PLANTS PEOPLE POSSIBILITIES

Genome Size Variation: Consequences and Evolution

Ilia Leitch and Martin Lysak

DNA C-VALUE

Genome size variation: consequences and evolution

(i) How genome size varies across plants

(ii) What are the consequence of this variation

(iii) How did such variation evolve

The Origin, Evolution and Proposed Stabilization of the Terms 'Genome Size' and 'C-Value' to Describe Nuclear DNA Contents

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- **Holoploid genome** – the whole chromosome set with chromosome number **n** (irrespective of polyploidy, aneuploidy etc.)
- **Monoploid genome** – one chromosome set of an organism and its DNA having the chromosome base number **x**
- **Genome size** – covering term for the amount of DNA in both holoploid and monoploid genomes

Sometimes terminology matters…

- **C-value** – DNA content of a holoploid genome with chromosome number **n**

- **1C-value** – DNA content of one non-replicated holoploid genome with chromosome number n (= the half of a holoploid non-reduced genome with the chromosome number 2n); cf. 2C-value, 4C-value,…

- **C_x-value** – DNA content of a monoploid genome with chromosome base number **x**

- **Diploids:** 1C-value = $1C_x$-value

- **Polyploids:** example 2C-value of allohexaploid wheat (*Triticum aestivum*; 2n=6x=42) is 34.6 →→ 1C-value: 17.3 pg; $1C_x$-value: 5.8 pg (34.6 : 6)

Remember ! 1 pg = 980 Mbp

Early genome size studies in plants

First genome size of a plant: *Lilium longiflorum*

Ogur M *et al*. 1951. *Exp. Cell Res.* **2:** 73-89.

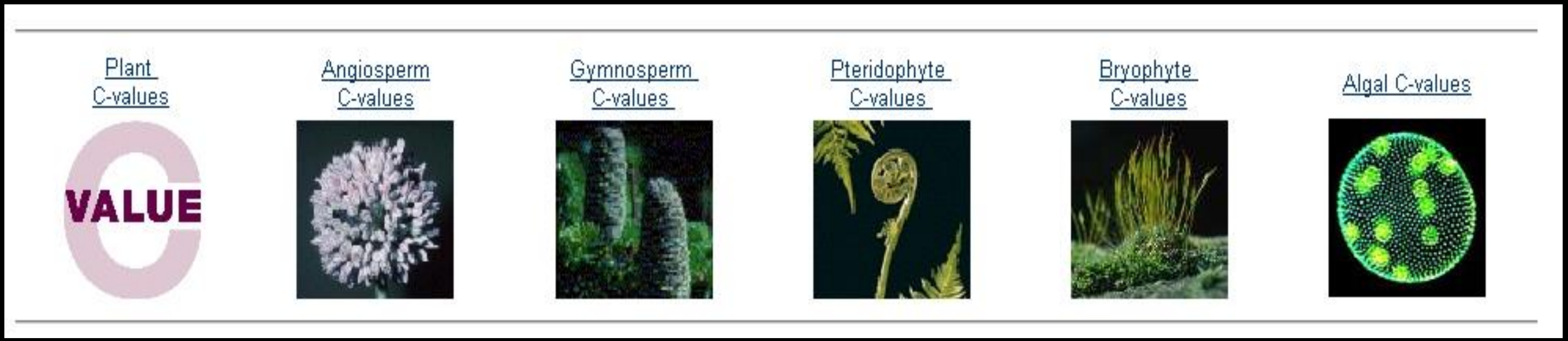
Concept of C-value:

DNA amount in unreplicated gametic nucleus

'C' means Constant

Swift H. 1950. *Proc. Natl. Acad. Sci. USA* **36:** 643-654.

Plant DNA C-values database



www.kew.org/genomesize/homepage.html

5150 species

Land plants	Algae
4427 angiosperms	91 Chlorophyta
207 gymnosperms	44 Phaeophyta
87 pteridophytes	118 Rhodophyta
176 bryophytes	

Kew
PLANTS PEOPLE POSSIBILITIES

C-values in angiosperms range nearly 2000-fold

Genlisea margaretae

1C = 0.065 pg

Greilhuber *et al*. 2006.
Plant Biology
8: 770-777

Utricularia gibba

1C = 0.090 pg

Greilhuber *et al*. 2006.
Plant Biology
8: 770-777

Trillium rhomboifolium

1C = 111.5 pg

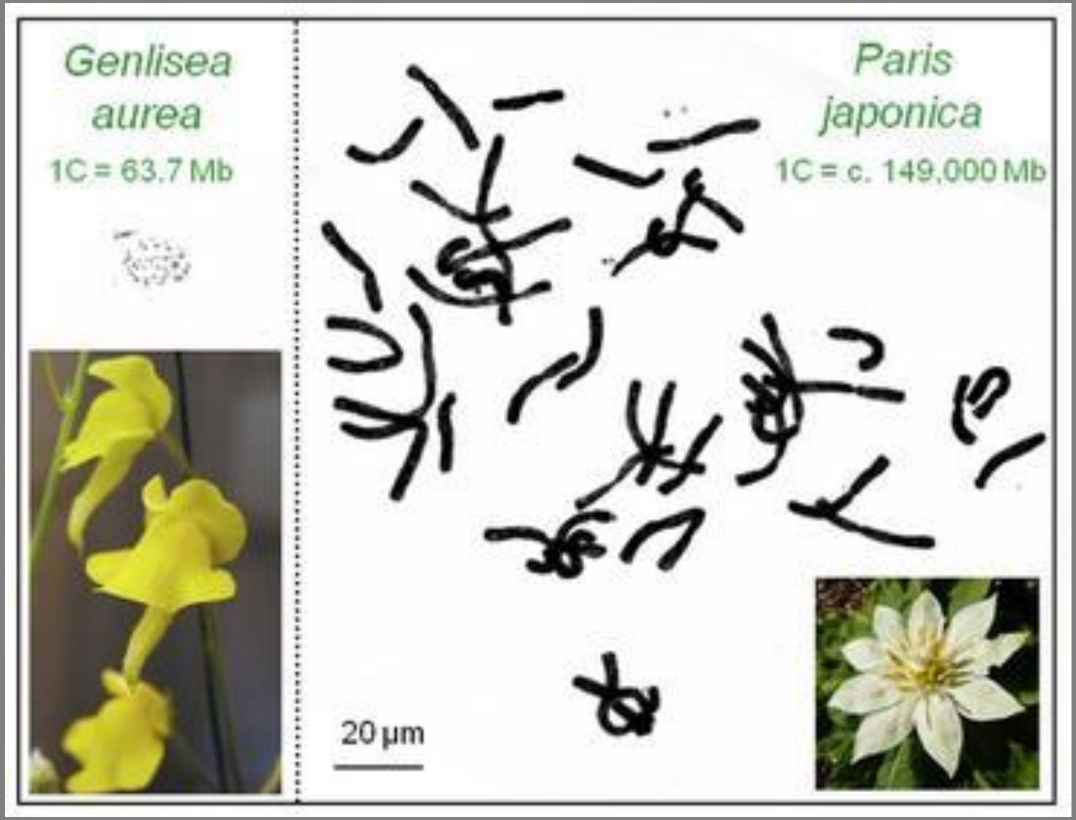
Grif *et al*. 1980.
Tsitologiya
22: 1331-1338

Fritillaria assyriaca

1C = 127.4 pg

Bennett. 1972.
Proc. Roy. Soc. Lond. B
181: 109-135.

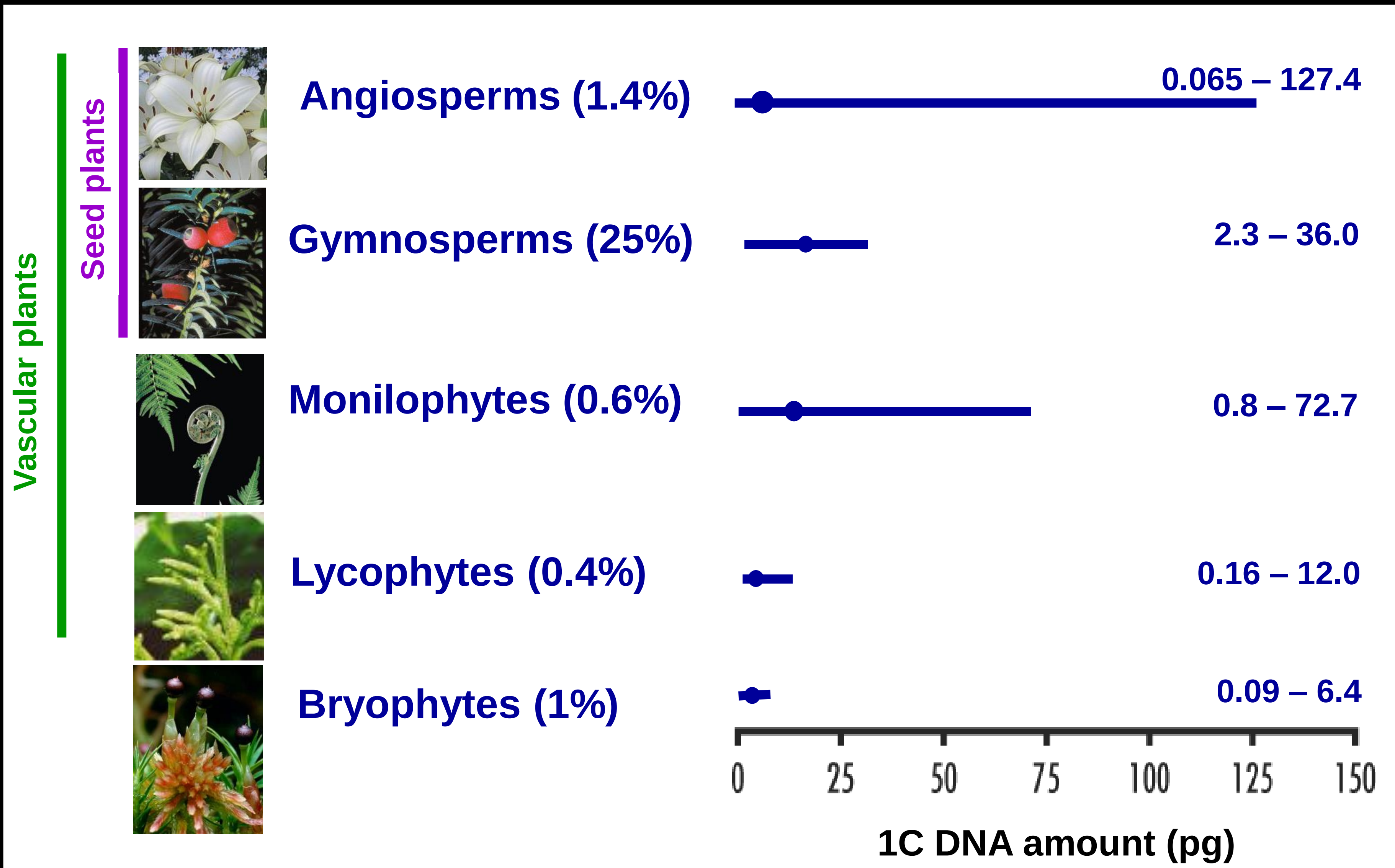
The smallest and largest plant genome



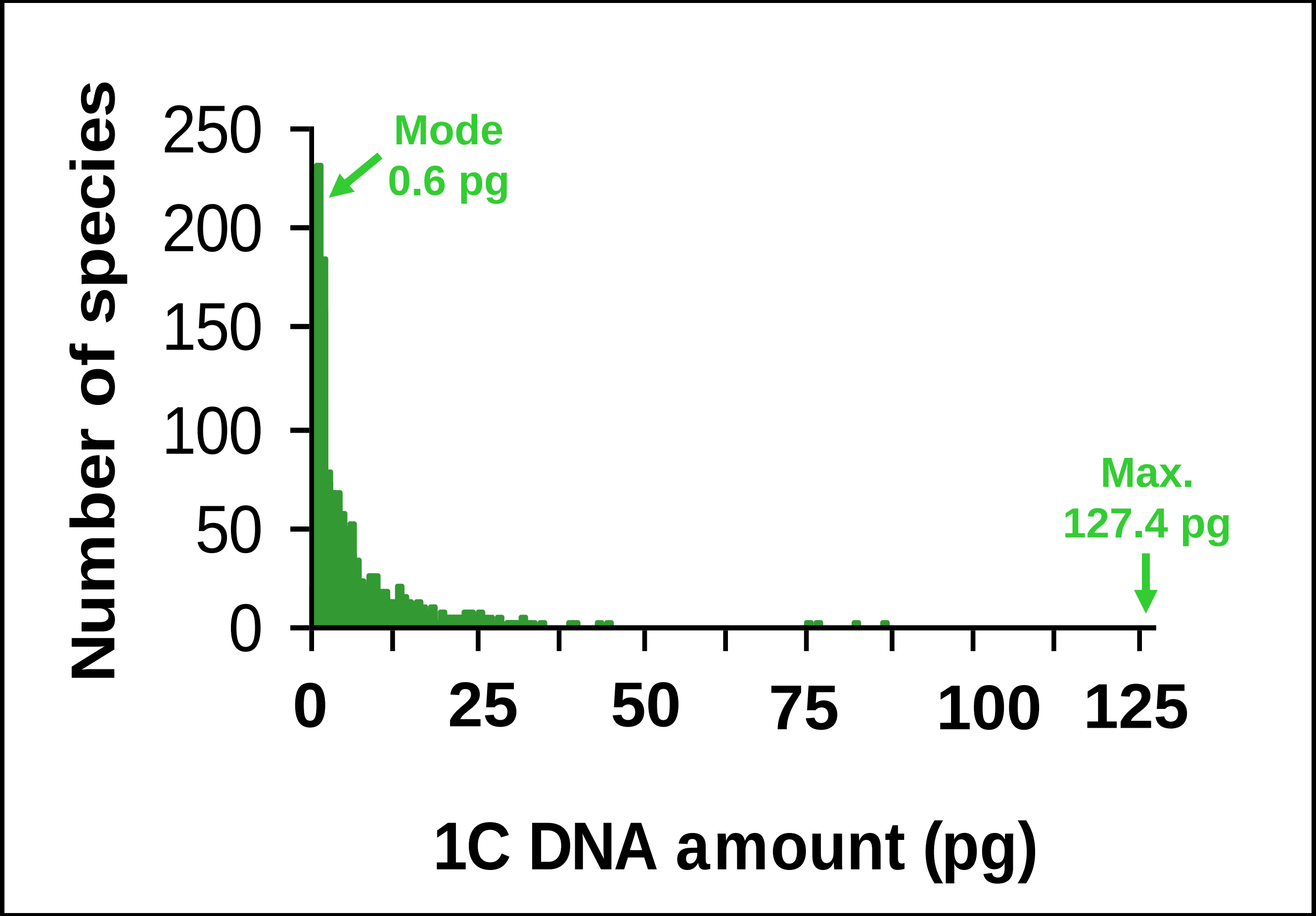
dicots, Lentibulariaceae

monocots, Melanthiaceae

Range of DNA amounts in land plants



DNA amount variation in angiosperms



C-value paradox

Thomas CA. 1971.

The genetic organization of chromosomes.

***Annual Review of Genetics* 5: 237-256.**

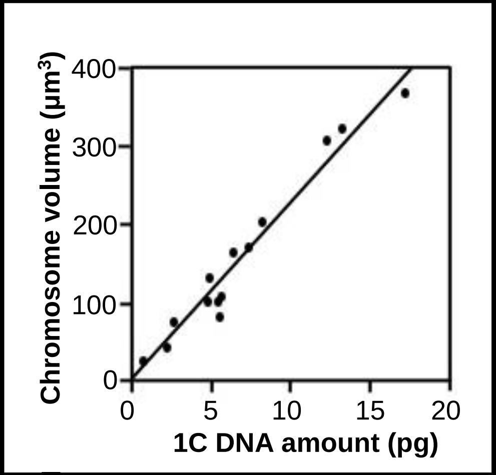
'why the lowly liverwort
has 18 times as much DNA as we have,
and the slimy, dull salamander
known as *Amphiuma* has 26 times our
complement of DNA'.

Comings DE. 1972.
Advances in Human Genetics **3:** 237-431.

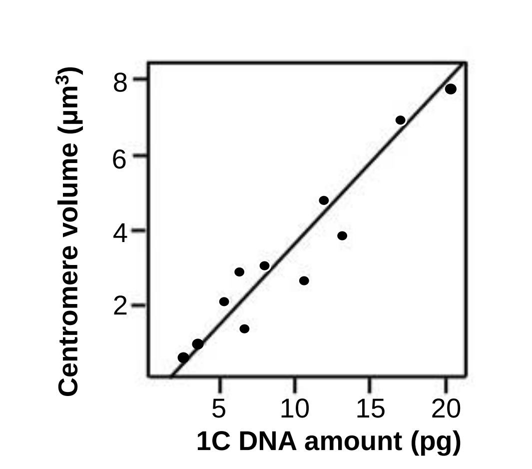
C-value enigma

Gregory TR. 2001. Coincidence, co-evolution, or causation? DNA content, cell size, and the C-value enigma. *Biological Reviews* **76:** 65-101.

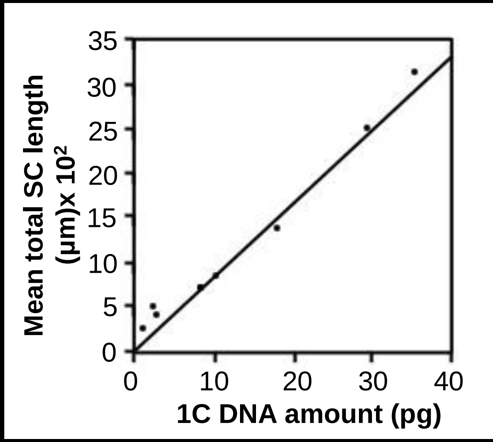
Variation of genome size: Consequences at nuclear level



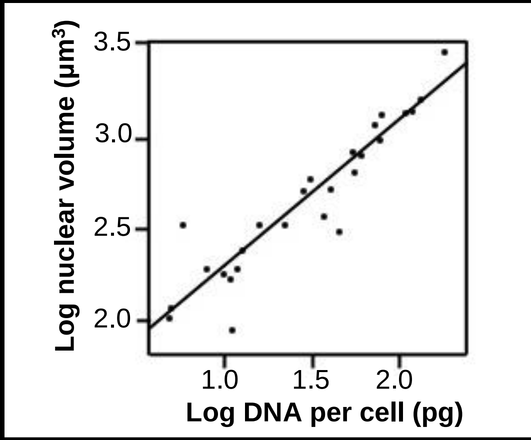
Bennett *et al.* 1983.
J. Cell Sci. **63:** 173-179.



Bennett *et al.* 1981.
J. Cell Sci. **47:** 91-115.

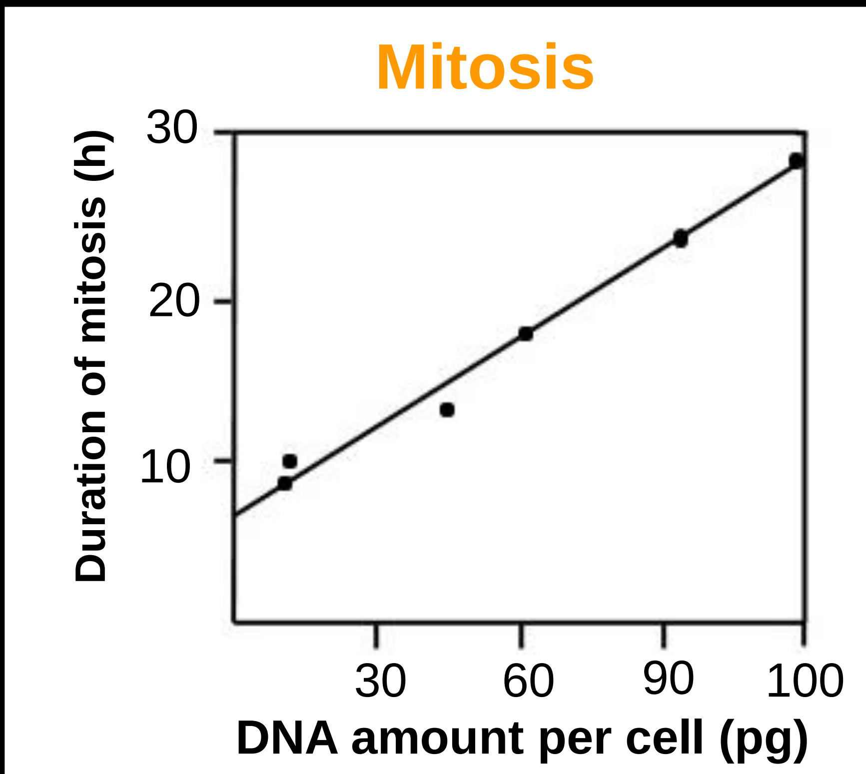


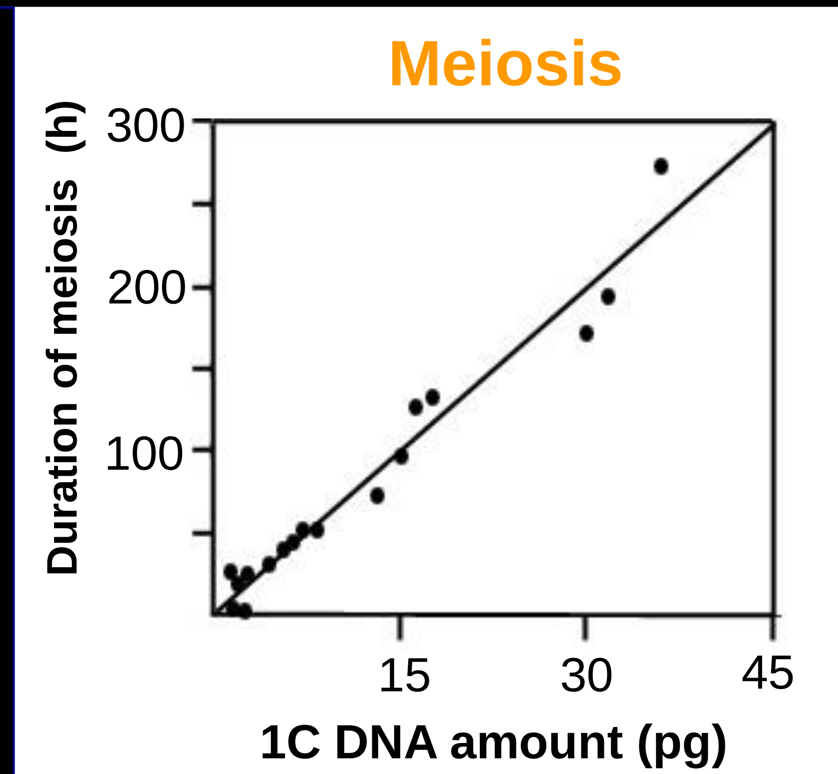
Anderson *et al*. 1985.
Exp. Cell Res. **156:** 367-378.



Baetcke *et al*. 1967.
Proc. Natl. Acad. Sci. **USA 58:** 533-540.

Variation of genome size: Consequences of timing

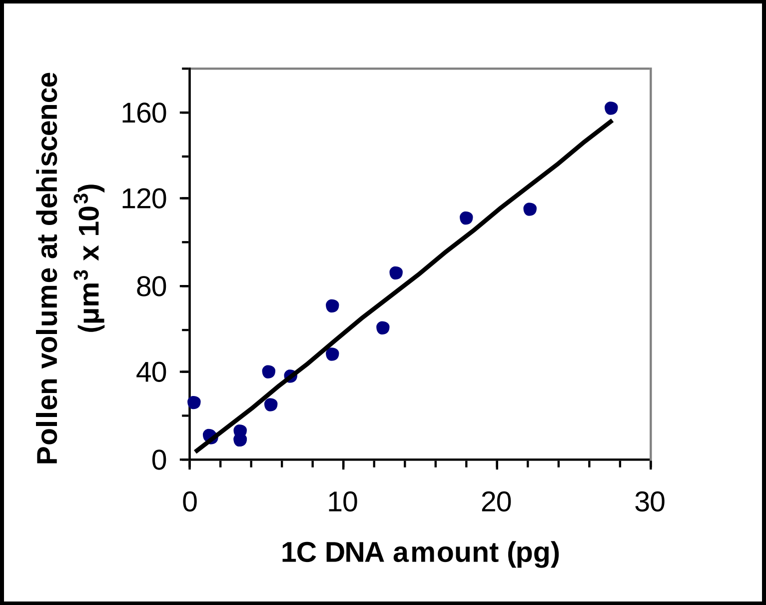


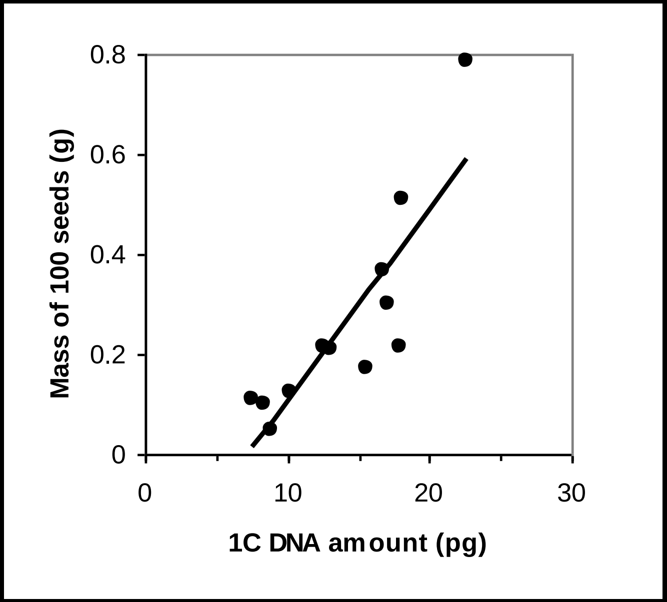


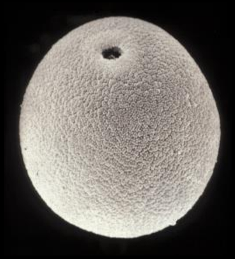
Van't Hof & Sparrow AH. 1963.
Proc. Natl. Acad. Sci. USA **49:** 897-902.

Bennett MD. 1977.
Phil. Trans. Roy. Soc. B **277:** 201-277.

Variation of genome size: Consequences at cell and tissue level







Relationship between pollen volume and DNA amount in 16 grass species.

Bennett *et al*. 1972

Relationship between seed weight and DNA amount in 12 *Allium* species.

Bennett *et al*. 1972

Consequences of variation in DNA amount

Whole plant level

a) **Life cycle options**

b) Life strategy options

c) Ecology options

d) Coping with environmental change

Consequences of variation in DNA amount

Whole plant level

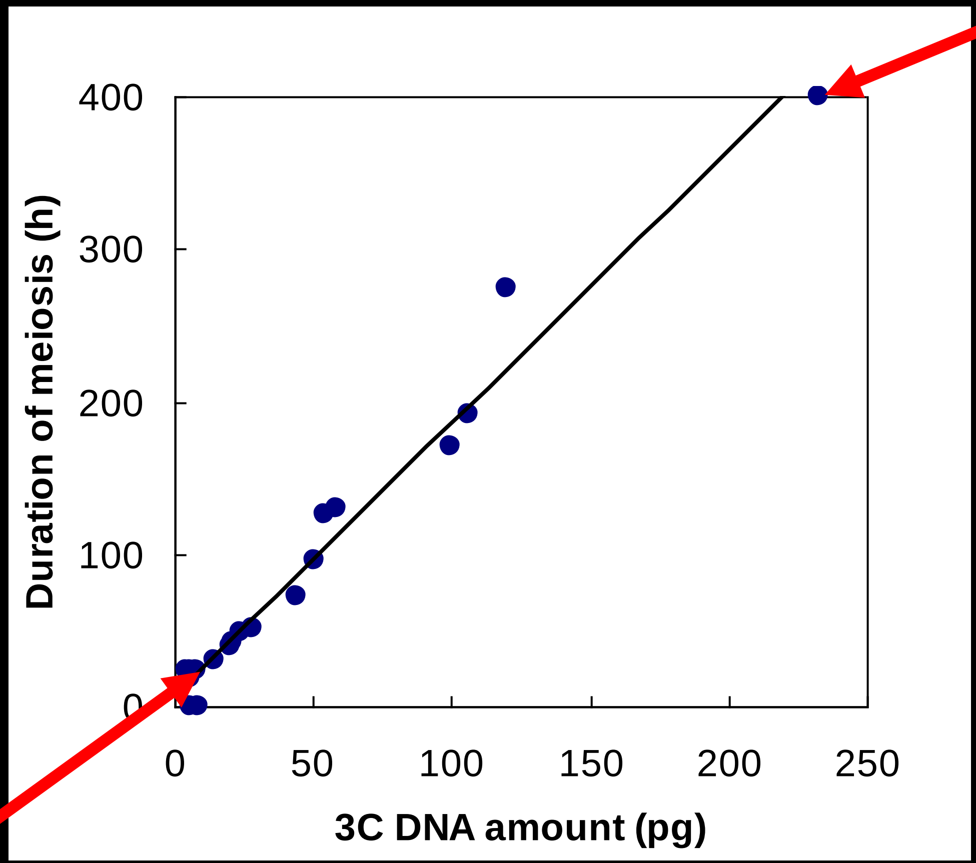
a) Life cycle options

Bennett MD. 1972.

Nuclear DNA content and minimum generation time in herbaceous plants.

Proceedings of the Royal Society of London Series B-Biological Sciences **181:** 109-135.

Consequences: life cycle options

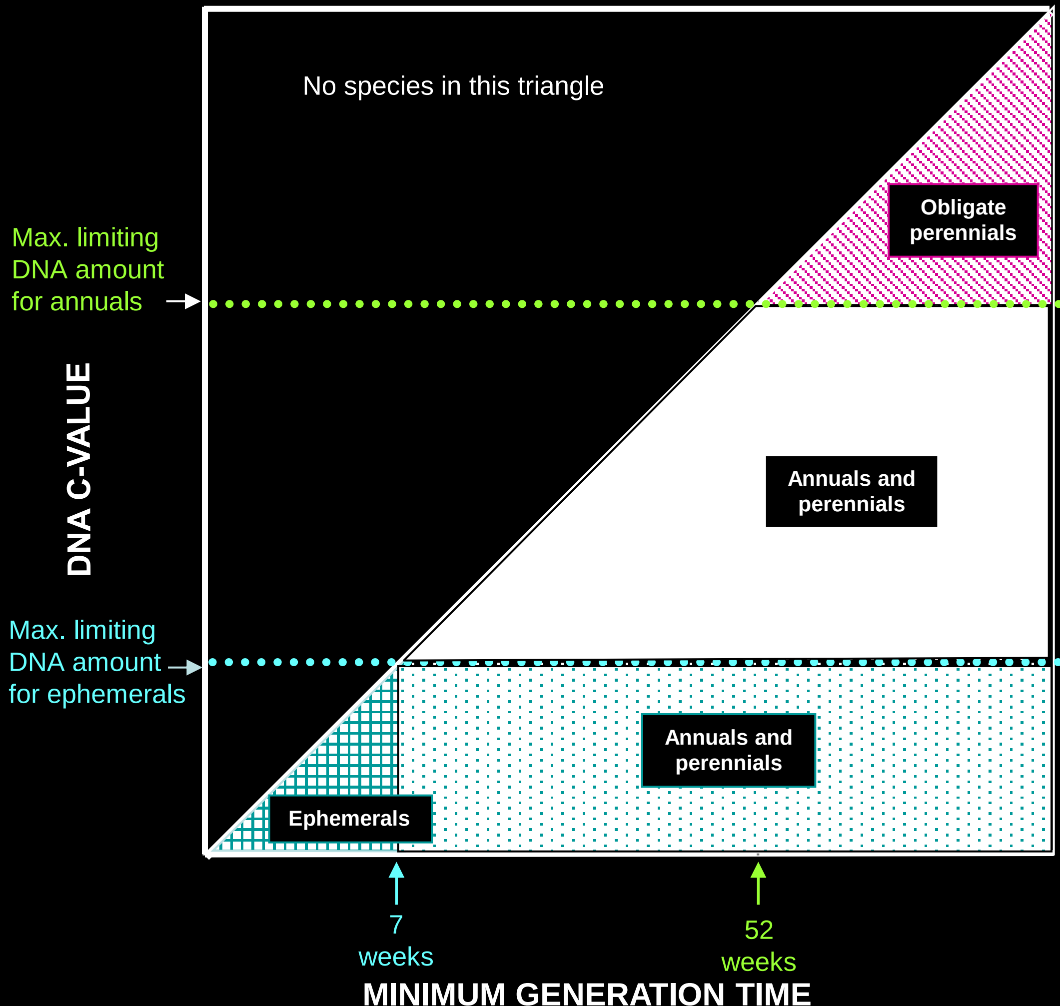


Fritillaria meleagris
1C = 70.7 pg

Arabidopsis thaliana
1C = 0.16 pg

Bennett MD. 1977.
Phil. Trans. Roy. Soc. B **277:** 201-277.

Consequences: life cycle options



Bennett MD. 1972. *Proc. Roy. Soc. Lond. B* **181**: 109-135

Consequences of variation in DNA amount

Life cycle options:

Conclusions

- DNA amount can impose limits on the type of life cycle a species can display
- Species with small genomes may be ephemerals, annuals or perennials
- Species with large genomes are restricted to being obligate perennials

Consequences of variation in DNA amount

Whole plant level

a) Life cycle options

b) Life strategy options

c) Ecology options

d) Coping with environmental change

Consequences of variation in DNA amount

Whole plant level

b) Life strategy options:

Potential to become a weed

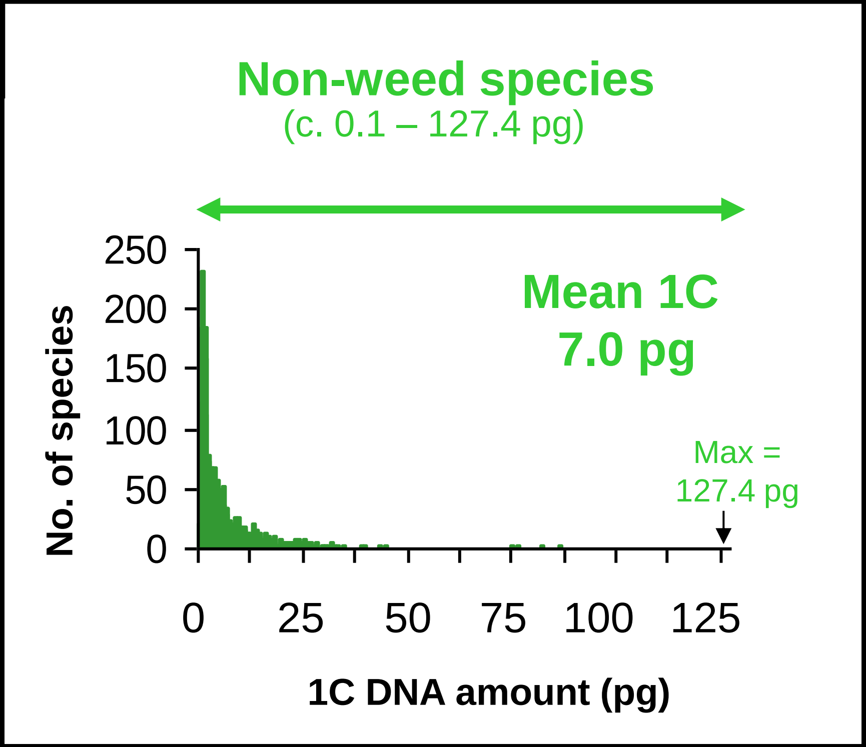
Bennett, Leitch & Hanson. 1998.
DNA amounts in two samples of angiosperm weeds.
Annals of Botany **82:** 121-134.

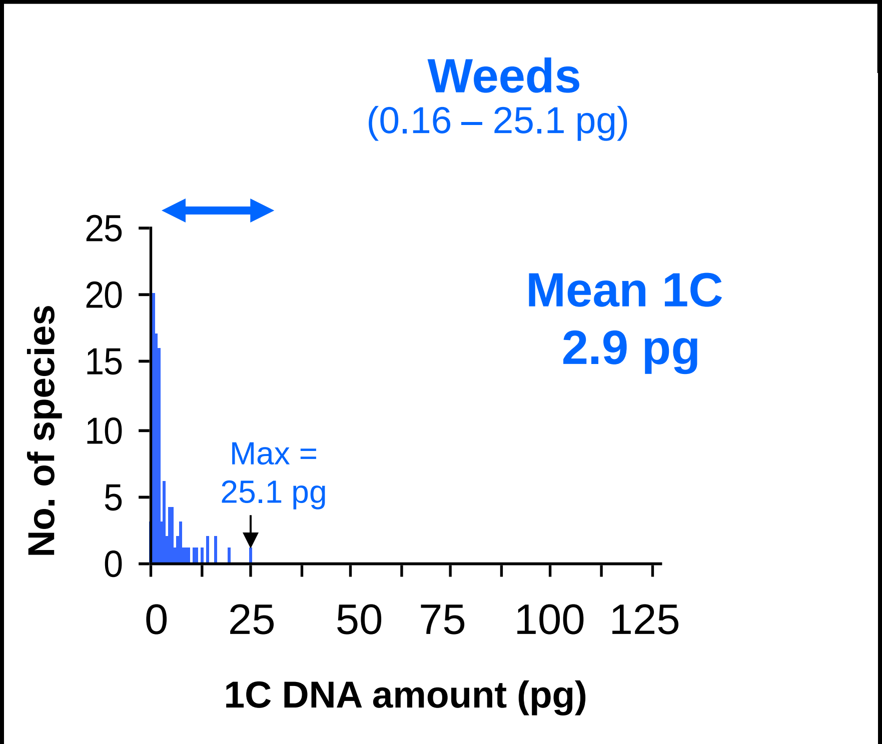
Consequences:
option to be a weed

Method

DNA amounts for 156 angiosperms recognised as weeds compared with 2685 non-weed species

Consequences: option to be a weed





Bennett, Leitch & Hanson. 1998.
DNA amounts in two samples of angiosperm weeds.
Annals of Botany **82:** 121-134.

Success of an invasive weed

- Rapid establishment or completion of reproductive development
- Short generation time
- Rapid production of many small seeds

Consequences of variation in DNA amount

Whole plant level

a) Life cycle options

b) Life style options

c) Ecology options

d) Coping with environmental change

Genome size and latitude

Pop.	Several *Picea sitchensis*	Miksche 1967, 1971
Sp.	Tropical vs. temperate grasses	Avdulov 1931
Sp.	329 tropical vs. 527 temperate plants	Levin and Funderburg 1979
Sp.	17 Poaceae and 15 Fabaceae crops	Bennett 1976
Pop.	24 *Berberis* in Patagonia	Bottini *et al.* 2000

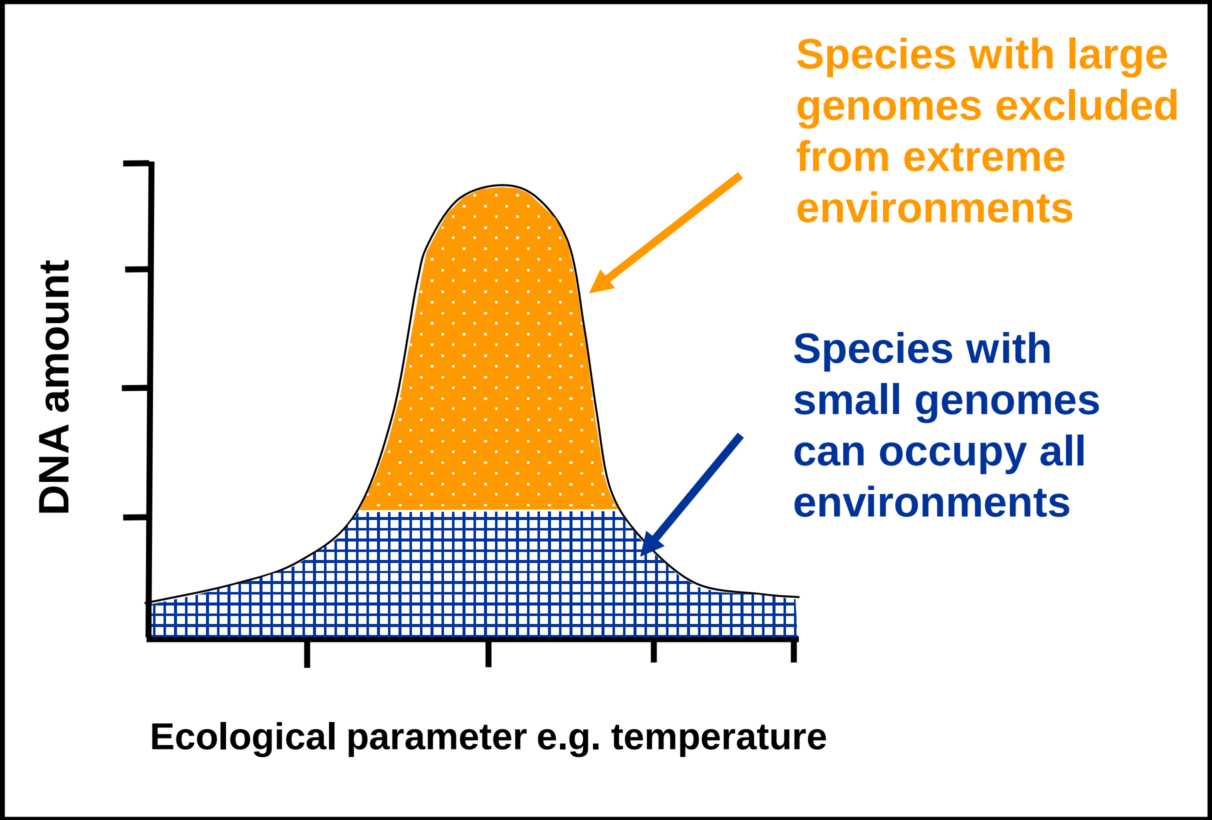
+ correlation

Consequences: ecology options

401 species in the state of California

Knight & Ackerly. 2002.
Variation in nuclear DNA content across environmental gradients: a quantile regression analysis.
Ecology Letters **5:** 66-76.

Consequences: ecology options



Knight & Ackerly. 2002.
Ecology Letters **5:** 66-76.

Consequences: ecology options

Summary

- The relationship between genome size and environmental factors is not uniform but appears to be stronger for species with large genomes
- Species with large genomes are excluded from extreme environments

Consequences of variation in DNA amount

Whole plant level

a) Life cycle options

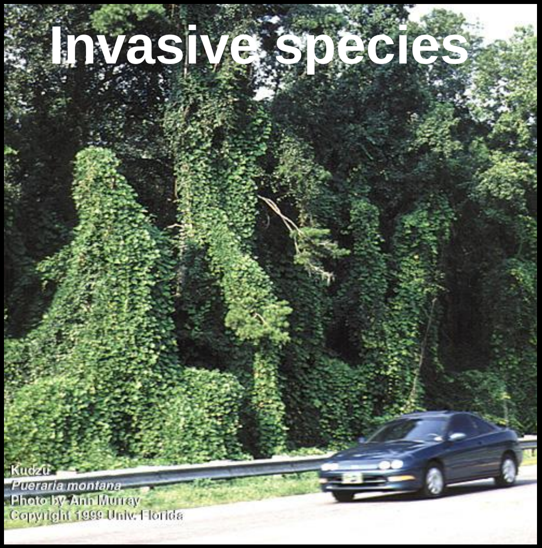
b) Life style options

c) Ecology options

d) Coping with environmental change

Threat of extinction

Consequences:
Genome size and threat of extinction



Is genome size important?

Vinogradov AE. 2003.
Selfish DNA is maladaptive: evidence from the plant Red List.
Trends in Genetics **19:** 609-614.

Consequences:
Genome size and threat of extinction

Data and analysis

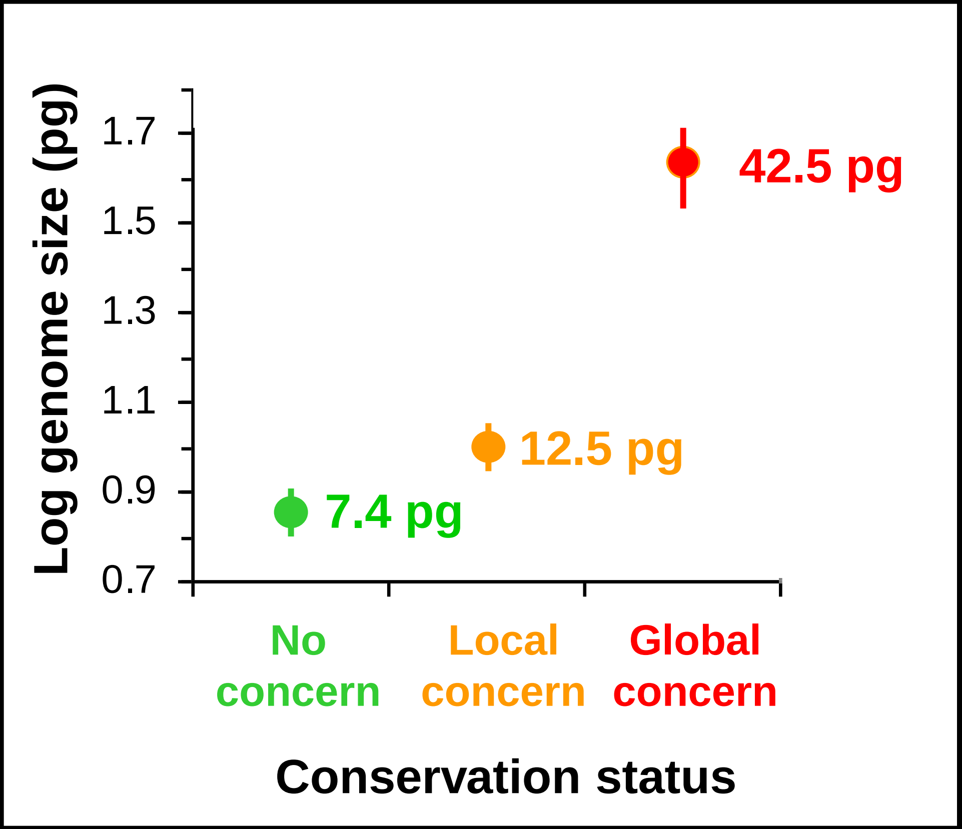
Plant DNA C-values database → 3036 species → UNEP WCMC

- → Global concern = 305
- → Local concern = 1329
- → No concern = 1402

Vinogradov AE. 2003.
Selfish DNA is maladaptive: evidence from the plant Red List.
Trends in Genetics **19:** 609-614.

Consequences:
Genome size and threat of extinction

Results



Vinogradov AE. 2003.
Trends in Genetics **19:** 609-614.

Consequences:
Genome size and threat of extinction

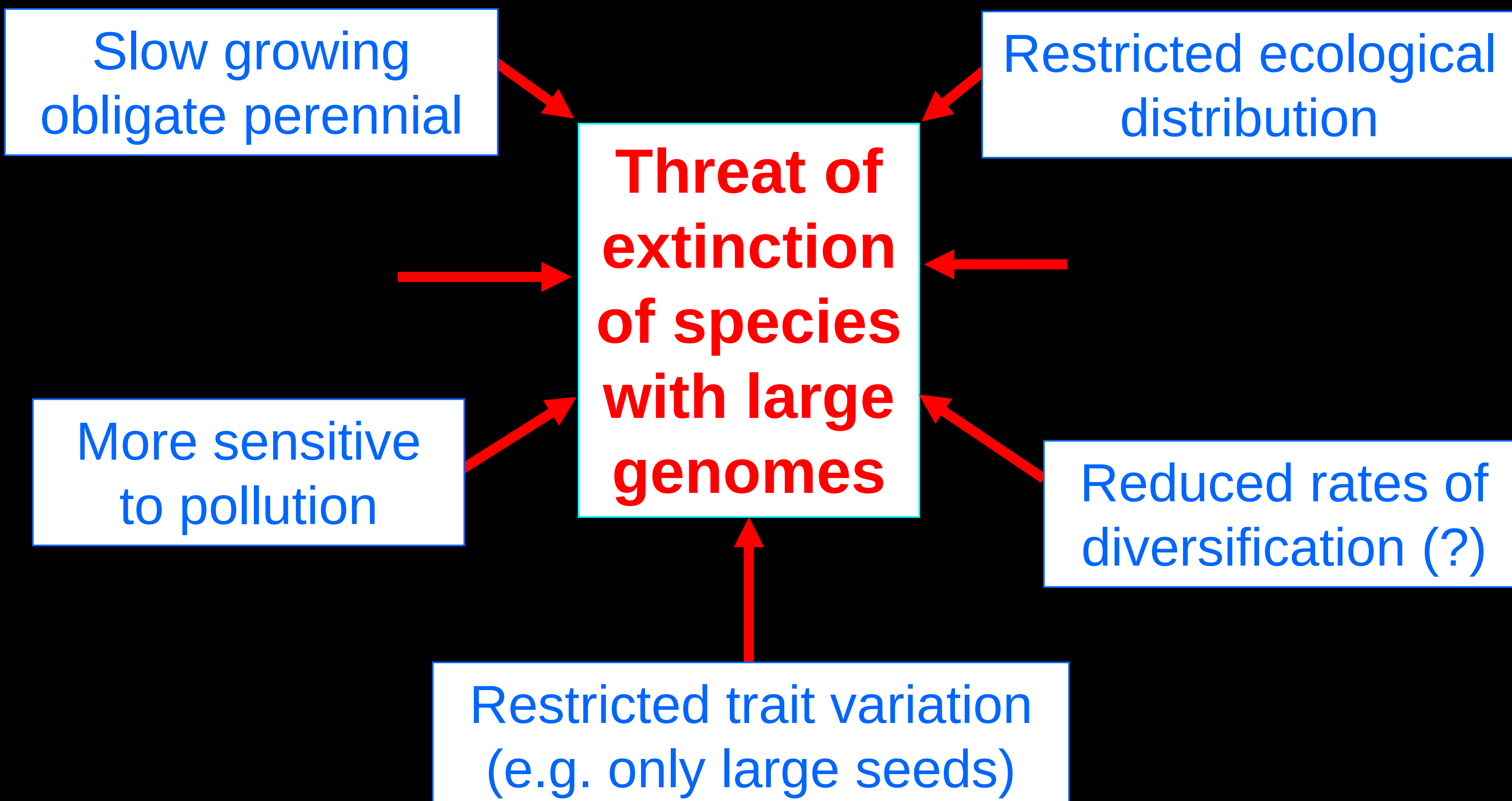
Conclusions

Species with large genomes are at greater risk of extinction than those with small genomes.

- Independent of life cycle type (at least partially)

- Independent of polyploidy

Consequences:
Genome size and threat of extinction



DNA amount variation and consequences

Summary

- Huge variation in DNA amount in plants
- Consequences of this variation visible at:
  - Cellular level
  - Tissue level
  - Whole organism level
- Possession of large genomes appear to impose constraints which operate at:
  - Functional level
  - Ecological level
  - Evolutionary level