8%	10.0%
1 cm	82.1%	-
2 cm	82.9%	75.4%
3 cm	81.1%	-
4 cm	74.6%	47.3%
5 cm	71.4%	-
6 cm	63.6%	25.8%
8 cm	-	1.7%
10 cm	-	1.5%

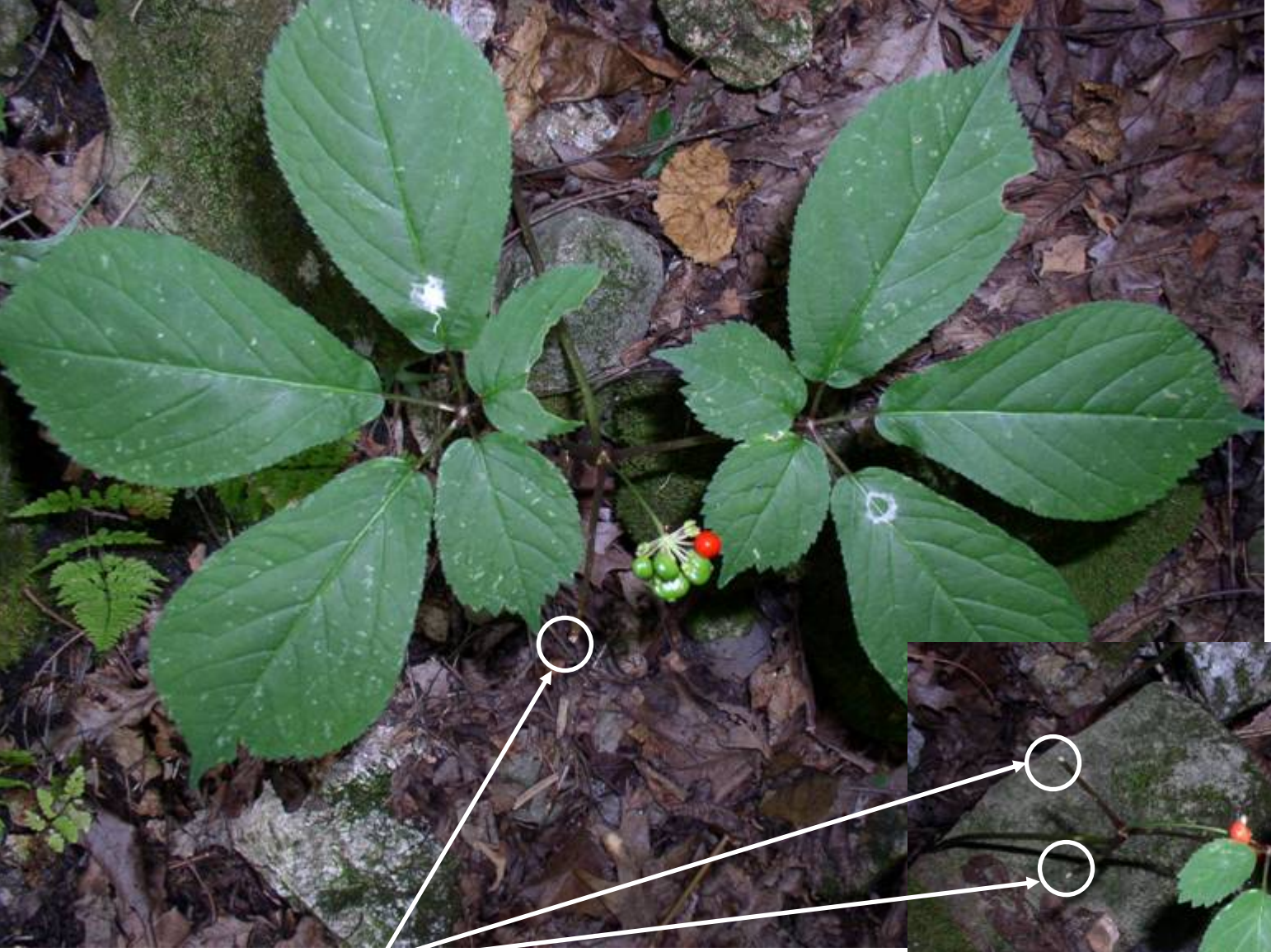
* McGraw 2000

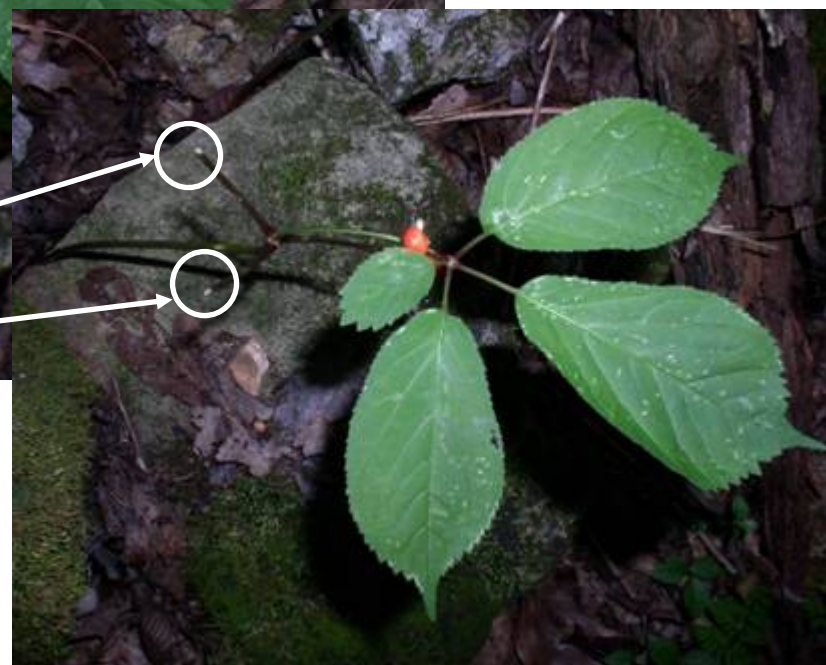
Conclusions

Best germination occurs between 1 and 3 cm (~1 inch).

If slope is not too steep and aspect is not too dry, growers sowing large amount of seeds may find broadcasting worthwhile.

Part II:
Effects of herbivory by white-tailed deer on population dynamics of American ginseng





Ginseng is not a preferred browse species: Individual leaves (“prongs”) may be browsed while others are left behind.

Nonetheless, ginseng suffers substantial deer browse

Few previous studies have used matrix population analysis to evaluate the effects of deer herbivory on plants (but see Rooney and Gross 2003,Knight 2004 and McGraw 2005)

Research Questions

1. Do deer preferentially browse larger plants?
2. Are browsed plants more likely to regress in size in the year following browse?
3. Are browsed plants more likely to remain dormant in the year following browse?
4. How does browsing affect ginseng's population dynamics (growth rate (λ), stable stage distribution, and elasticity)?

Methods

- 6 populations located within a 28 km^2 area on public land in east central Missouri

- Populations numbered from 25 to 200 plants and totaled 644 individually marked plants

- Monitoring began in 1998

Engraved aluminum nails identify each stem

Data recorded for each plant:

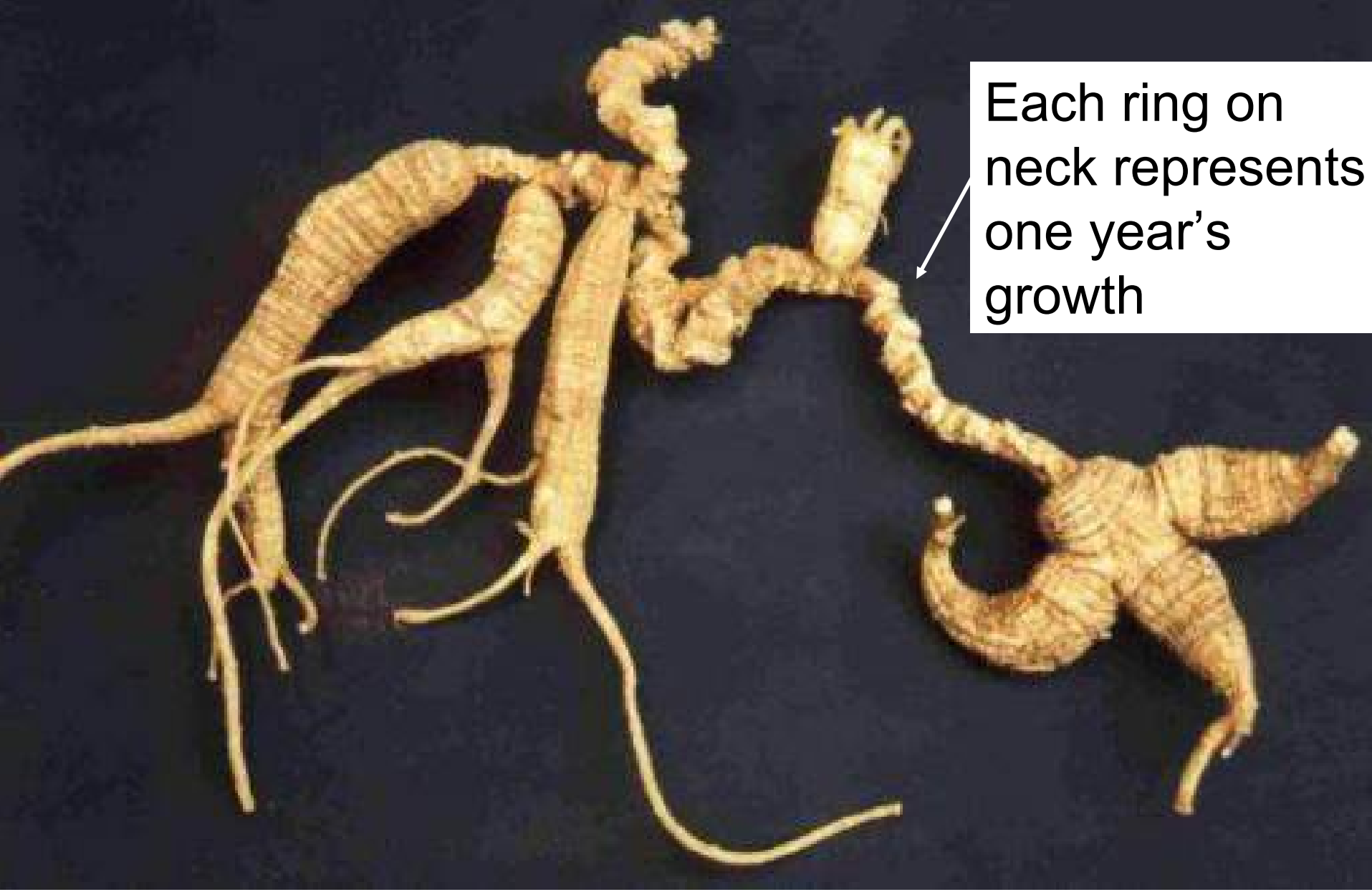
Height
# of leaves
# of leaflets
pedicels
fruit
seeds
damage and
cause of damage

Ragged torn stem indicating deer browse

Invertebrate herbivory

2.7% of the population was dormant in any given year

Dormant bud and viable root



100 year old root from Catskill Mountains

(Photo by Sylvan Botanicals http://www.catskillginseng.com)

Average annual vital rates 1999-2005

Average seed to seedling rate = 8.5%

Seedling mortality = 16.8%

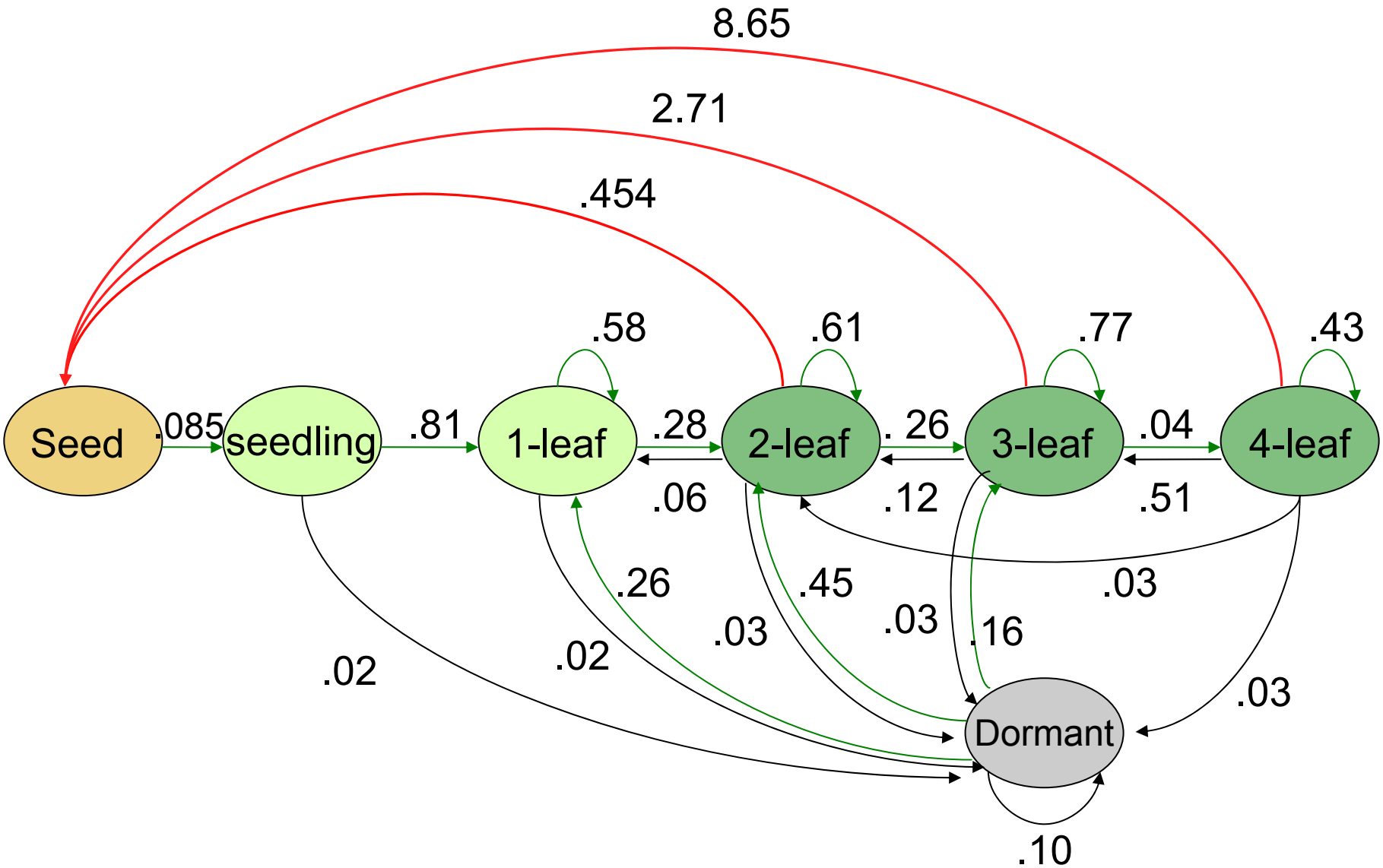
1-leaf mortality = 12.0%

2-leaf mortality = 4.3%

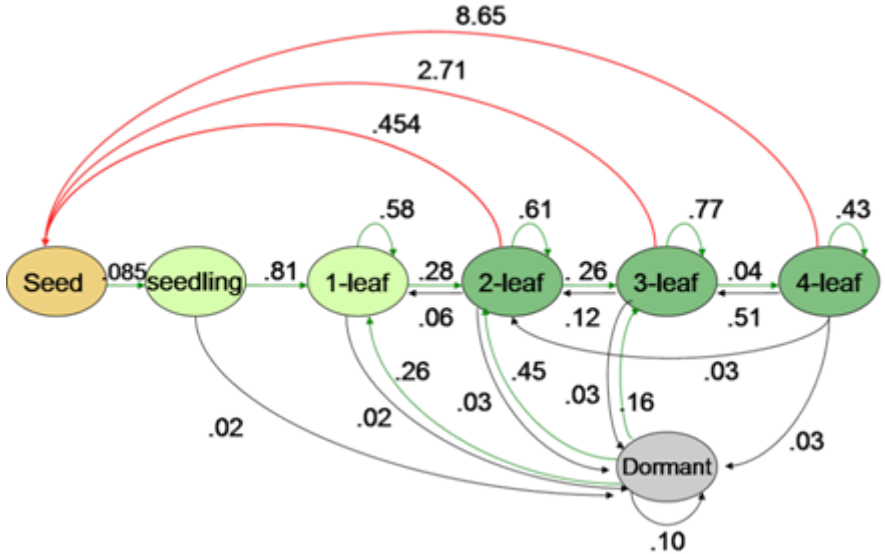
3-leaf mortality = 3.2%
(4.9% if poached plants included)

No 4-leaf plants died during the 8 years of this study

Construction of Demographic Matrix Model



Average Transition Matrix 1999-2005



Year 1

Year 2	seed	seedling	1 leaf	2 leaf	3 leaf	4 leaf	dormant
seed	**0**	**0**	**0**	**0.45**	**2.71**	**8.63**	**0**
seedling	**0.09**	**0**	**0**	**0**	**0**	**0**	**0**
1 leaf	**0**	**0.81**	**0.58**	**0.06**	**0.00**	**0**	**0.28**
2 leaf	**0**	**0.01**	**0.28**	**0.61**	**0.12**	**0.03**	**0.45**
3 leaf	**0**	**0**	**0.00**	**0.26**	**0.77**	**0.51**	**0.16**
4 leaf	**0**	**0**	**0**	**0**	**0.04**	**0.43**	**0**
dormant	**0**	**0.02**	**0.02**	**0.03**	**0.03**	**0.03**	**0.10**

What is lambda (λ)???

The projected growth rate of a population when it has reached its stable stage distribution.

This assumes that the transition rates represented in the matrix model remain the same.

$$\lambda = e^{r}$$

When lambda is greater than 1…

the population is projected to be growing.

Example: $\lambda = 1.03$

the population will increase by 3% each year

When lambda is less than 1…

the population is projected to be decreasing.

Example: $\lambda = .97$

the population will decrease by 3% each year

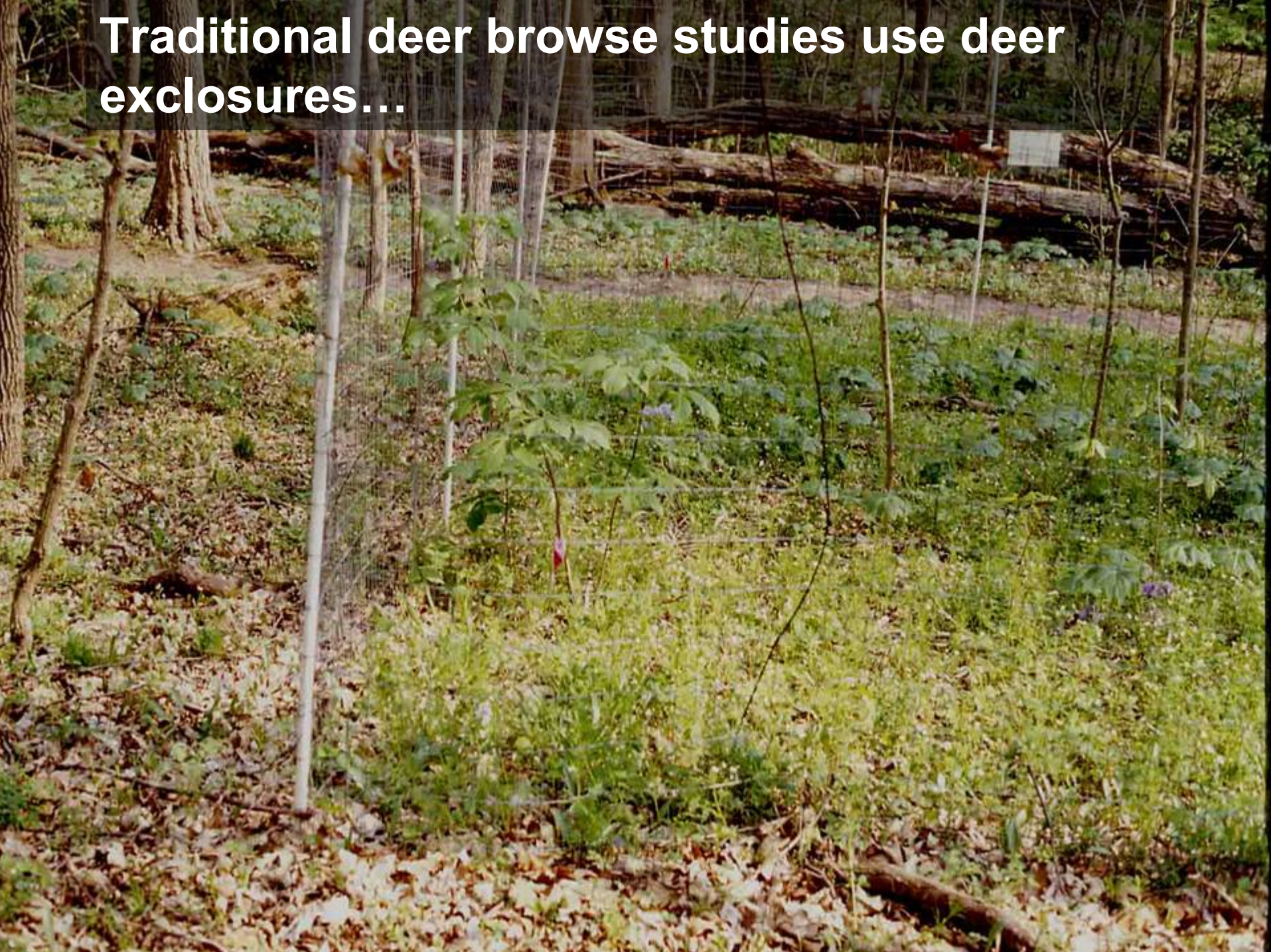
Elasticity values: show the proportional effect of small changes to each transition rate on the population growth rate.

Elasticity analysis

	seed	seedling	1 leaf	2 leaf	3 leaf	4 leaf	dormant
seed	0	0	0	0	0.02	0.01	0
seedling	0.04	0	0	0	0	0	0
1 leaf	0	0.04	0.10	0.02	0	0	0
2 leaf	0	0	0.06	0.19	0.03	0	0
3 leaf	0	0	0	0.07	0.31	0.01	0
4 leaf	0	0	0	0	0.02	0.02	0
dormant	0	0	0	0.01	0.01	0	0

LTRE (Life Table Response Experiment) Analysis:

Decomposes the observed differences in λ between two matrices based on the actual contribution of each vital rate.


Traditional deer browse studies use deer exclosures…

Instead of physically excluding the deer, we used a matrix population analysis approach to separate unbrowsed plants from th ambient population:

Ambient matrix for total population 1999-2005.

	seed	seedling	1-leaf	2-leaf	3-leaf	4-leaf	dormant
seed	0	0	0	0.45	2.71	8.63	0
seedling	0.085	0	0	0	0	0	0
1-leaf	0	0.81	0.58	0.06	0.00	0	0.28
2-leaf	0	0.01	0.28	0.61	0.12	0.03	0.45
3-leaf	0	0	0.00	0.26	0.77	0.51	0.16
4- leaf	0	0	0	0	0.04	0.43	0
dormant	0	0.02	0.02	0.03	0.03	0.03	0.10

'No herbivory' matrix for unbrowsed population 1999-05.

	seed	seedling	1-leaf	2-leaf	3-leaf	4-leaf	dormant
seed	0	0	0	0.54	3.62	13.16	0
seedling	0.085	0	0	0	0	0	0
1-leaf	0	0.81	0.58	0.06	0.00	0	0.28
2-leaf	0	0.004	0.29	0.60	0.09	0	0.45
3-leaf	0	0	0.00	0.26	0.81	0.44	0.16
4-leaf	0	0	0	0	0.04	0.53	0
dormant	0	0.02	0.02	0.03	0.03	0.03	0.10

Following method of Knight (2004)

Ambient matrix for total population 1999-2005.

	seed	seedling	1-leaf	2-leaf	3-leaf	4-leaf	dormant
seed	0	0	0	0.45	2.71	8.63	0
seedling	0.085	0	0	0	0	0	0
1-leaf	0	0.81	0.58	0.06	0.00	0	0.28
2-leaf	0	0.01	0.28	0.61	0.12	0.03	0.45
3-leaf	0	0	0.00	0.26	0.77	0.51	0.16
4- leaf	0	0	0	0	0.04	0.43	0
dormant	0	0.02	0.02	0.03	0.03	0.03	0.10

'No herbivory' matrix for unbrowsed population 1999-05.

seed	0	0	0	0.54	3.62	13.16	0
seedling	0.085	0	0	0	0	0	0
1-leaf	0	0.81	0.58	0.06	0.00	0	0.28
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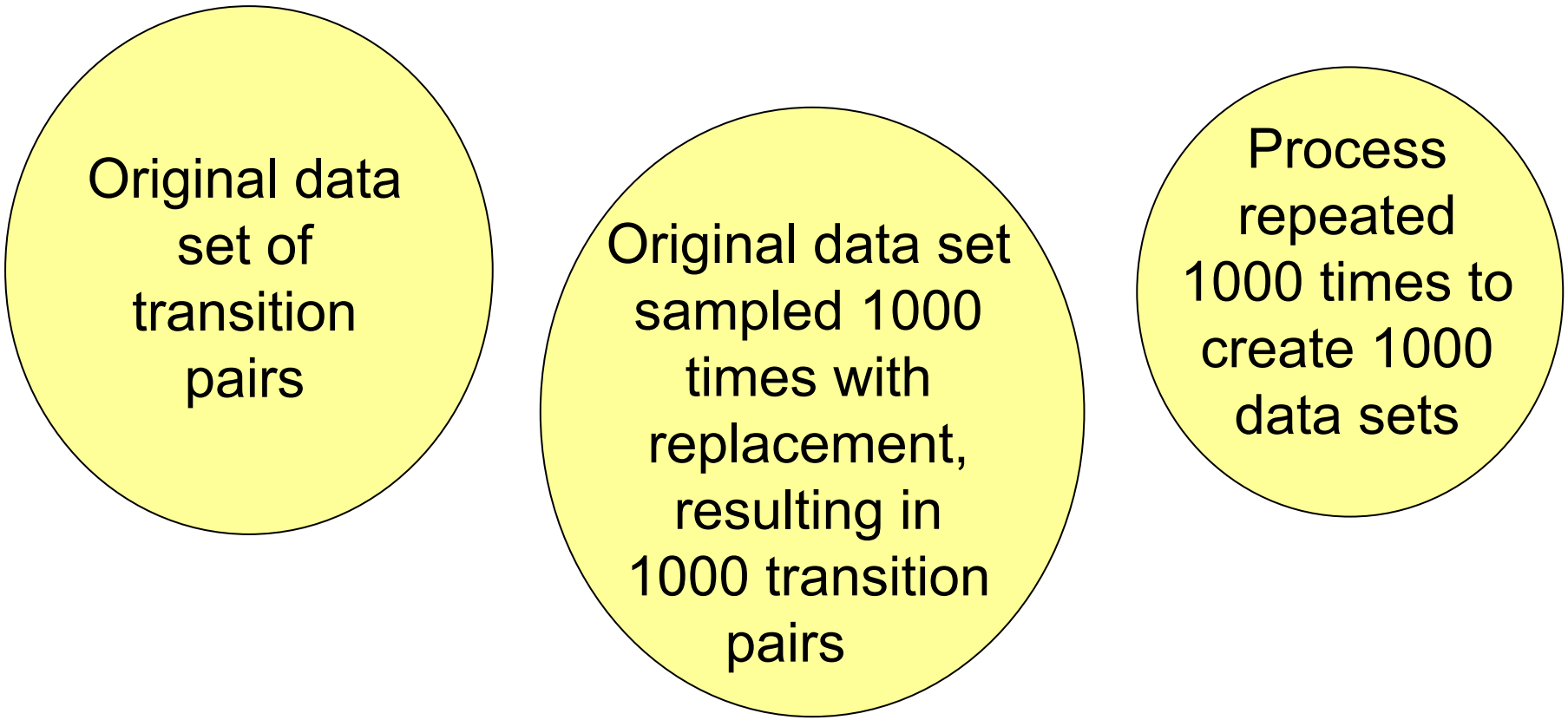
3-leaf	0	0	0.00	0.26	0.81	0.44	0.16
4-leaf	0	0	0	0	0.04	0.53	0
dormant	0	0.02	0.02	0.03	0.03	0.03	0.10

Bootstrapping



McPeek and Kalisz (1993) and Caswell (2001)

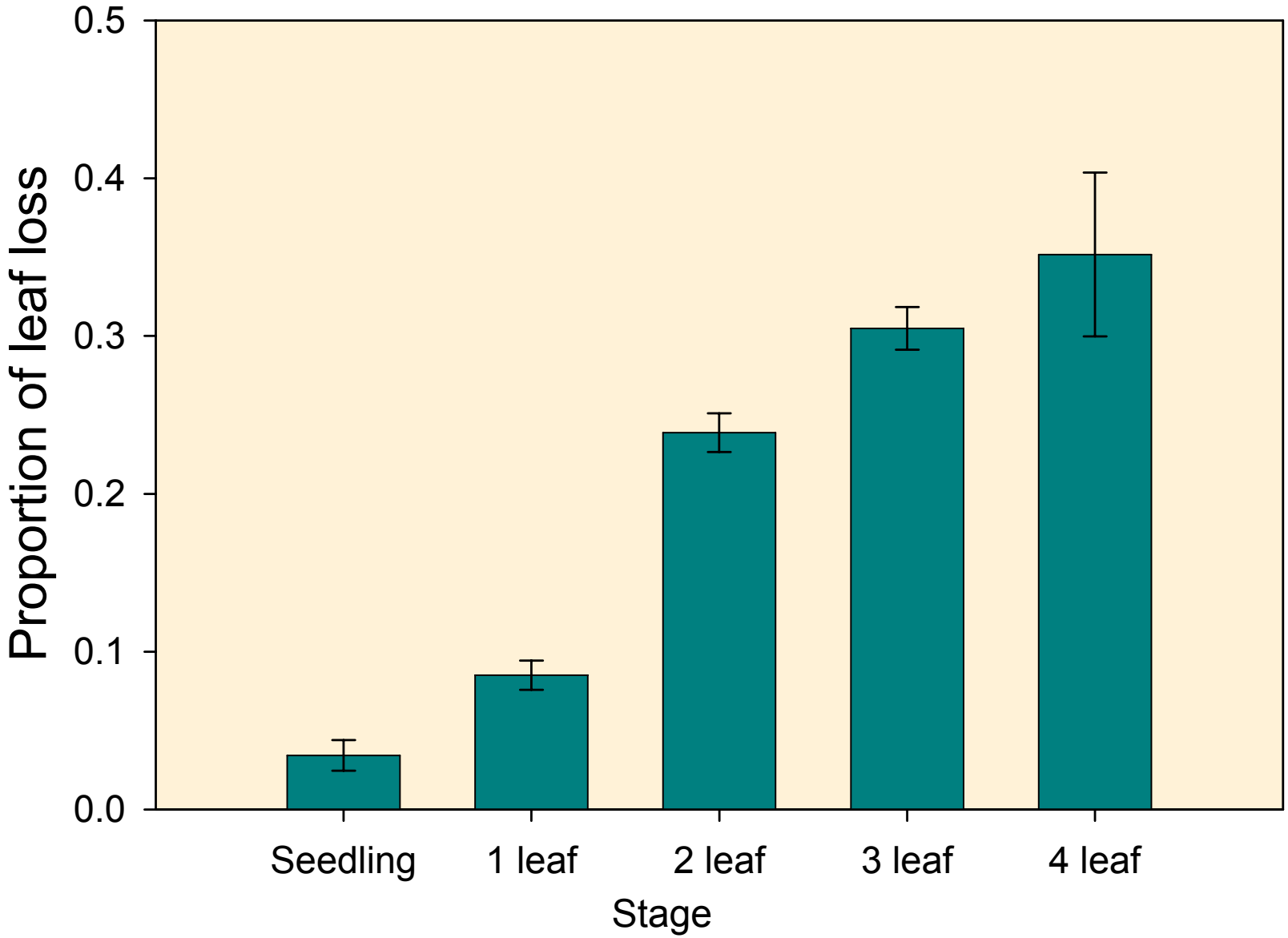
Bootstrapping

Each set of transitions was transformed into a transition matrix.

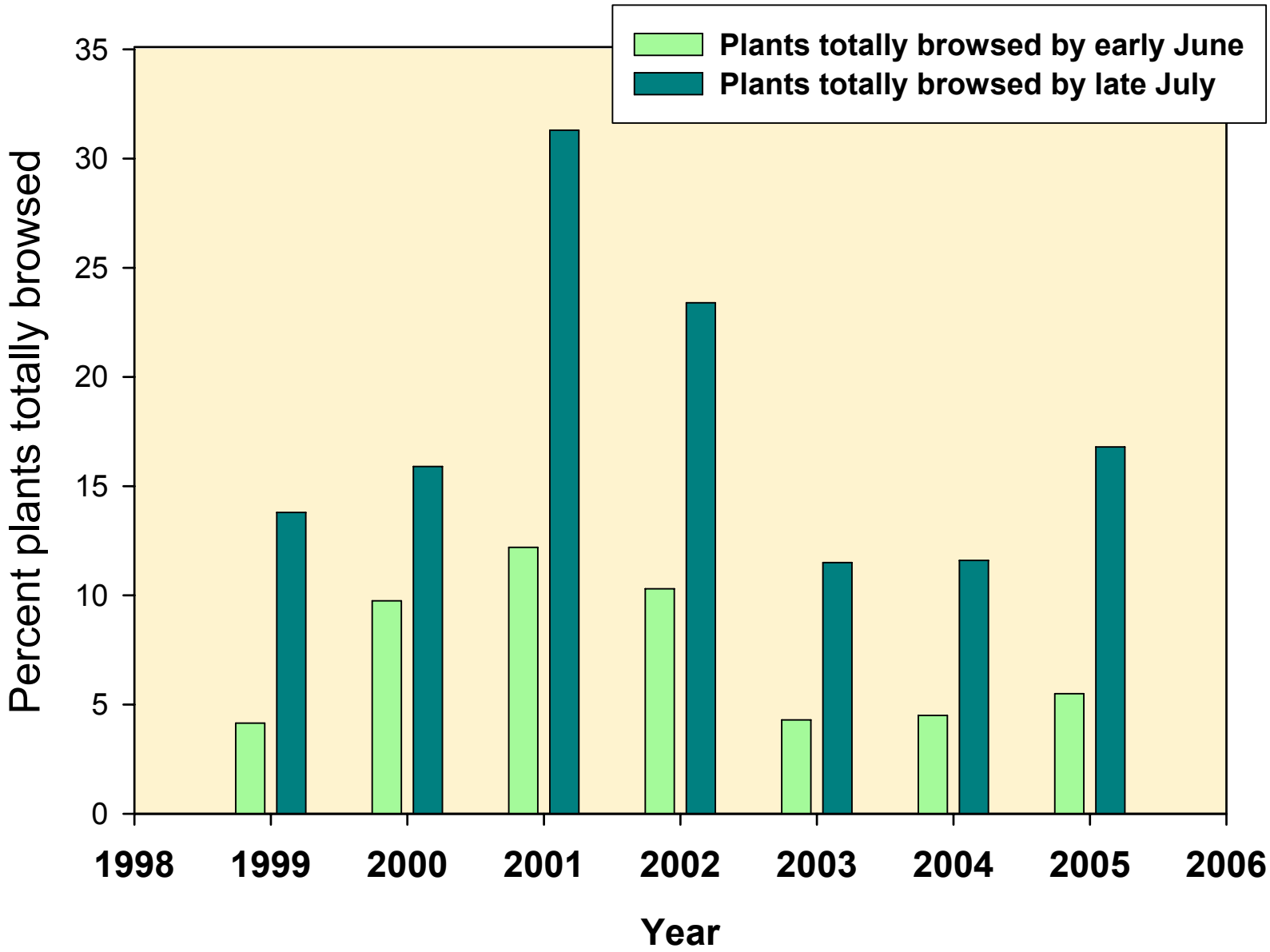
Analysis was run using program written by Dr. Tiffany Knight in Matlab (2002).

95% confidence interval was obtained by discarding lowest 2.5% and highest 2.5% estimates.

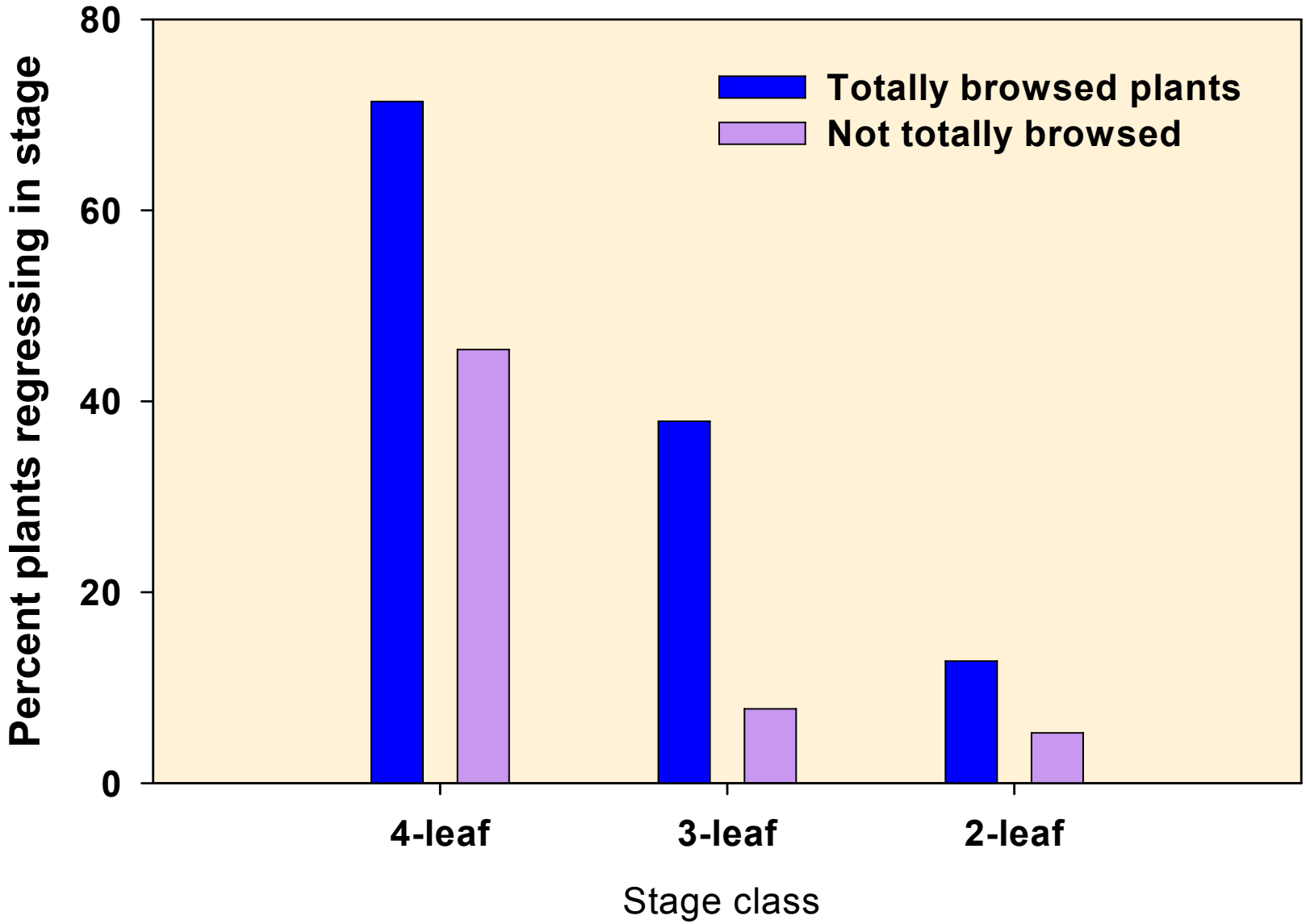
Damage by deer is significantly greater in larger plants (4, 3 and 2 leaf) than in smaller plants ($p<.001$, $df=4$).



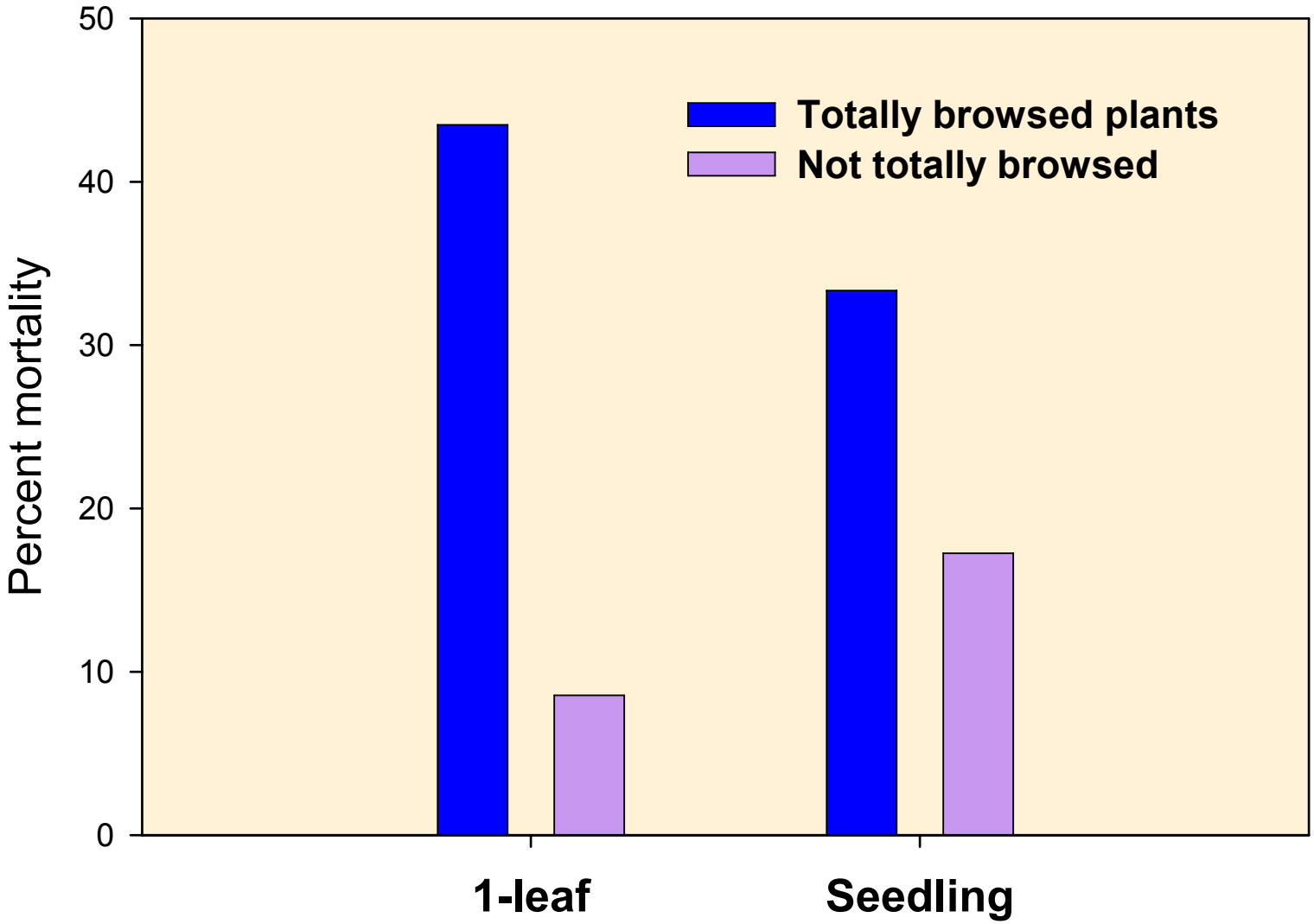
Timing of herbivory



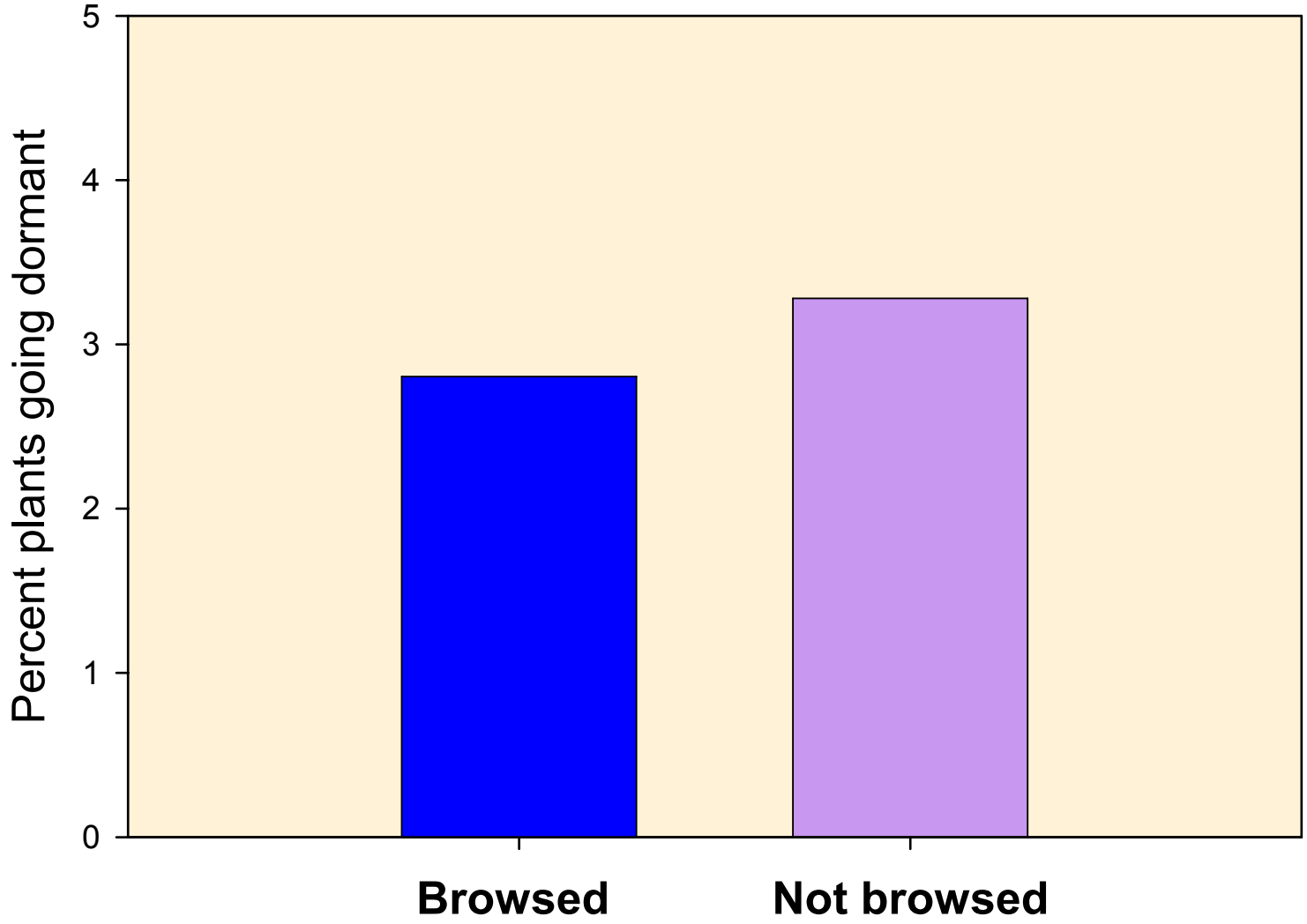
Early browsed plants are more likely to regress in size than unbrowsed plants (χ^2=58.9, df=1, p<.001)



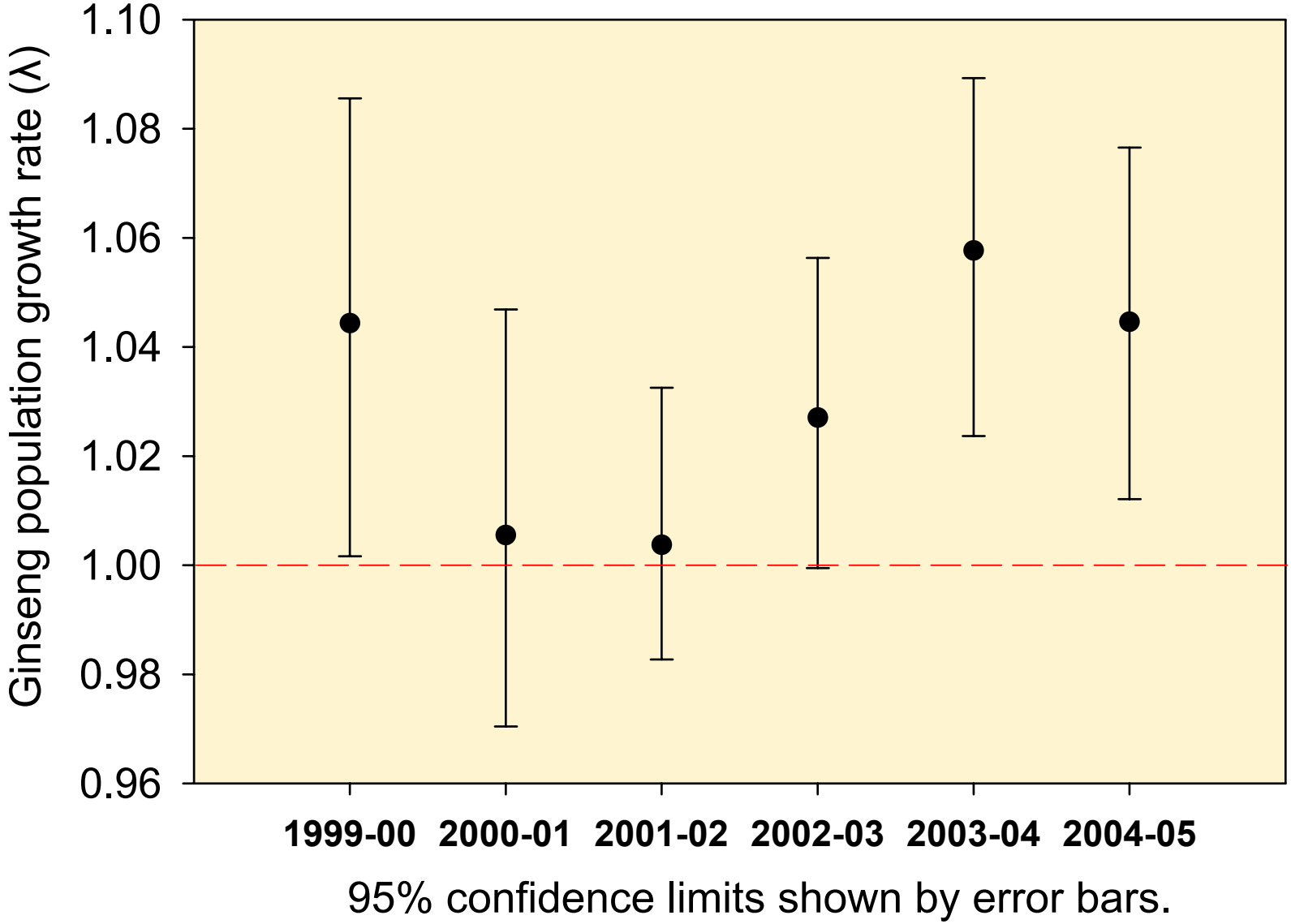
Smaller plants are more likely to die if totally browsed early in season (χ^2=24.2, df=1, p<.001)



Browsed plants are not more likely to go dormant in the year following browse (χ^2=24.2, df=1, p<.001)

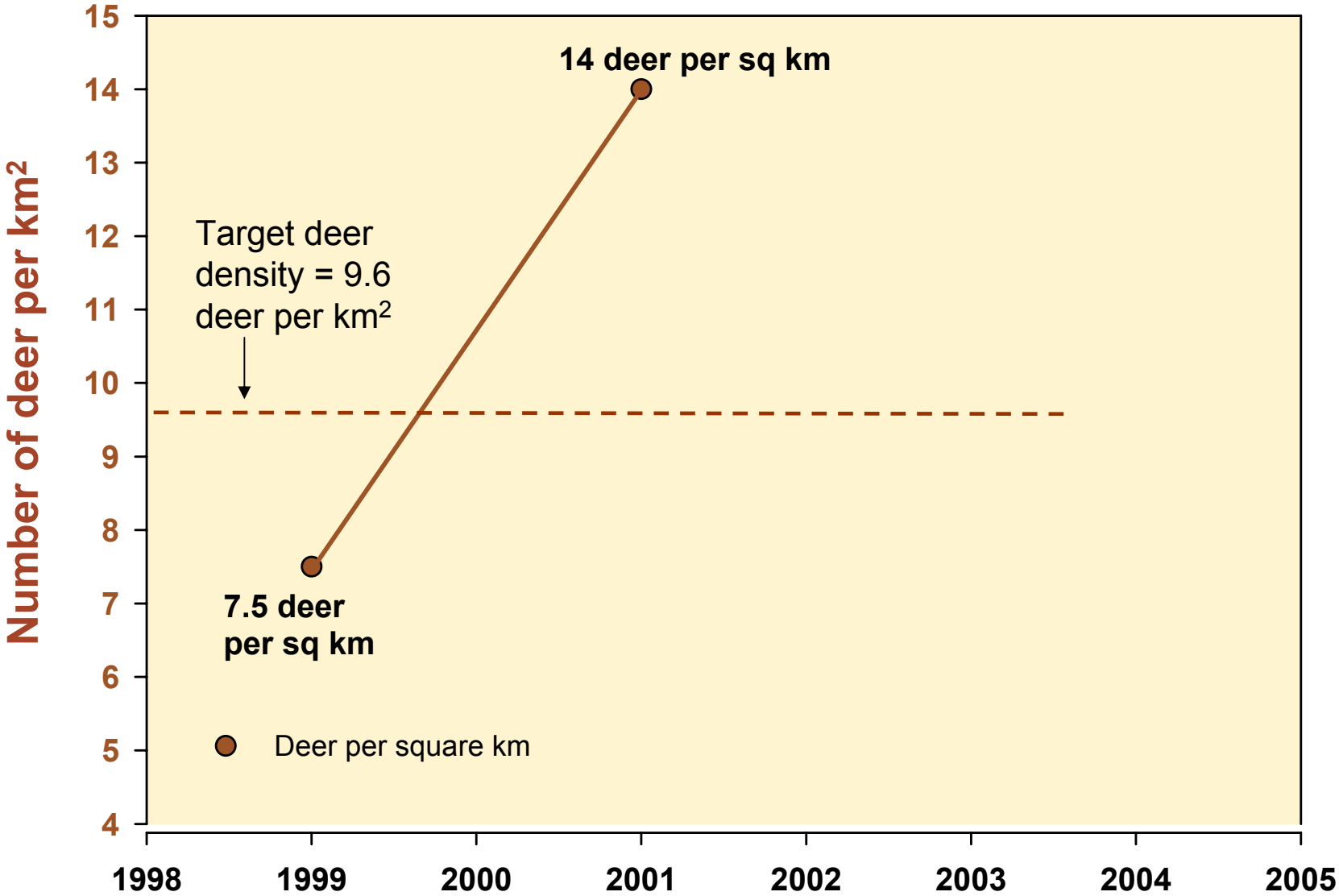


Population growth rates (λ) of ambient ginseng population 1999-2005.

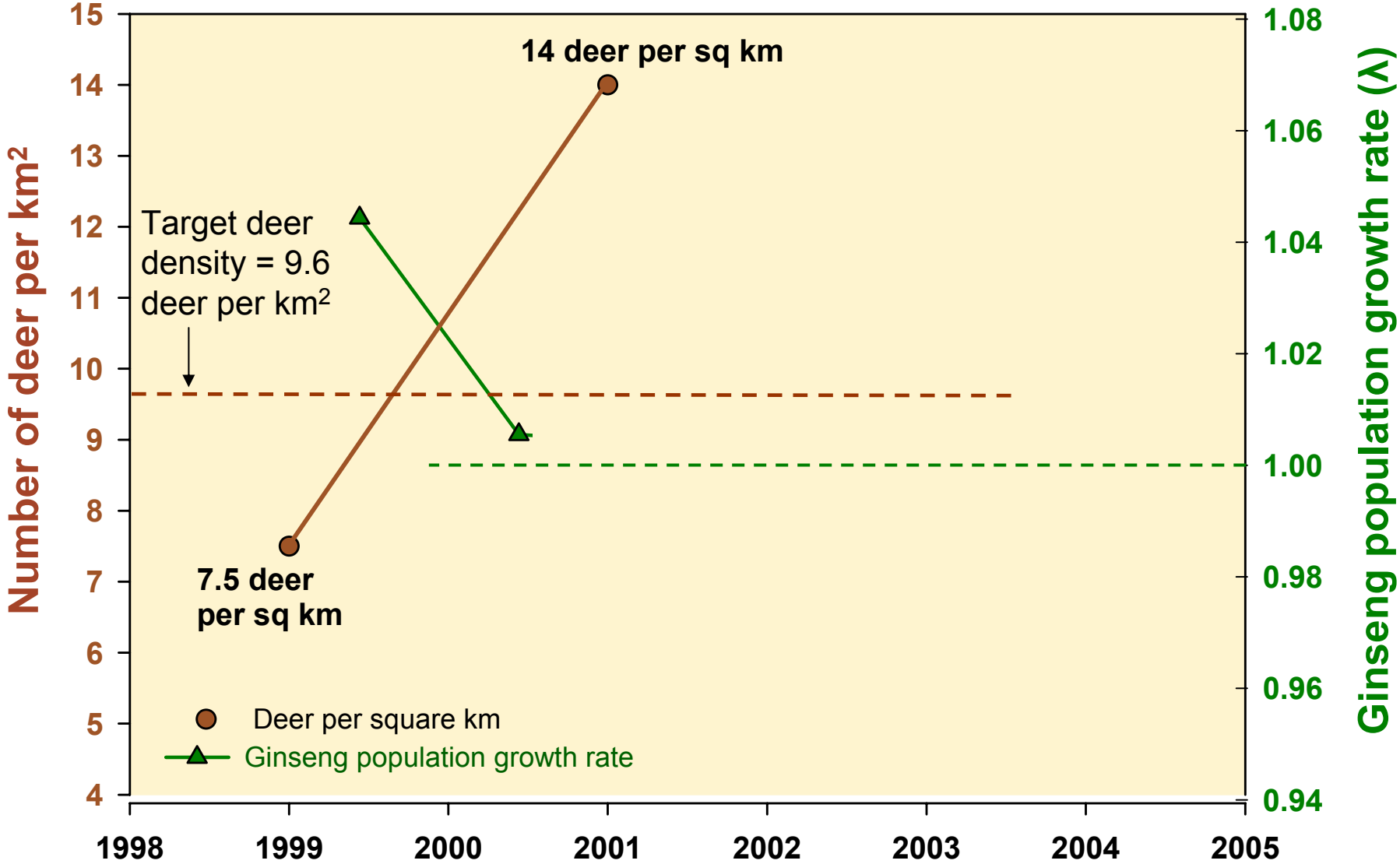


Deer were counted by helicopter over snow…

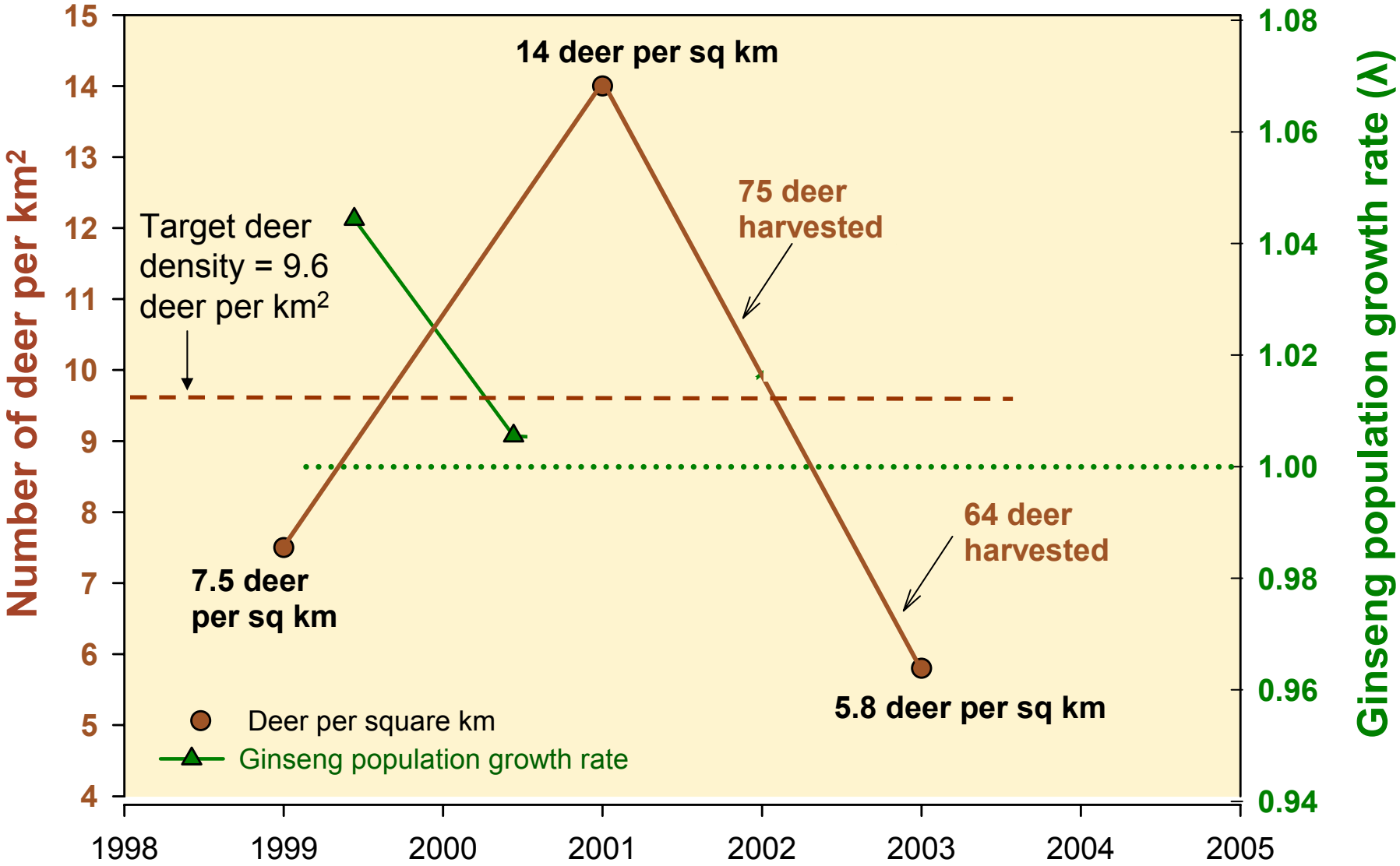
Helicopter deer counts Jan 1999 and Jan 2001



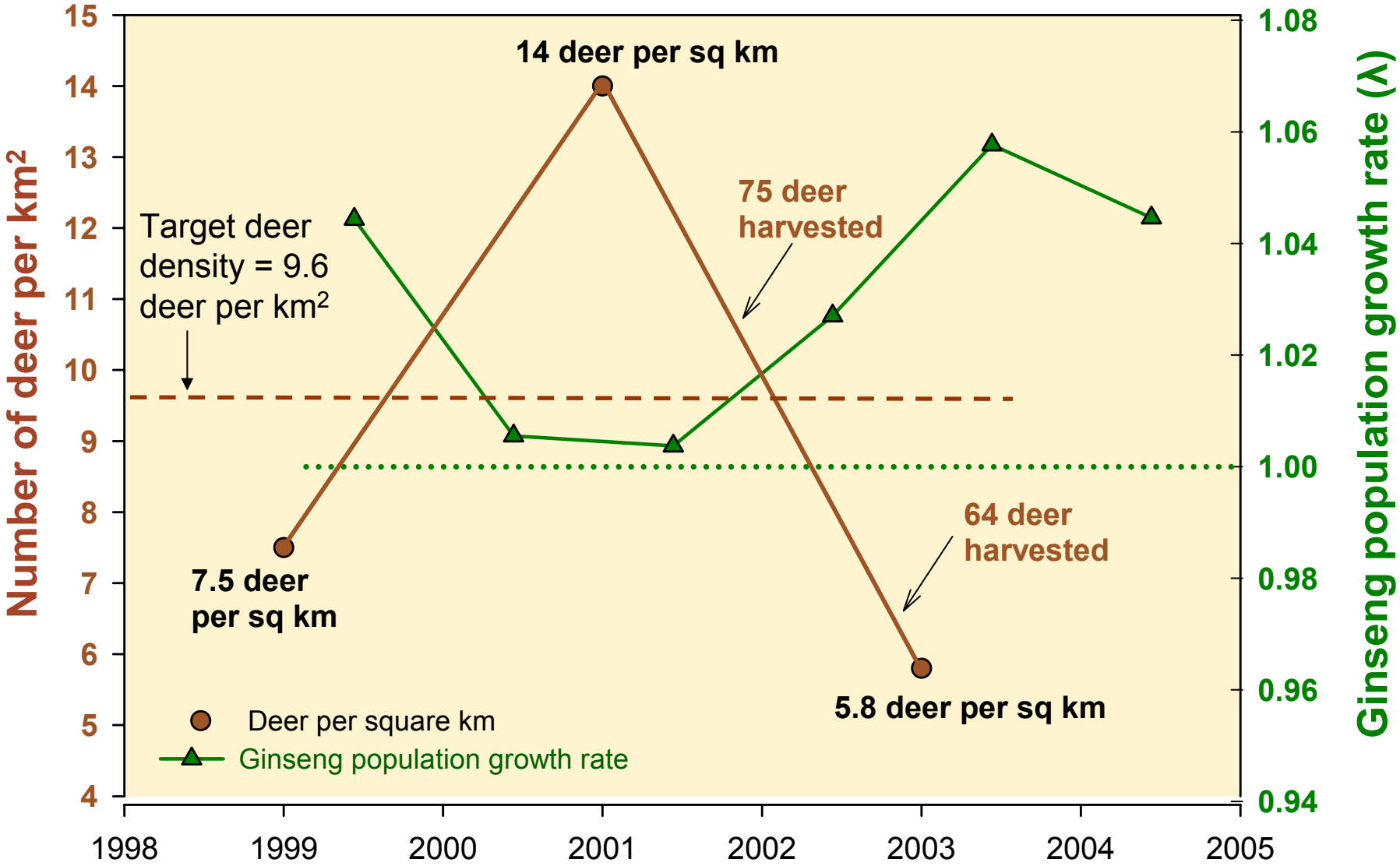
Population growth rate (λ) of ginseng declines



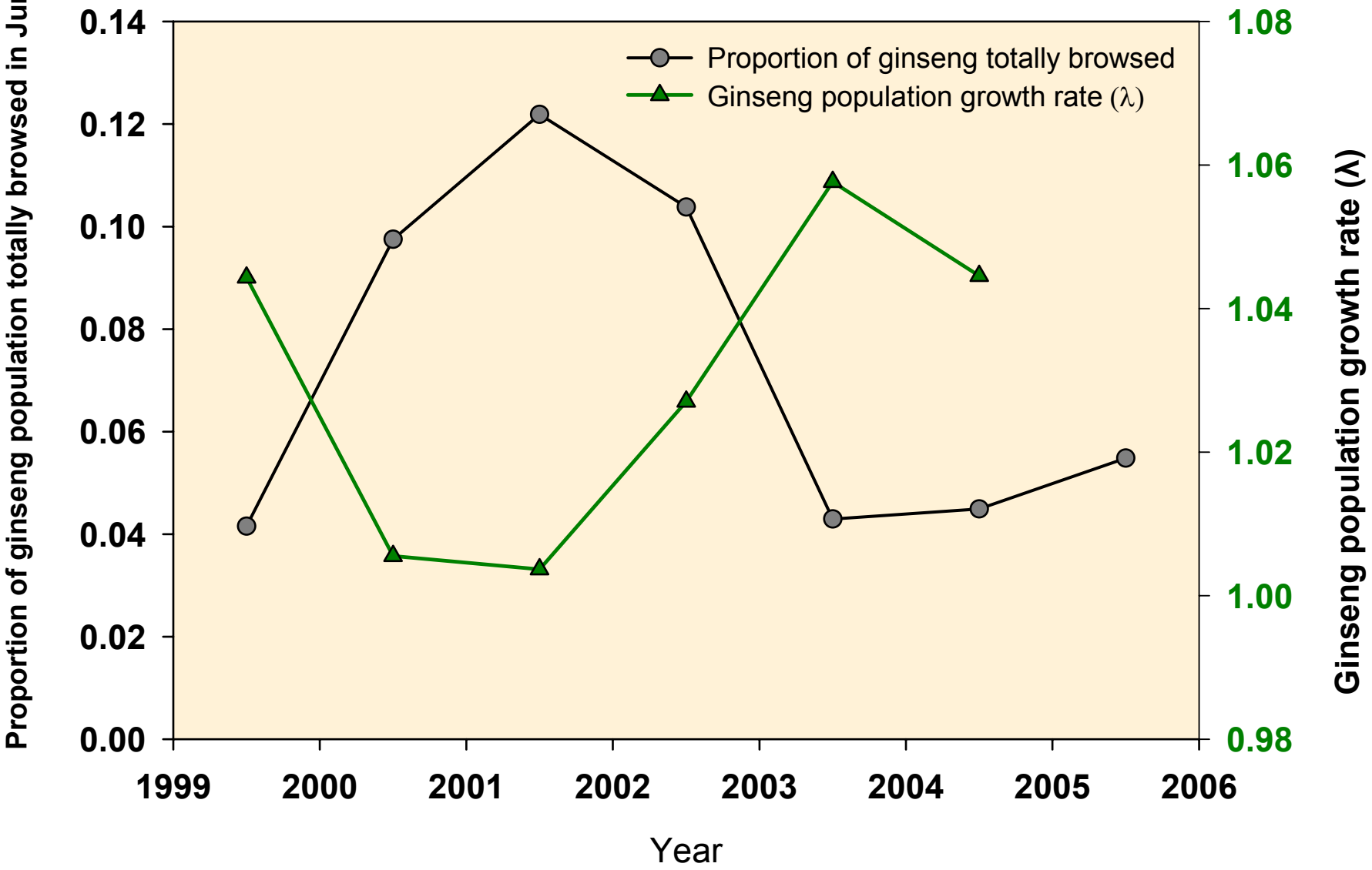
Managed hunts conducted 2001 and 2002



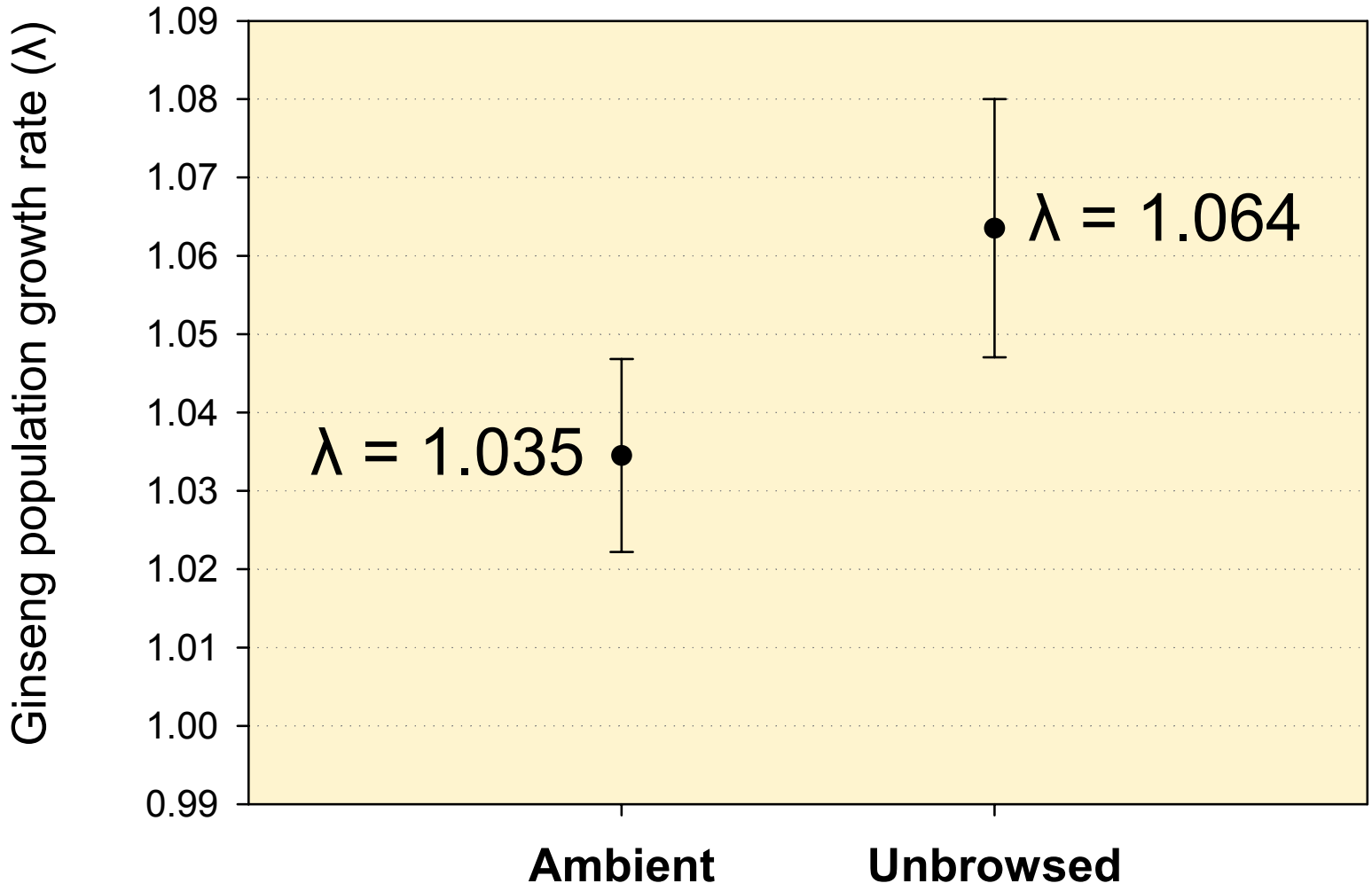
Ginseng population growth rate (λ) increases



Proportion of ginseng totally browsed by early June and ginseng population growth rate (λ)

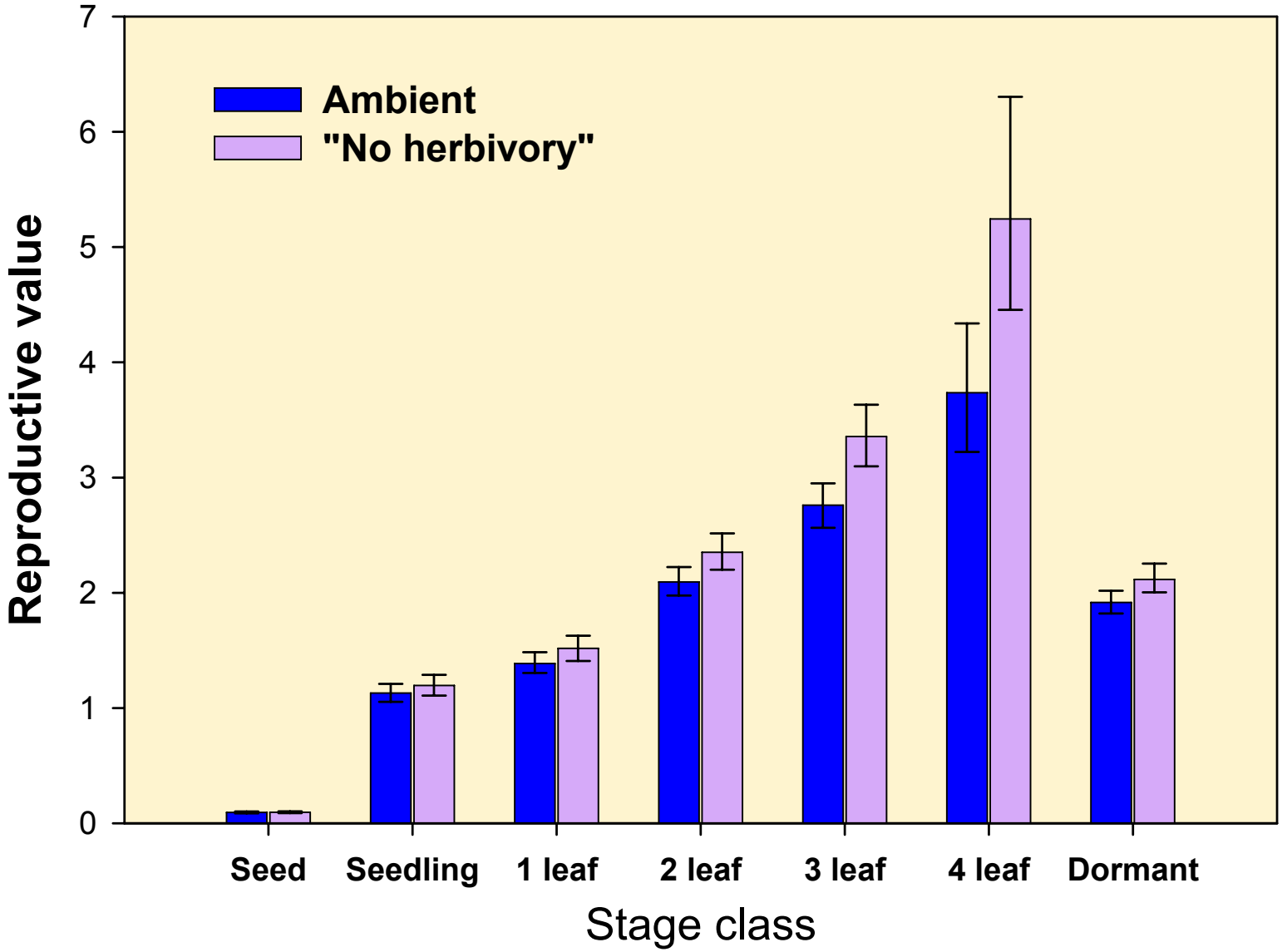


Population growth rate of the ambient matrix and the ‘no herbivory’ matrix 1999-2005.

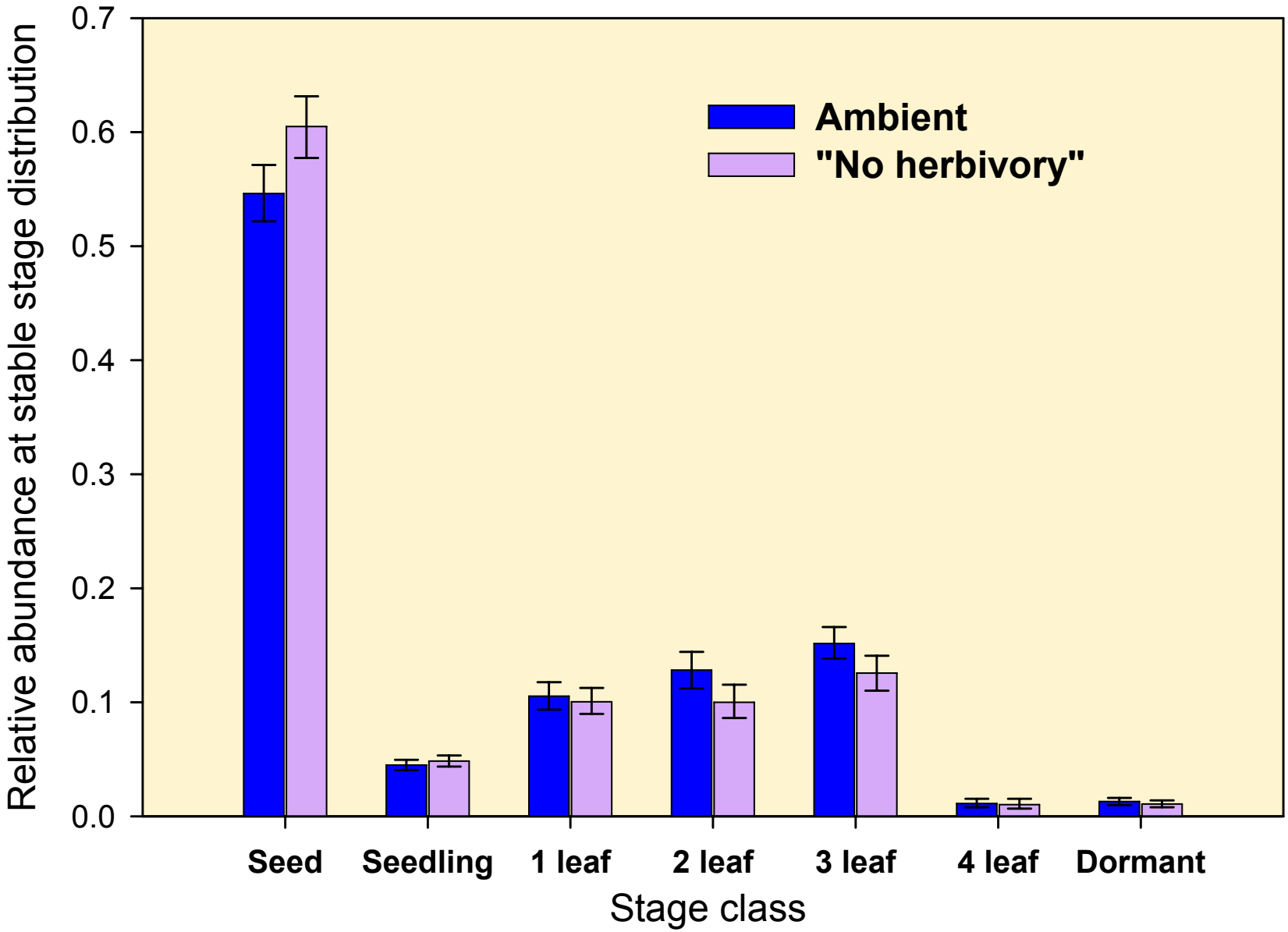


Error bars indicate the 95% confidence intervals.

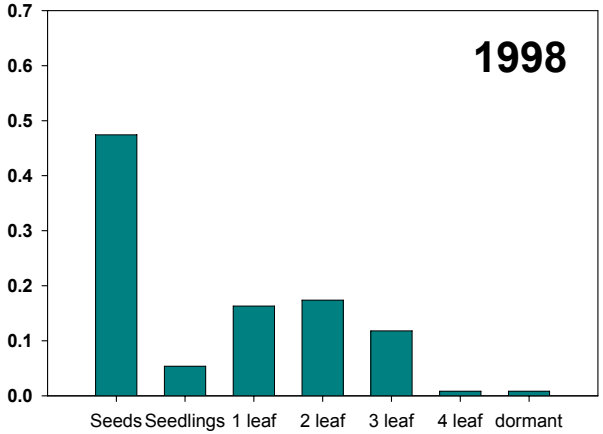
Reproductive values of the ambient population compared to the unbrowsed population 1999 to 2005.

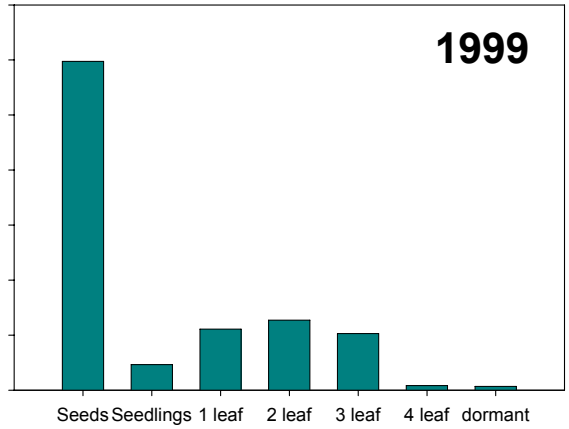


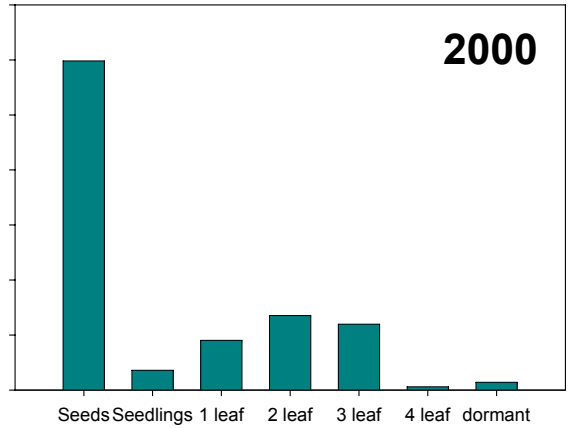
Stable stage distribution of the ambient population compared to the unbrowsed population 1999 to 2005.

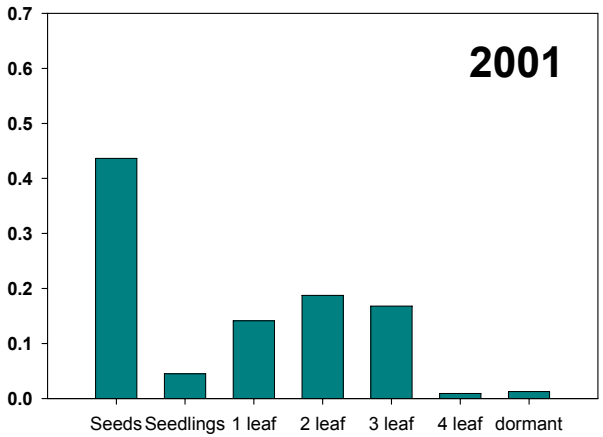


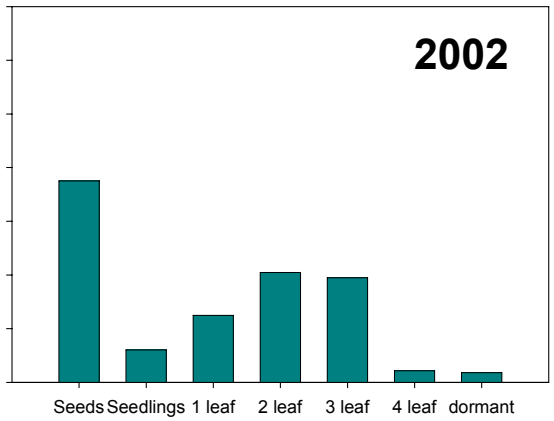
Stage distribution of ginseng populations monitored 1998-2005.

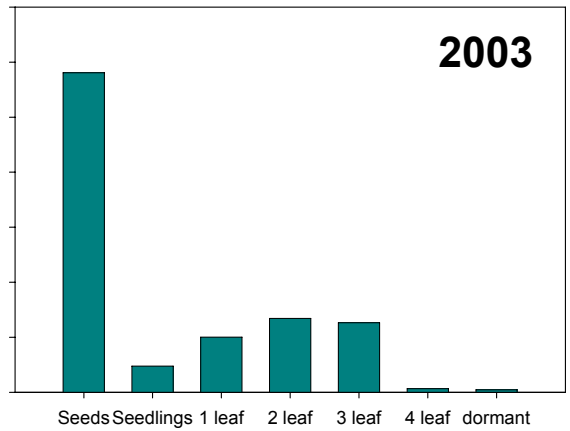


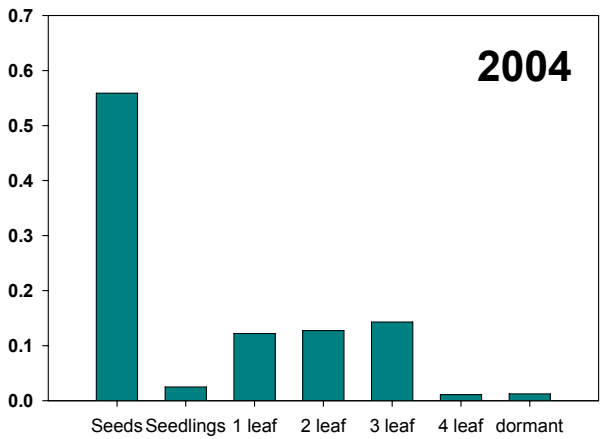


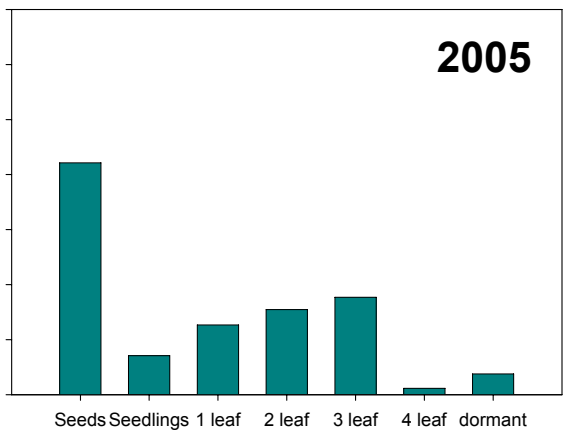




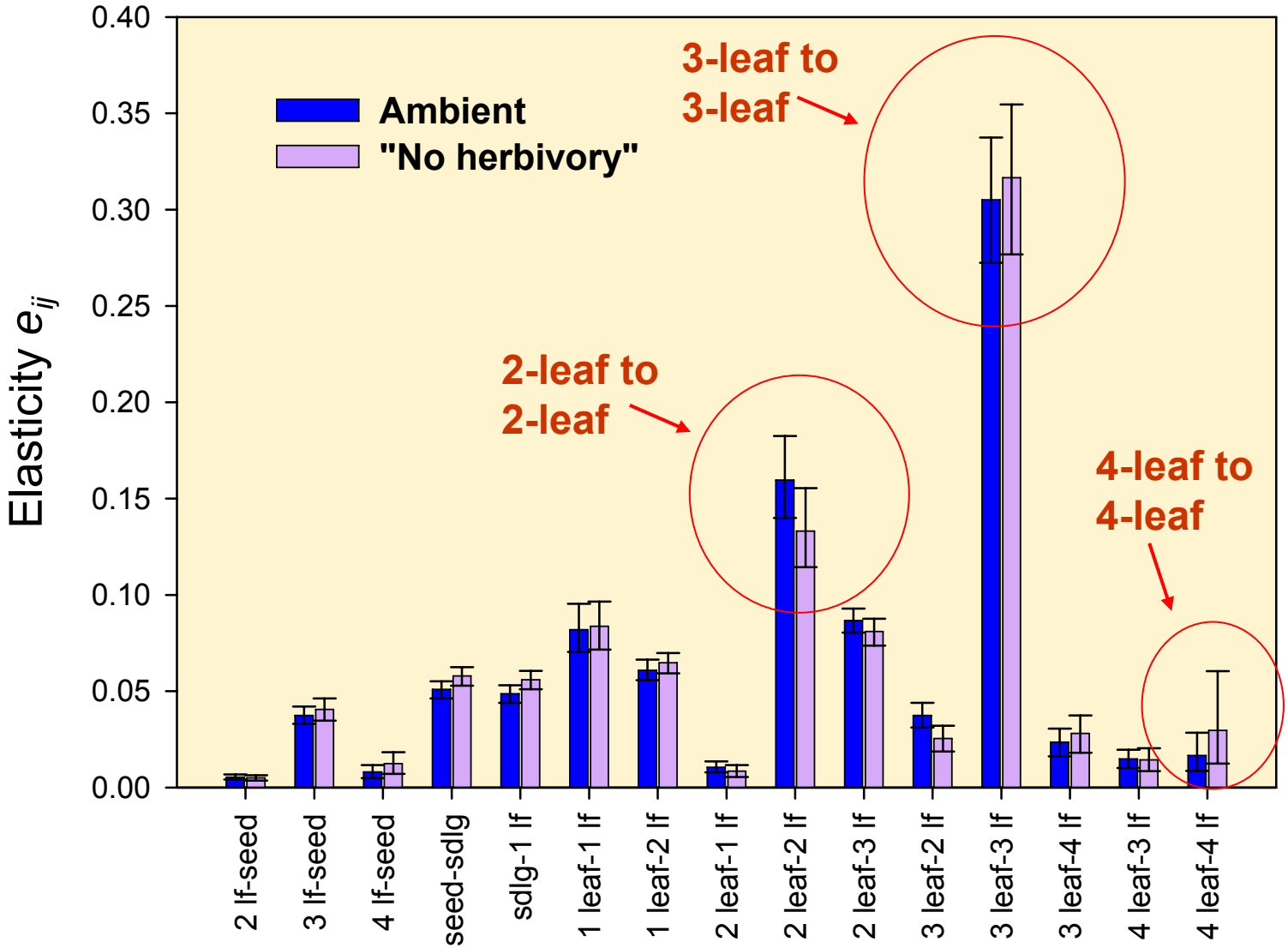








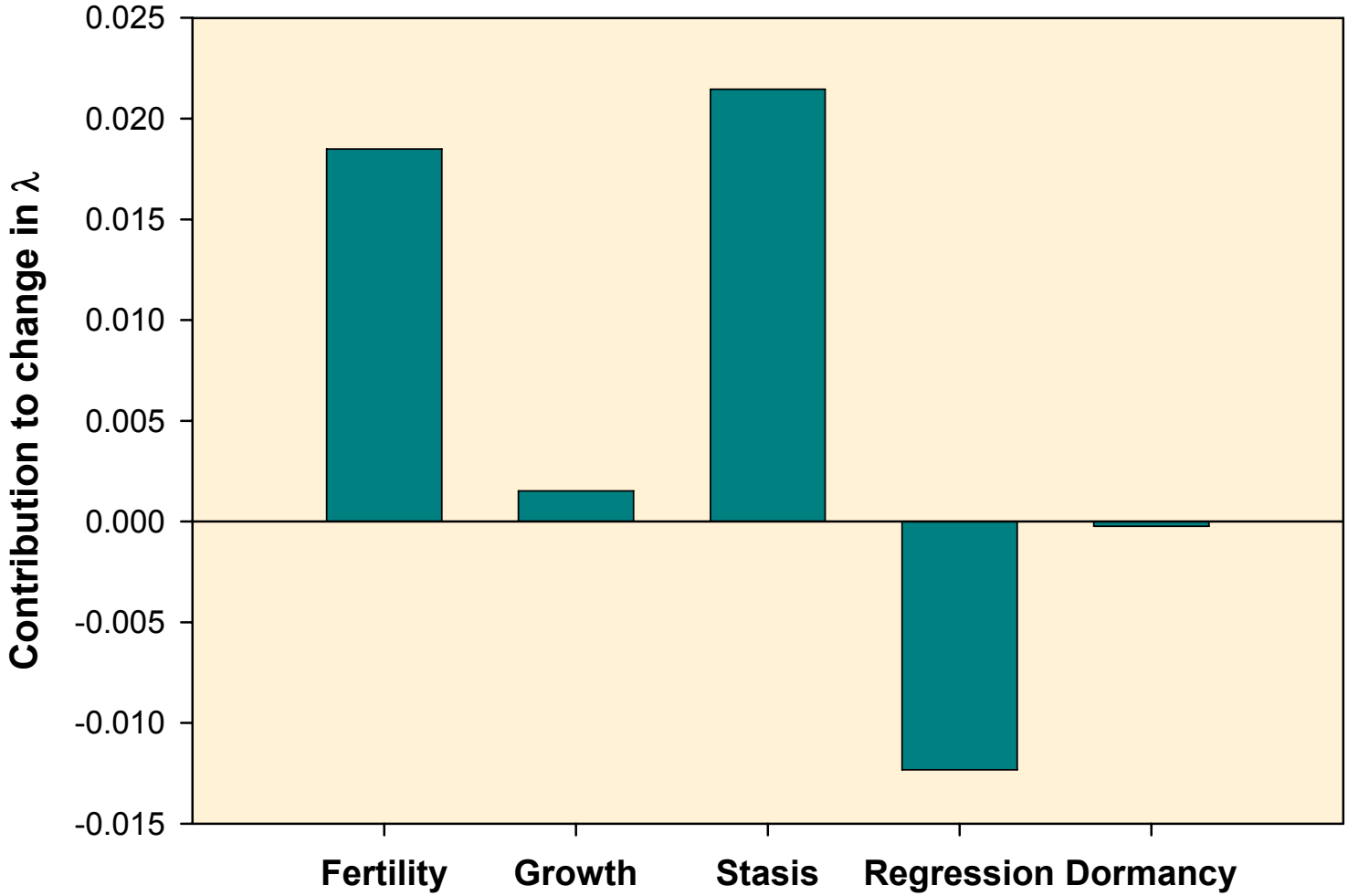
Elasticity of the ambient population matrix compared to the unbrowsed matrix 1999-05.



Life Table Response Experiment (LTRE) analysis

	seed	seedling	1-leaf	2-leaf	3-leaf	4-leaf	dormant
seed	0	0	0	.001	.013	.005	0
seedling	0	0	0	0	0	0	0
1-leaf	0	.0002	.0009	-.0003	0	0	0
2-leaf	0	0	-.0003	-.0011	-.009	-.0007	0
3-leaf	0	0	0	.0008	.017	-.0021	0
4-leaf	0	0	0	0	-.0007	.0044	0
dormant	0	0	0	.0008	-.0009	0	0

Life Table Response Experiment (LTRE) analysis



Conclusions:

Even a non-preferred browse species can be negatively affected by high densities of deer.

Deer density at this study site ranged from 5.3 to 14 deer/km^2 from 1999 to 2003
West Virginia study populations ranged from 15 to 49 deer/km^2 in 2002 (Furedi 2004)

Larger deer densities at this site could be expected to cause the ginseng population growth rate to decline.

Ginseng faces pressure from human harvesting (legal and illegal).
Managing deer herds may assist in maintaining increasingly rare ginseng populations.

How many deer is too many??

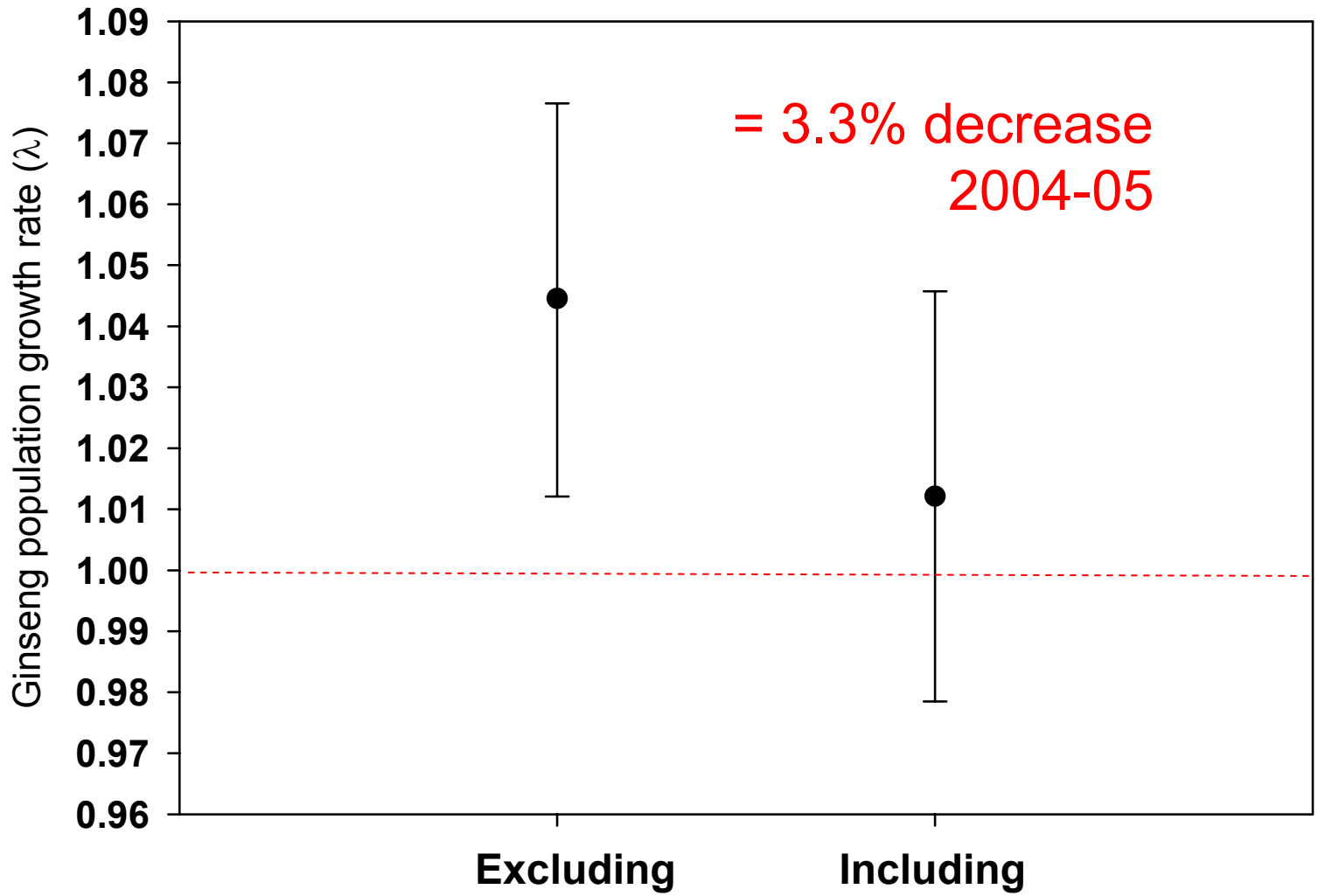
Our study site found ginseng maintained itself at 14 deer/km^2, and grew at levels <14 deer/km^2

Part III: Effects of Harvest

18 poached roots (16 3-prong and 2 2-prong) represented 8.3% of all 3-leaf plants in combined populations,1.2% of all 2-leaf plants, and 3% of all plants

Poached plants were not included in previous analysis so that effects of deer herbivory are not confused with effects of harvest

Effects of excluding or including 18 roots removed by poachers (3.0% of total population) in fall of 2004…



Methods:

Stochastic simulation program* randomly chooses one of 6 matrices (1999-00, 2000-01, 2001-02, 2002-03, 2003-04, or 2004-05)

Assumptions:

- Each environment is independent (no carry-over effects from one year to next)
- Each environment is identically distributed (has an equal probability of occurring)

50,000 simulations are run to produce the stochastic population growth rate ($\log\lambda_s$)

*program written by Tiffany Knight in Matlab (2002)

At selected intervals (1, 5 or 10 years), randomly chosen matrix is multiplied by diagonal harvest matrix

$$\begin{pmatrix} 0 & 0 & 0 & 0.47 & 3.12 & 18.1 & 0 \\ 0.05 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0.81 & 0.64 & 0.08 & 0 & 0 & 0.13 \\ 0 & 0 & 0.27 & 0.64 & 0.13 & 0.14 & 0.56 \\ 0 & 0 & 0.00 & 0.17 & 0.78 & 0.43 & 0.13 \\ 0 & 0 & 0 & 0 & 0.04 & 0.43 & 0 \\ 0 & 0 & 0.02 & 0.03 & 0.02 & 0 & 0.29 \end{pmatrix} \times \begin{pmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0.3 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0.3 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{pmatrix}$$

“Responsible” harvester	vs.	**“Irresponsible” harvester**
Harvests in season		Harvests out of season
Digs carefully, causing minimal (up to 5%) collateral mortality to smaller plants		Digs carelessly, causing considerable (up to 33%) collateral mortality to smaller plants
Plants seeds from harvested plants at 2 cm (increases recruitment)		Seeds from harvested plants are removed (decreases fecundity)

Assumptions:

38% of seeds fall before harvester arrives

→ 8.5% germination (average rate)

62% of seeds are planted by responsible harvester

→ 75% germination*

OR

62% of seeds are removed by irresponsible harvester

→ 0% germination

*based on seed germination trials by McGraw (2000) and this study

Results:

Maximum % of 3 leaf and 4 leaf plants that can be harvested (stochastic growth rate ≥ 1.00):

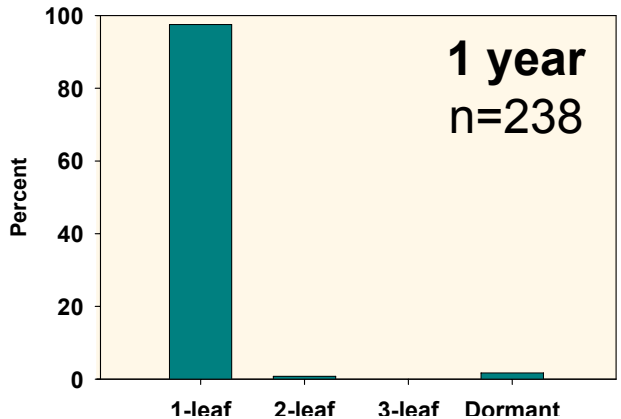
Harvest Frequency:	Seeds unaffected:	Seeds removed:	Seeds planted at 2 cm: Ambient	No herbivory
Annual	8%	0%	53%	65%
Every 5 yrs	38%	27%	75%	99%
Every 10 yrs	69%	58%	100%	100%

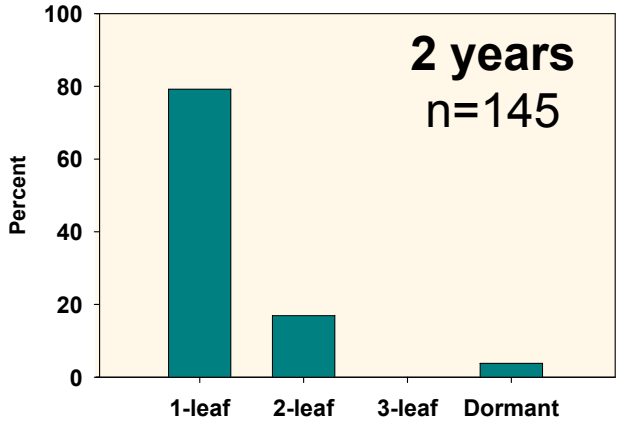
Results:

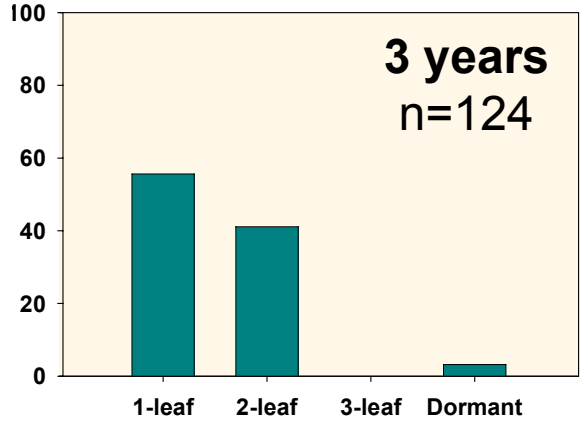
Maximum % of 3 leaf and 4 leaf plants that can be harvested (stochastic growth rate ≥ 1.00):

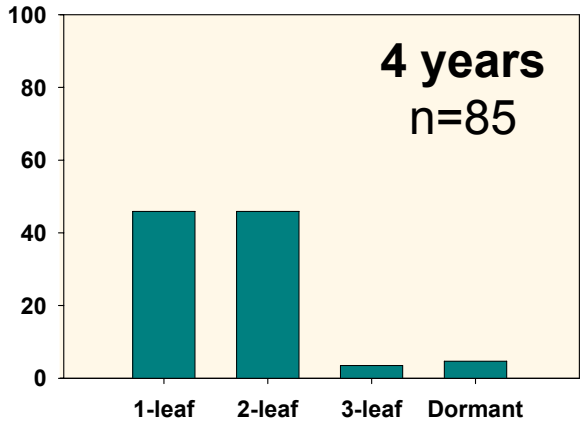
Harvest Frequency:	Seeds unaffected:	Seeds removed/ 33% collateral mortality:	Seeds planted at 2 cm/ 5% collateral mortality:	
			Ambient	No herbivory
Annual	8%	0%	42%	52%
Every 5 yrs	38%	0%	74%	95%
Every 10 yrs	69%	24%	100%	100%

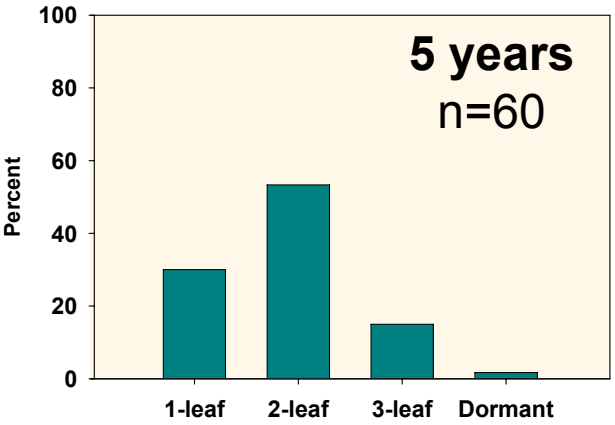
Time required for a ginseng seedling to mature: Percent of plants in each stage class 1 to 7 years after seedling status

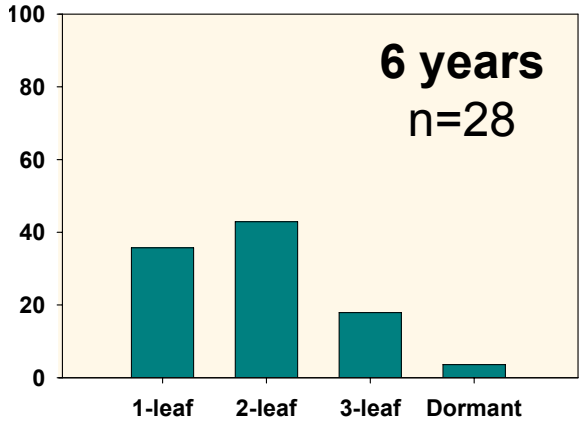


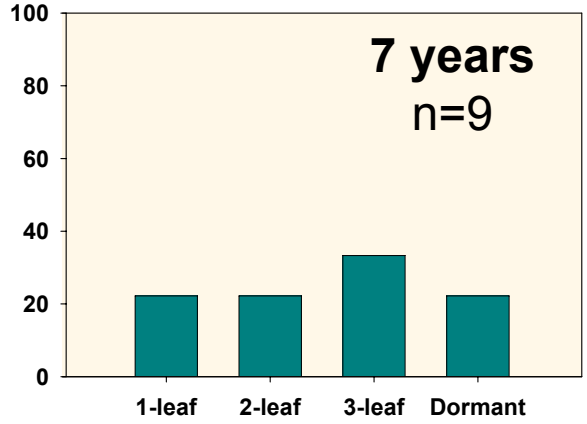




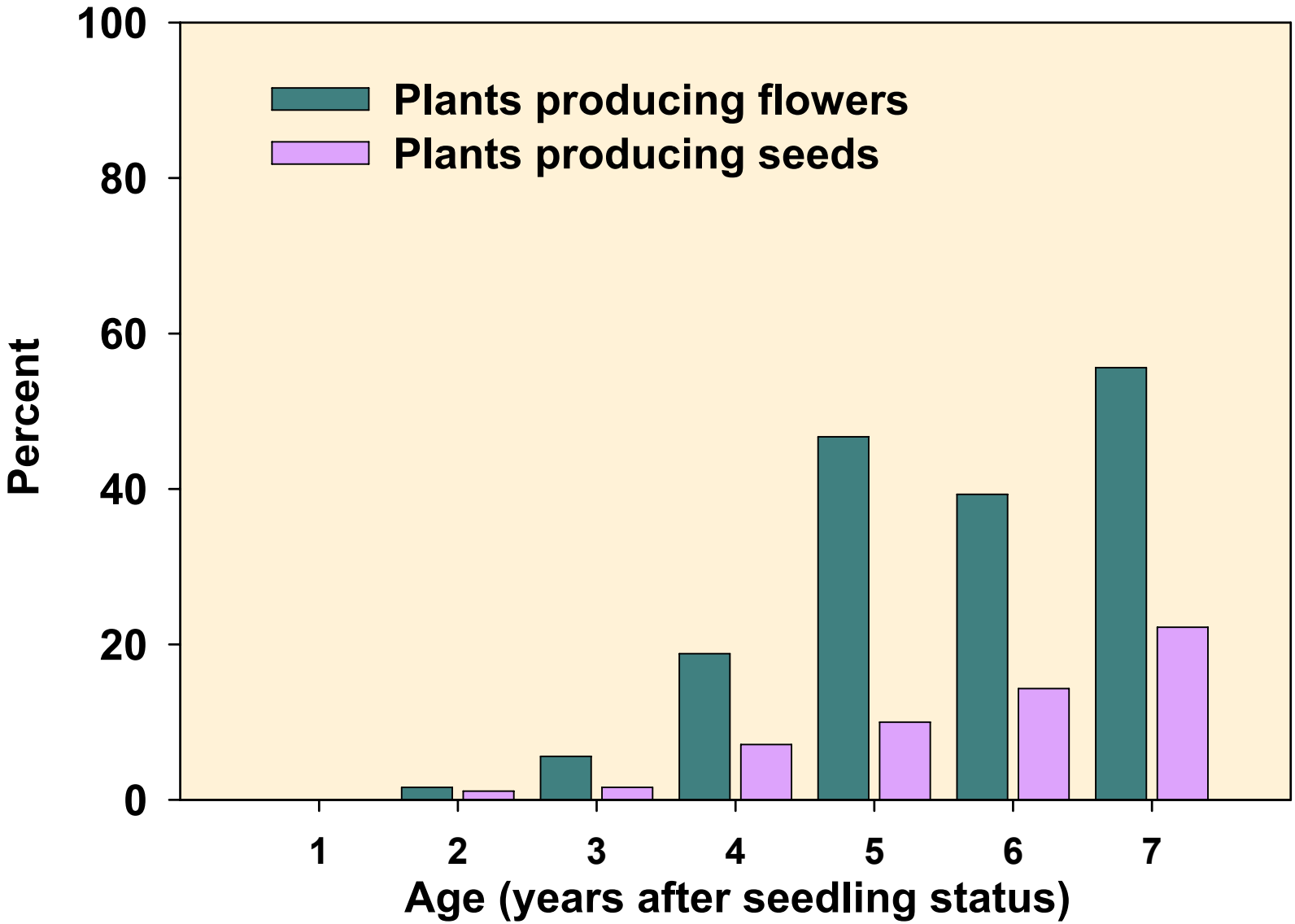








Percentage of plants producing flowers and seeds 1 to 7 years after seedling status



Number of seeds required to produce a 7 yr old plant

33 seeds

X

8.5% average recruitment rate

=

2.8 seedlings produced

X

36% survival rate to 7 years

=

1 plant that reaches 7 years of age

Assumptions:

8 yr old plants are mature 3 leaf plants

and

14 yr olds are mature 4 leaf plants

(Zenger 1983)

Then…

2.7 seeds per year x 6 years

= 16.2 seeds

8.6 seeds per year for 2 years

= 17.2 seeds

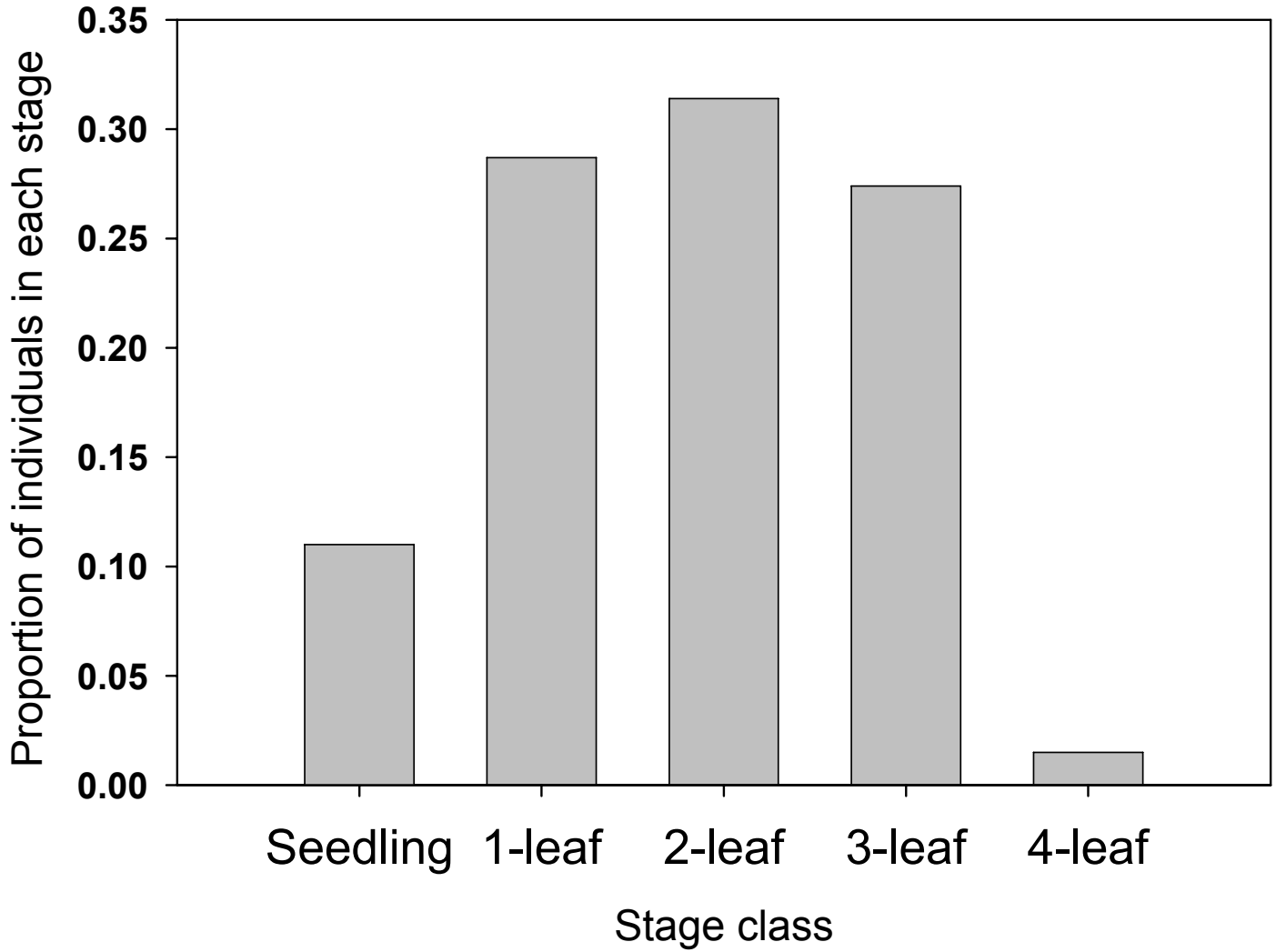
Total = 33.4 seeds by age 15

Funding is needed to continue this long-term monitoring study…

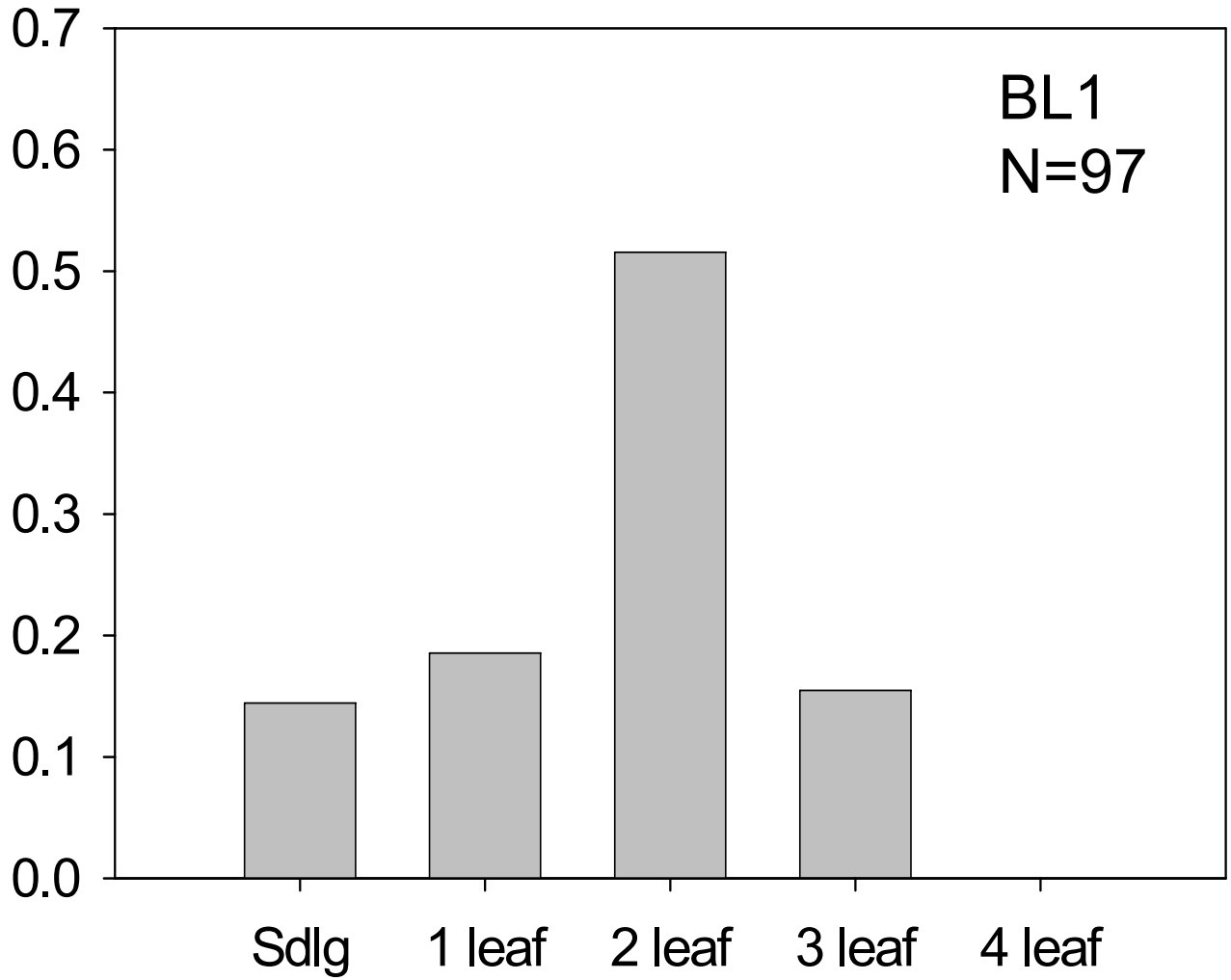
Ecological characterization of ginseng in the Missouri Ozark Highlands

Data collected: Slope, aspect, canopy closure, woody and herbaceous plant composition, soil analysis.

Average distribution of stage classes in 18 ginseng sites in 13 Missouri counties

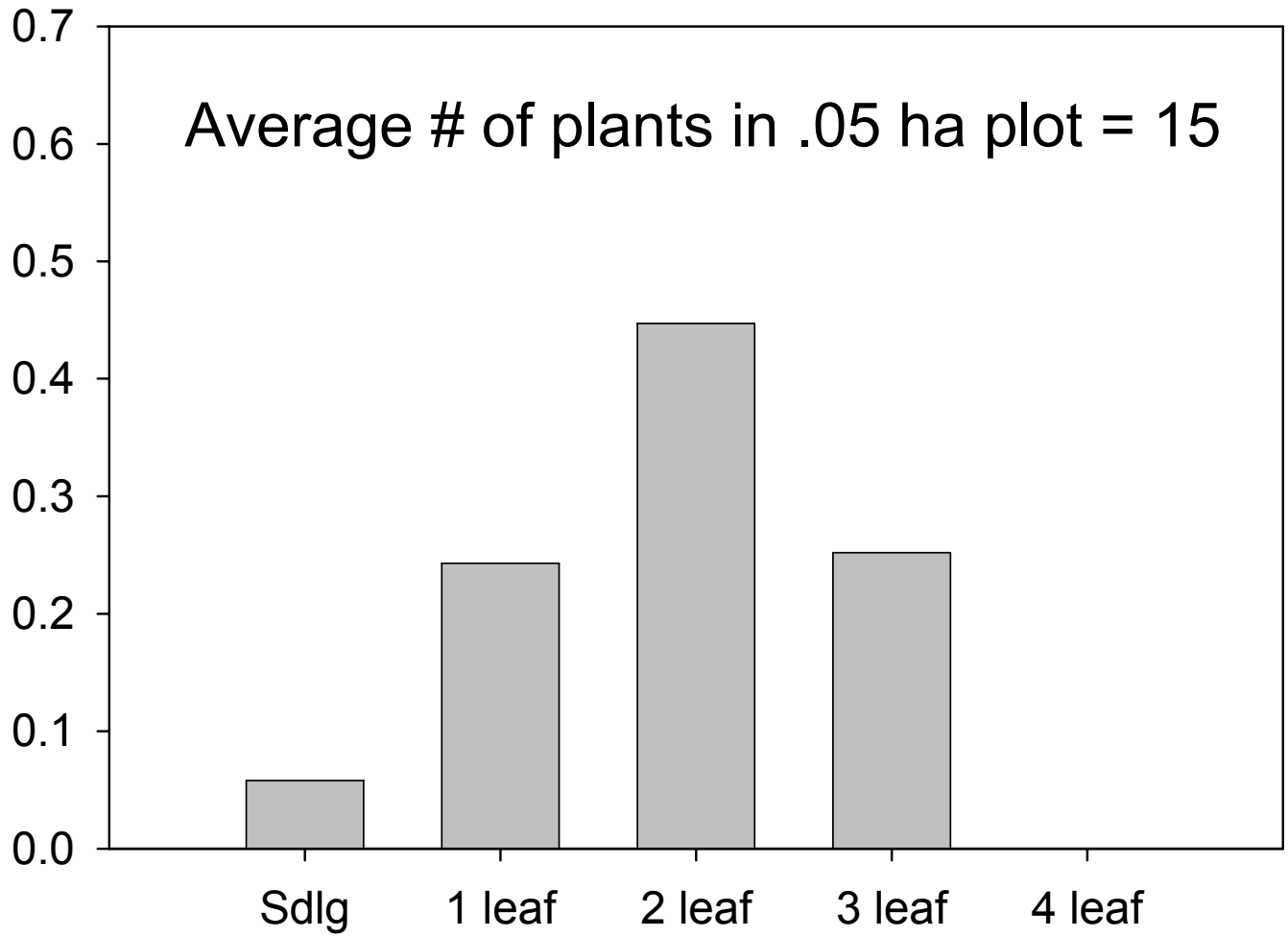


Distribution of stages in a harvested population*

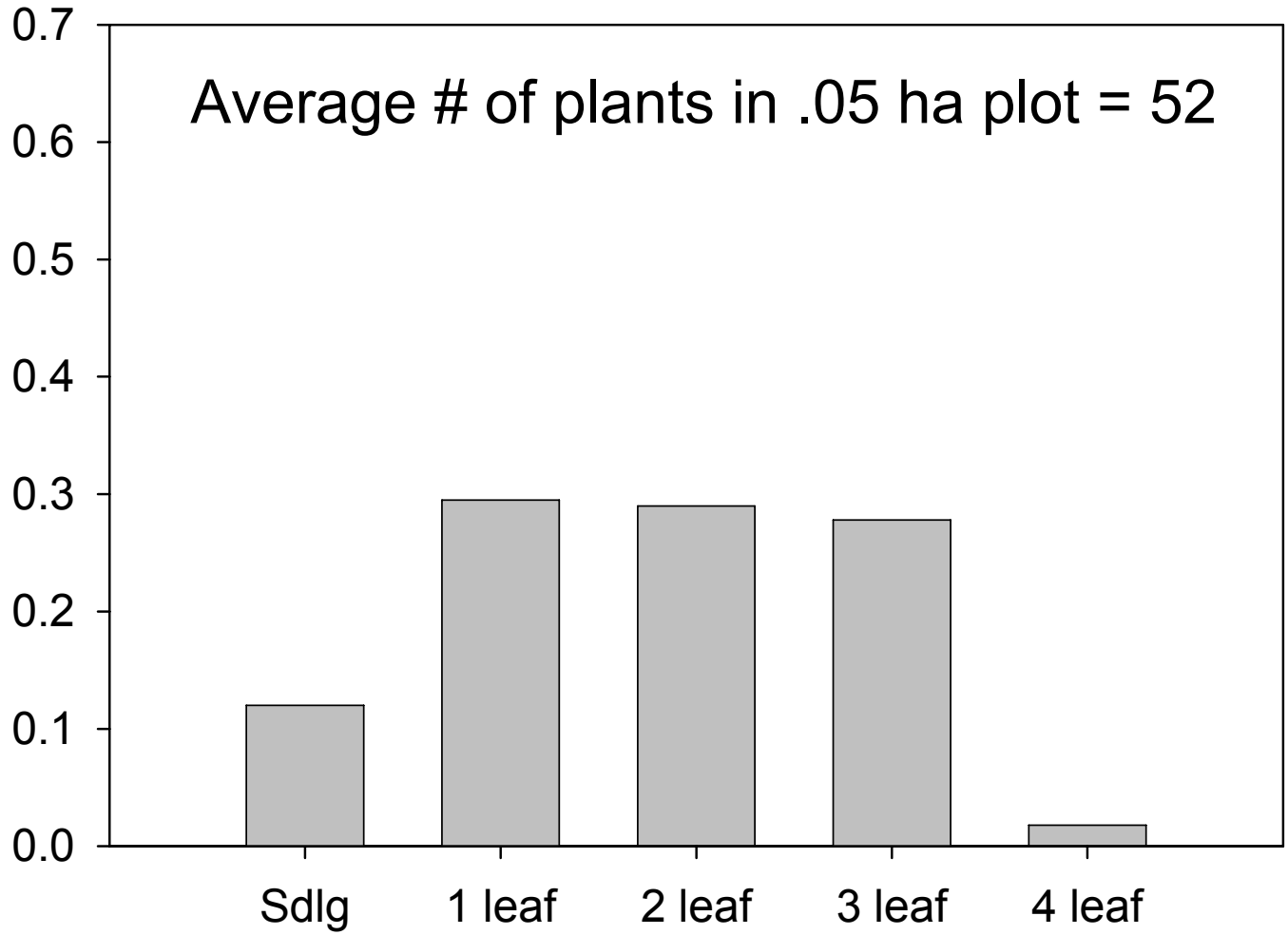


*This population was illegally harvested 2 consecutive years prior to observation.
Large overall population: many more plants located outside of .05 ha plot

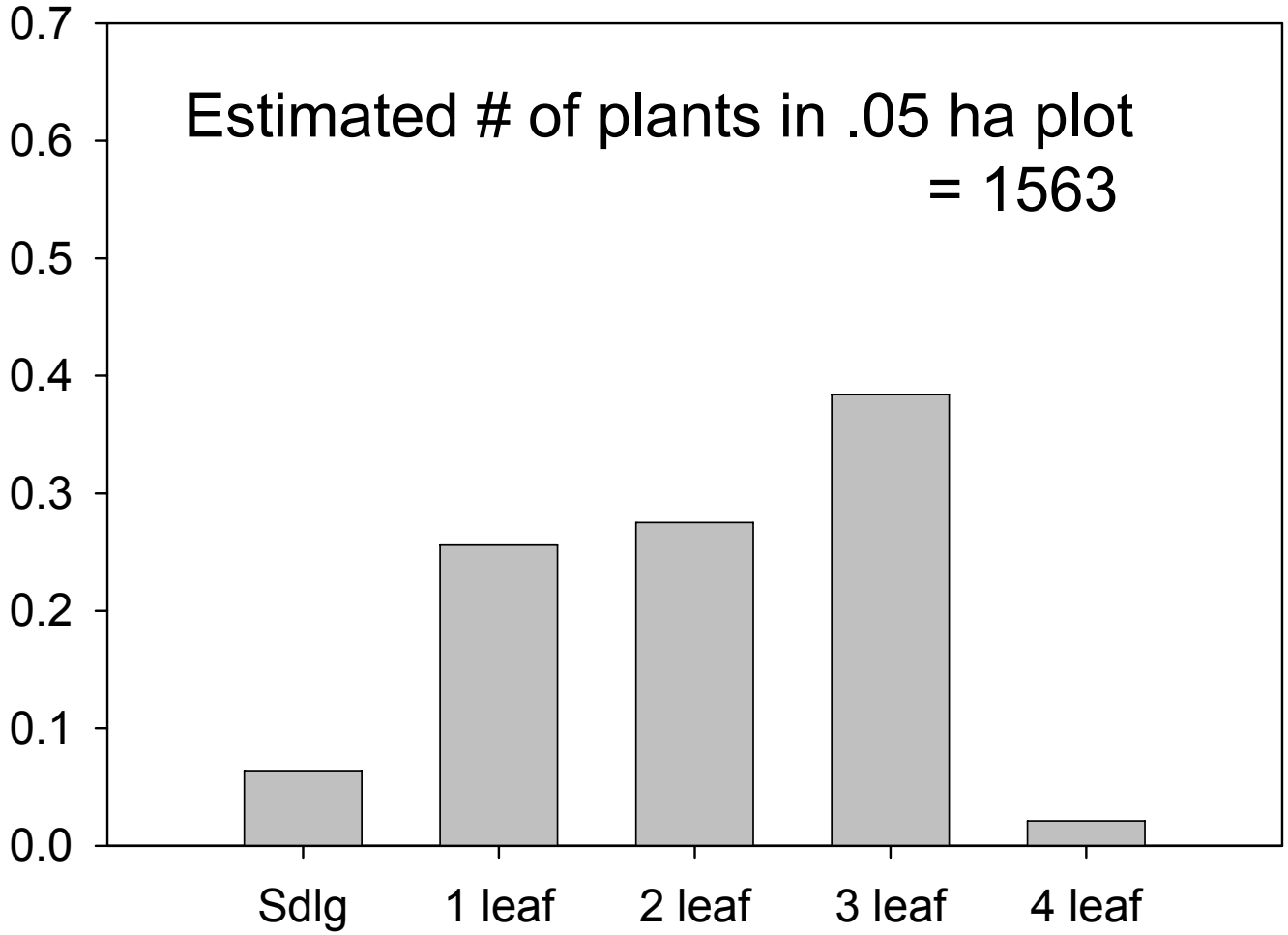
Distribution of stages in 7 smaller populations
Very few plants observed outside of plot



Distribution of stages in 10 larger populations
Additional plants observed outside of plot



Distribution of stages in a very large wild simulated population



Acknowledgements

**Dr. Rose-Marie Muzika,
Thesis supervisor**

**Committee:
Dr. Candace Galen
Dr. Matthew Gompper
Dr. Michael Gold**

**Dan Drees
Dr. Tiffany Knight
Brian Wilcox
Jody Miles
Ken McCarty
Dr. Mark Ellersieck**

**Tim Smith
Dr. Paul McKenzie
Dennis Meinert
Dennis Lindberg
Alan Brant
Kevin Hosman**

and numerous seasonal field assistants

Funding provided by the University of Missouri Center for Agroforestry.

Support also provided by Missouri Department of Natural Resources and Missouri Department of Conservation.