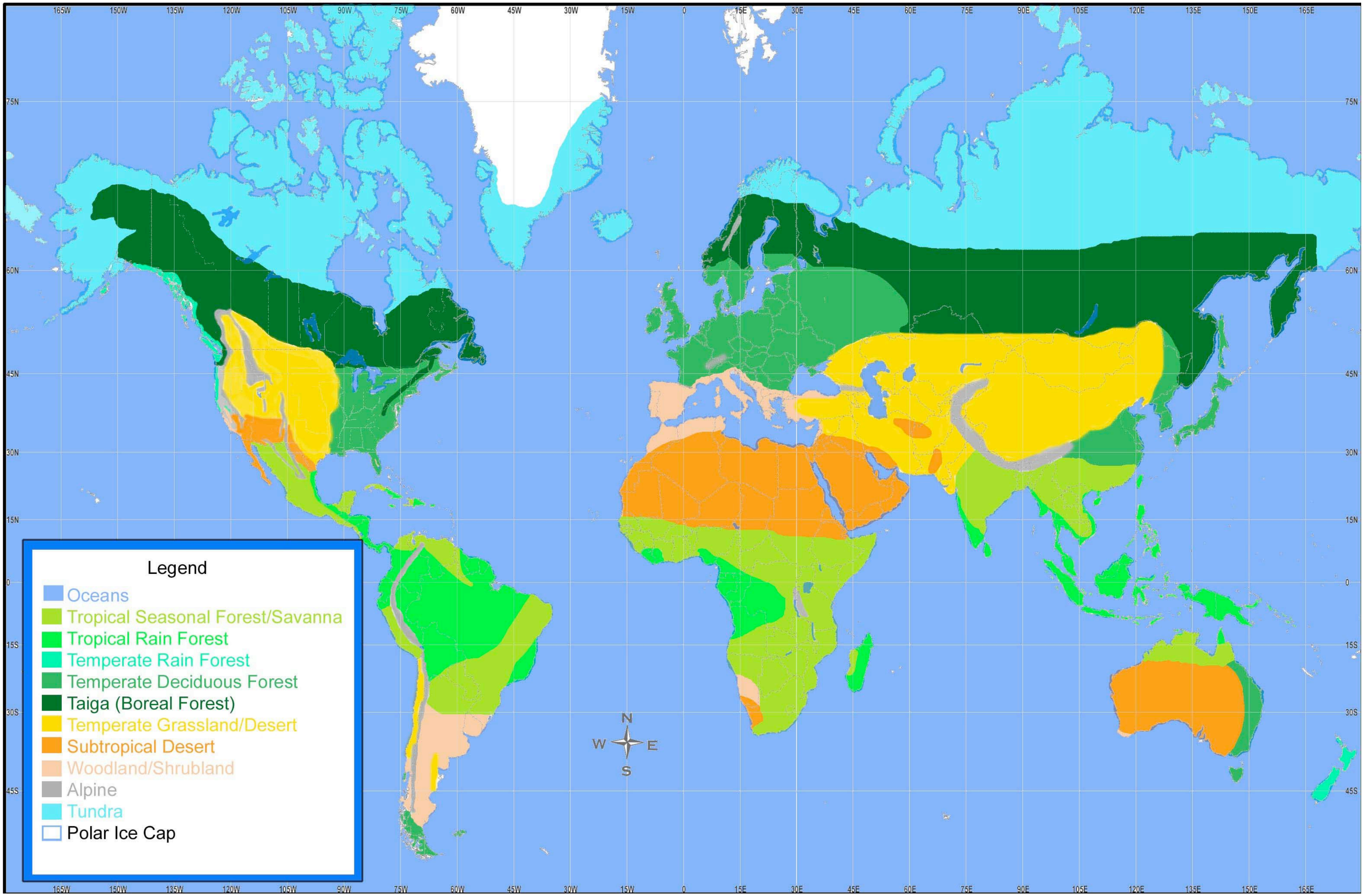
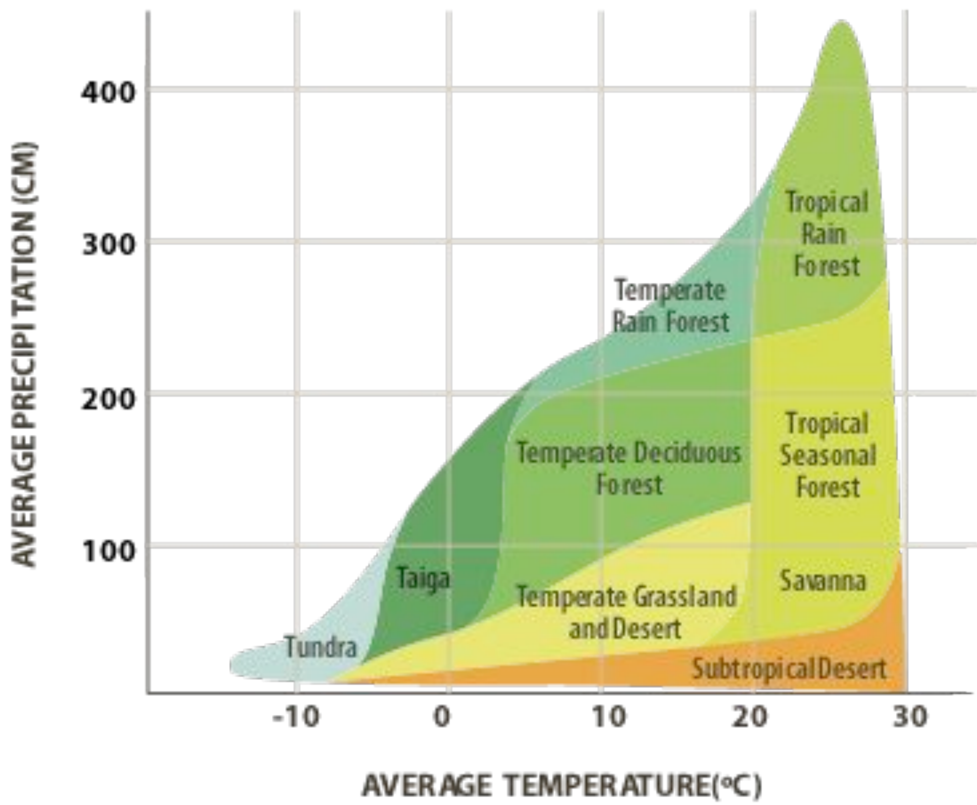
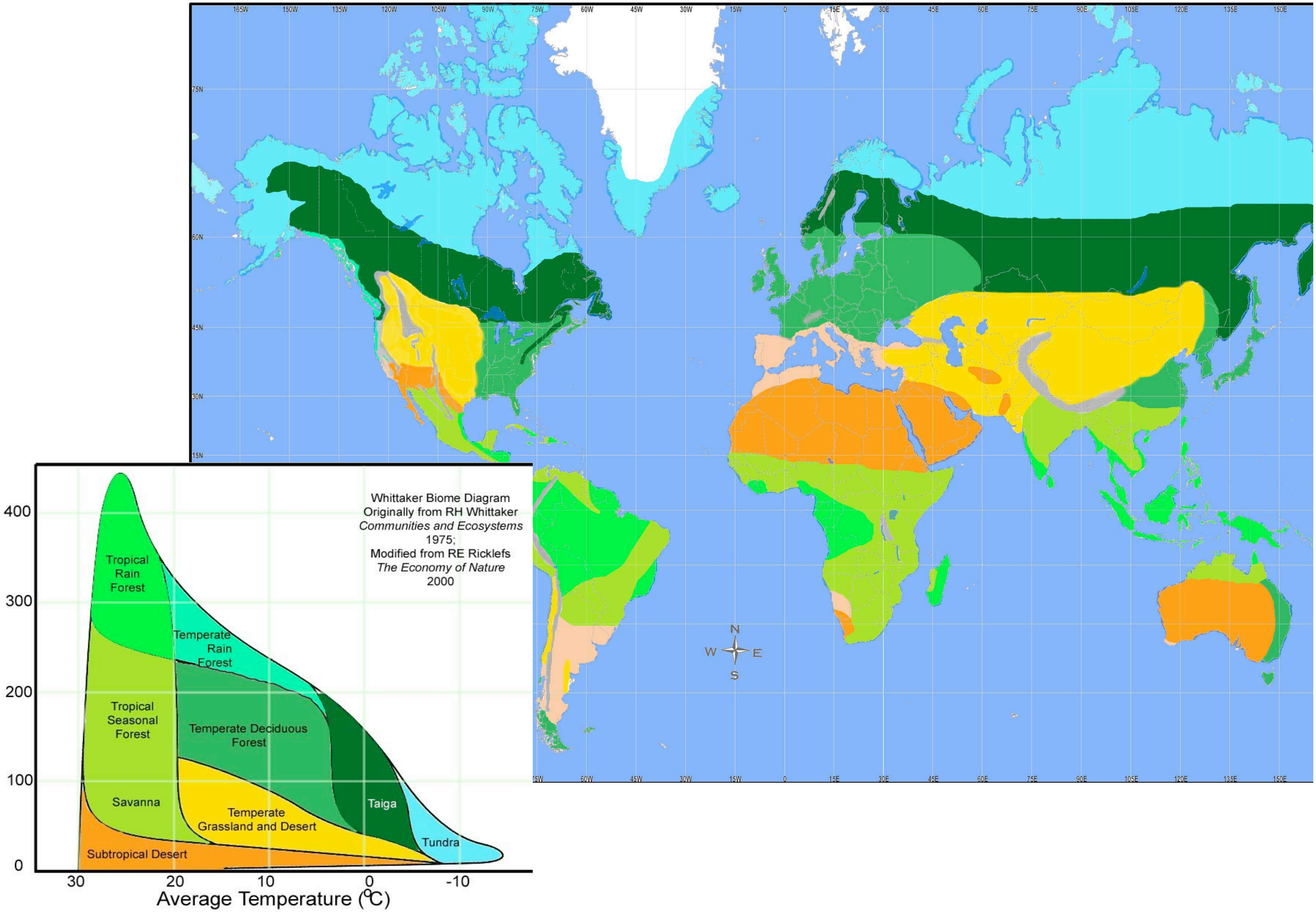


http://www.marietta.edu/~biol/biomes/



400
300
200
100
AVERAGE PRECIPITATION (CM)
-10
0
10
20
30
AVERAGE TEMPERATURE(°C)
Tropical Rain Forest
Temperate Rain Forest
Tropical Seasonal Forest
Temperate Deciduous Forest
Taiga
Savanna
Temperate Grassland and Desert
Tundra
Subtropical Desert



http://www.marietta.edu/~biol/biomes/

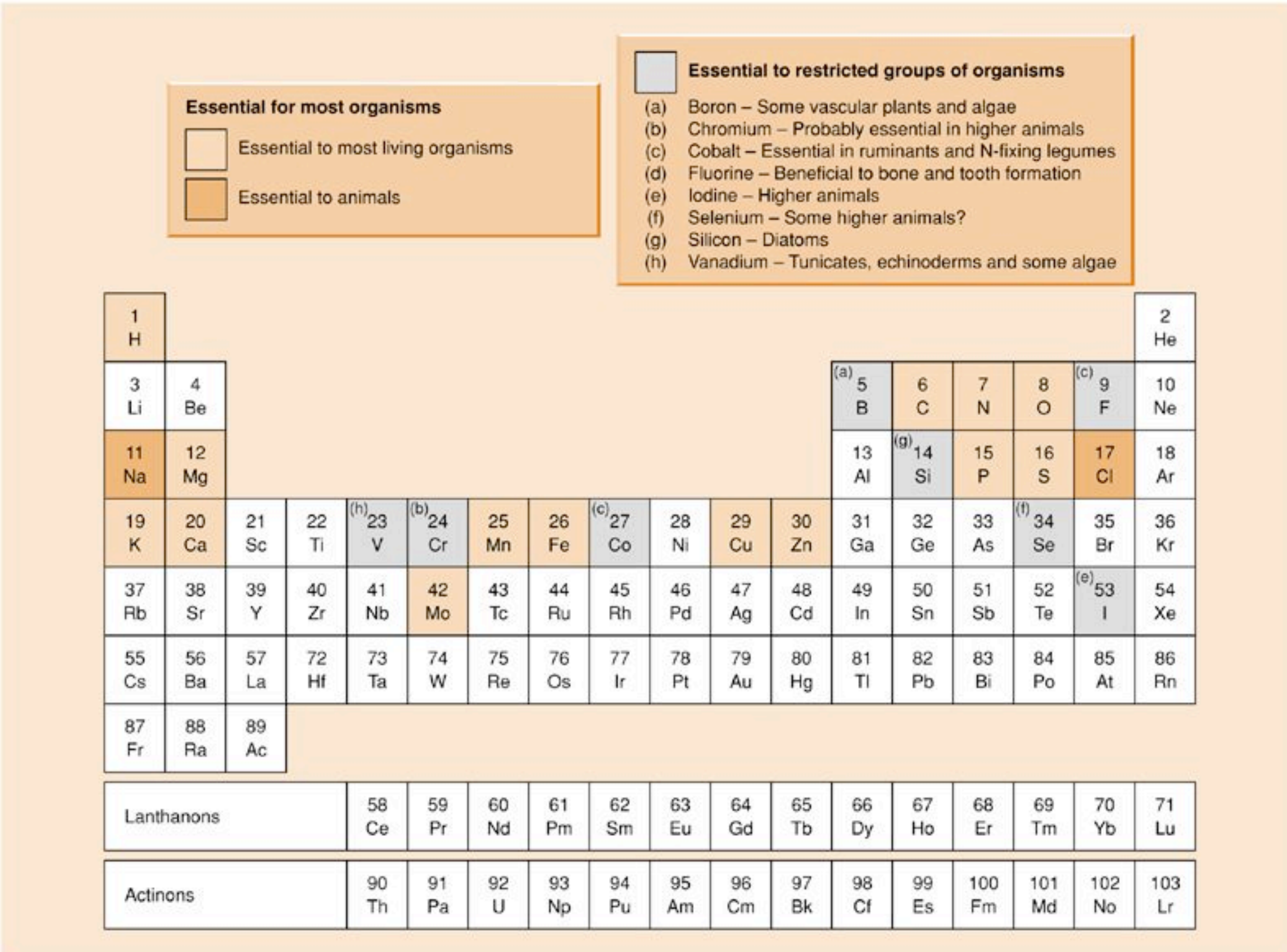
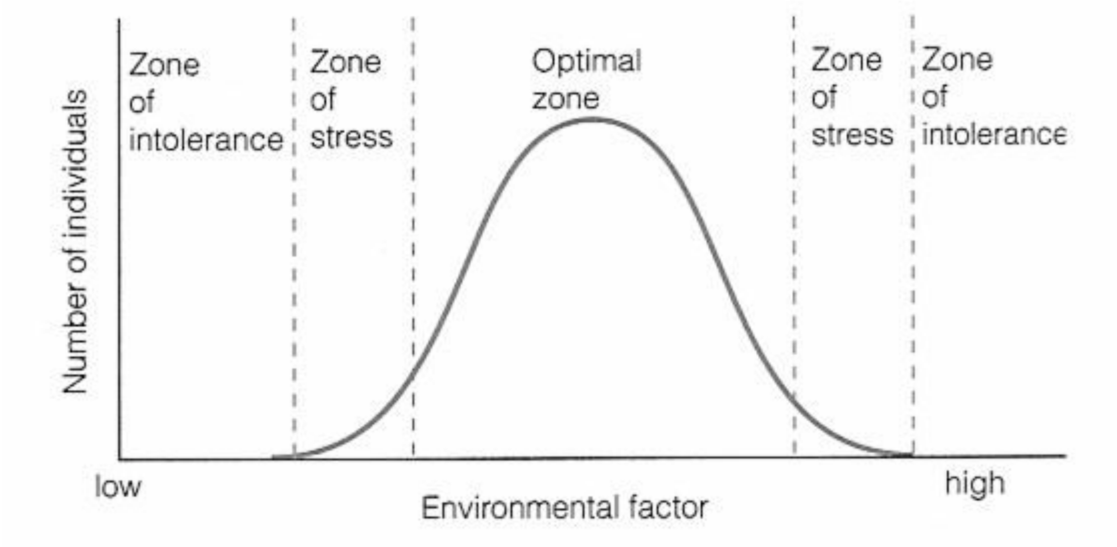
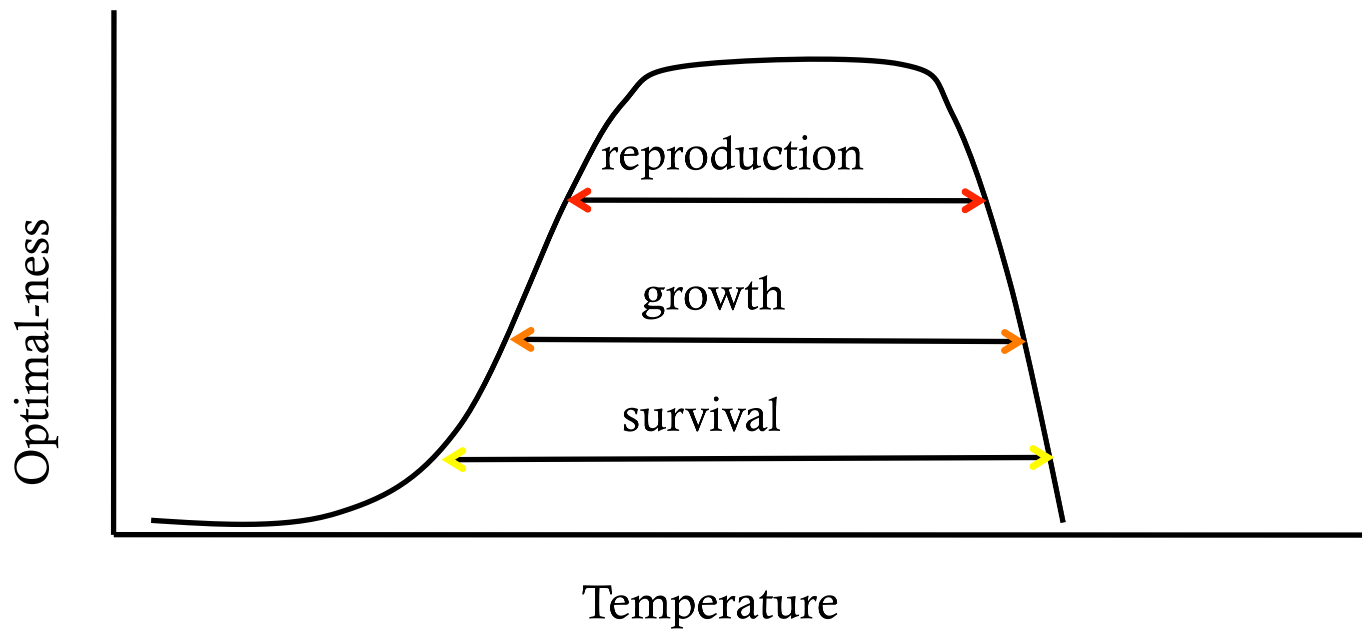


Figure 3.18 Periodic table of the elements showing those that are essential resources in the life of various organisms.



Physiological tolerances

- narrower limits for reproduction than growth than survival
- not necessarily symmetric



Lyme disease

Symptoms:

- Fatigue, chills, fever, muscle & joint aches
- **Erythema migrans**
- **Bell's palsy**
- Severe headaches & neck pain from meningitis
- **Arthritis, with severe joint pain and swelling**

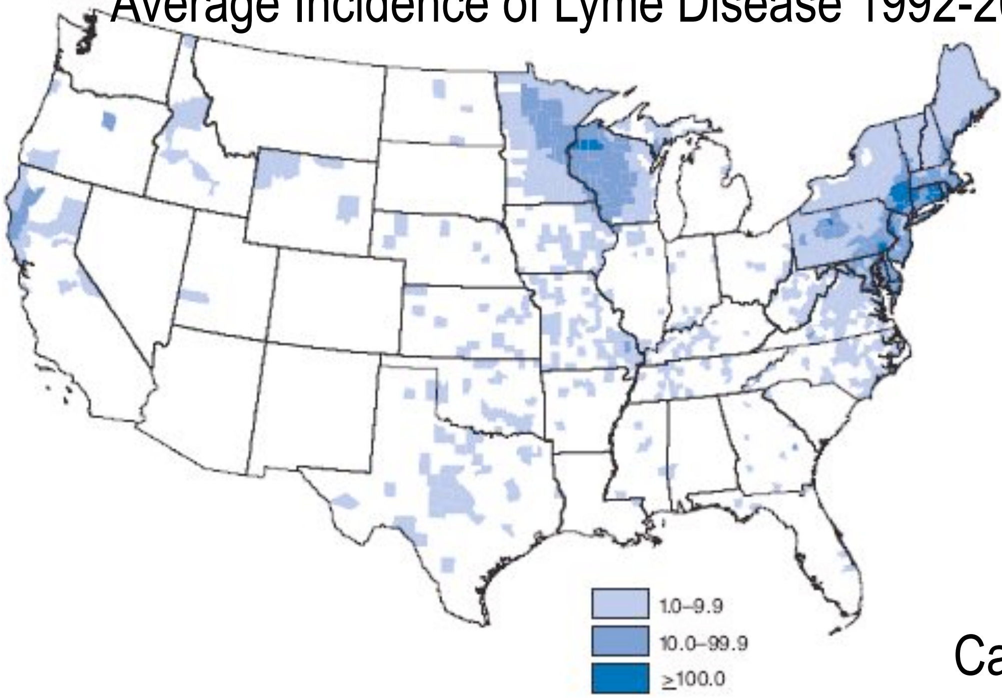
Easily treated <u>if</u> detected early, but...

Poor diagnostic tests

No vaccine for humans

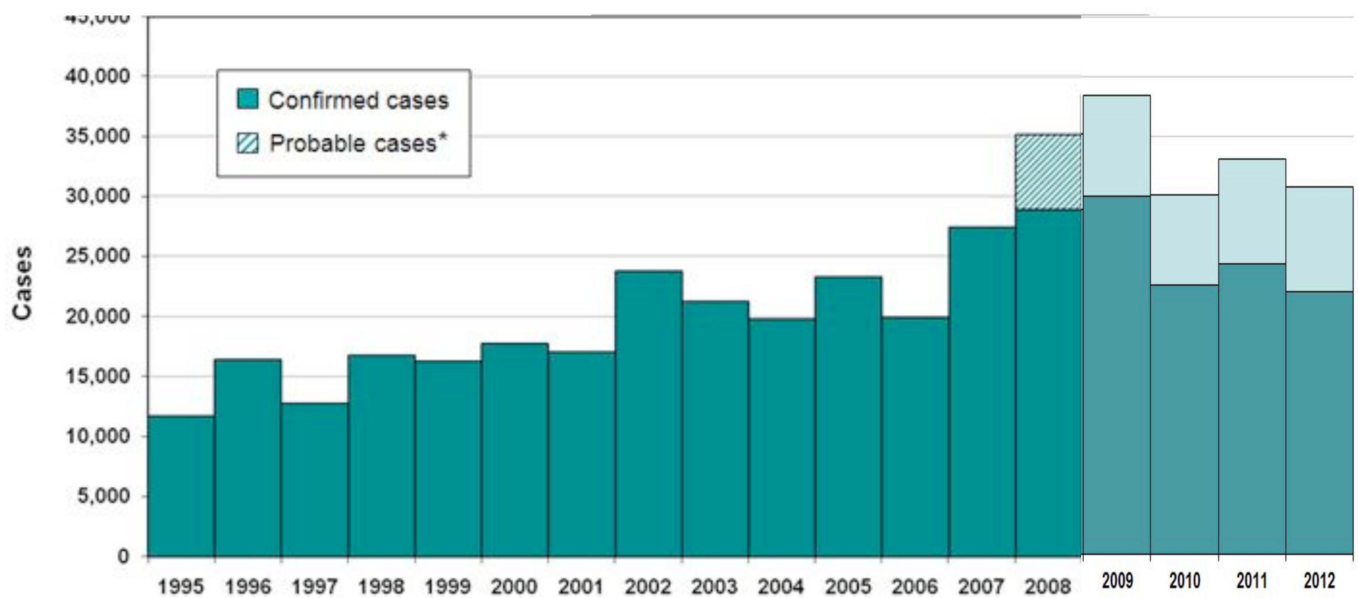
--> <u>avoid infected ticks</u>

Average Incidence of Lyme Disease 1992-2006



An emerging zoonotic disease

Cases of Lyme Disease 1995-2009



http://www.cdc.gov/ncidod/dvbid/lyme/

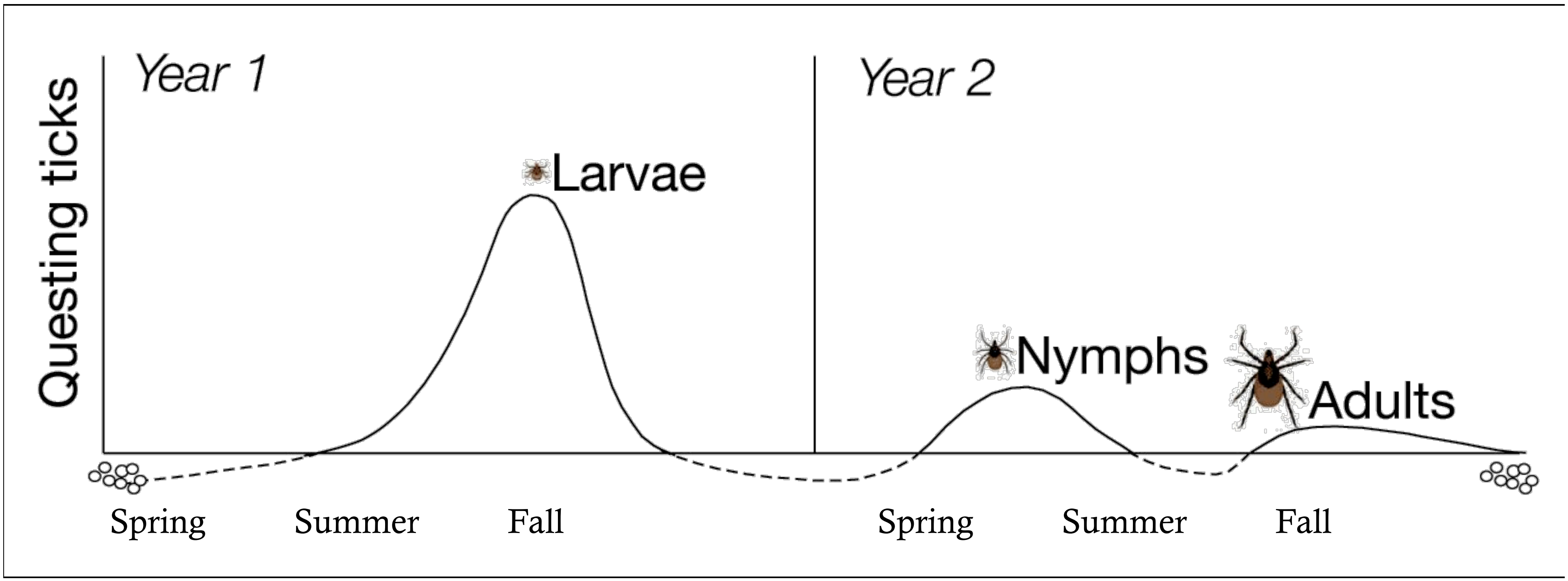
Life cycle of *Ixodes scapularis*

Each life stage takes a single blood meal

Juvenile stages feed primarily on small mammals & birds

Adults feed primarily on deer

Ticks become infected by feeding on infected hosts



Life cycle of *Ixodes scapularis*

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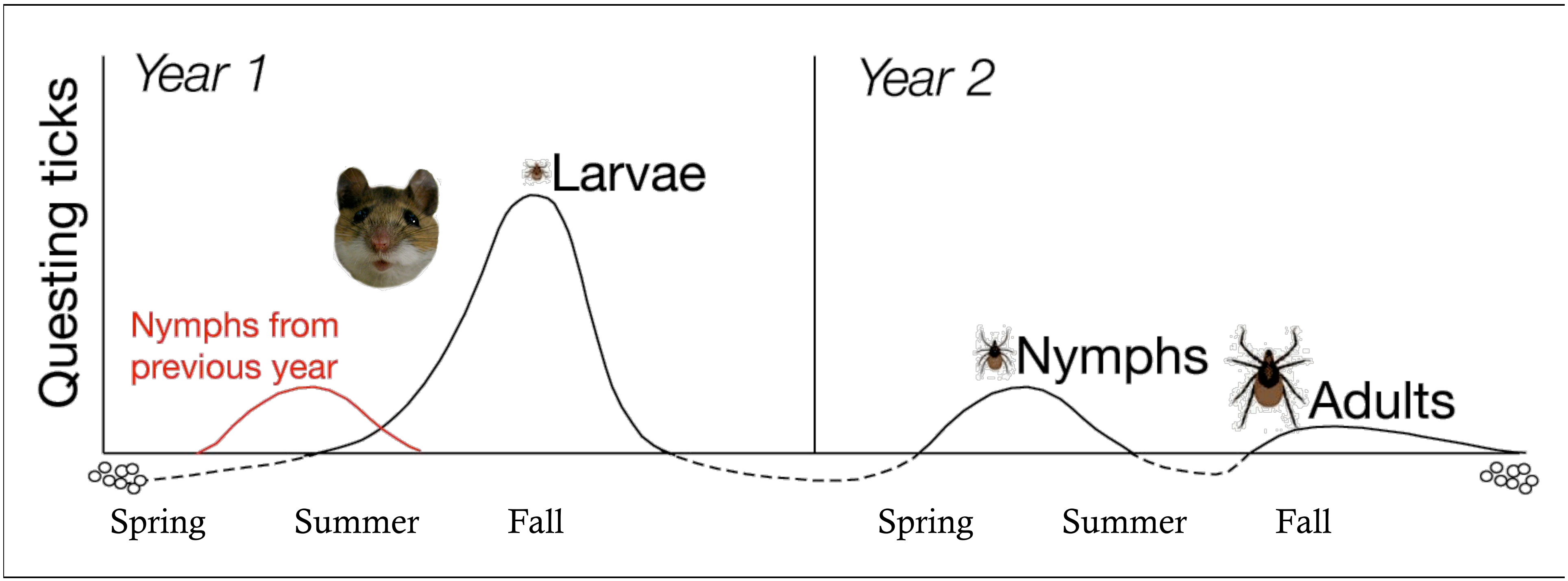


Survival of *Ixodes scapularis* (Acari: Ixodidae) Exposed to Cold

J. Med. Entomol. 33(1): 6–10 (1996)

JOHN K. VANDYK, DAVID M. BARTHOLOMEW,[1]
WAYNE A. ROWLEY, AND KENNETH B. PLATT[2]

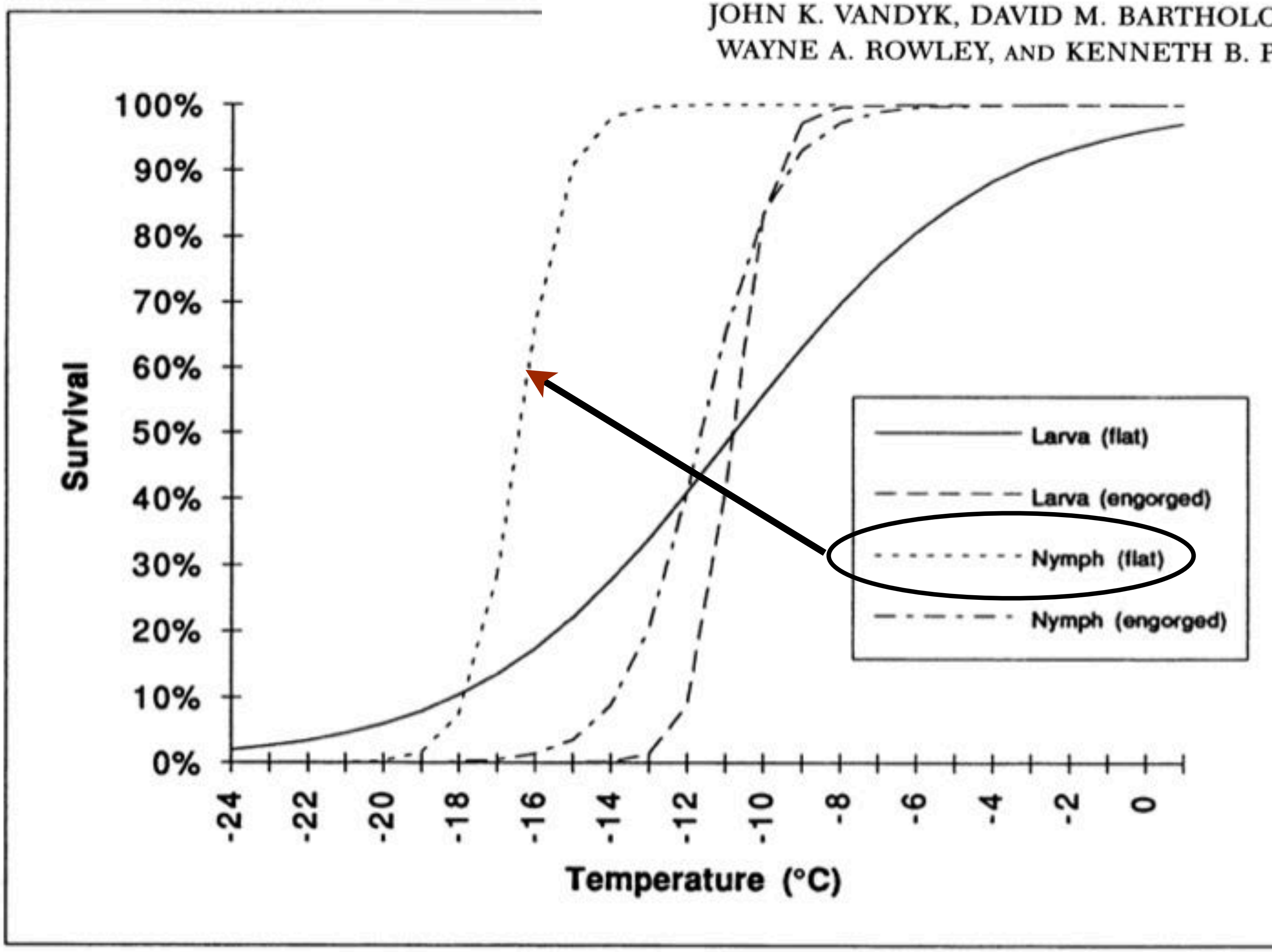


Fig. 1. Survival of *I. scapularis* life stages after 8 h exposure to cold.

The role of direct chilling injury and inoculative freezing in cold tolerance of *Amblyomma americanum*, *Dermacentor variabilis* and *Ixodes scapularis*

CHARLES S. BURKS, RICHARD L. STEWART, Jr,*
GLEN R. NEEDHAM* and RICHARD E. LEE, Jr

Physiological Entomology (1996) **21**, 44–50

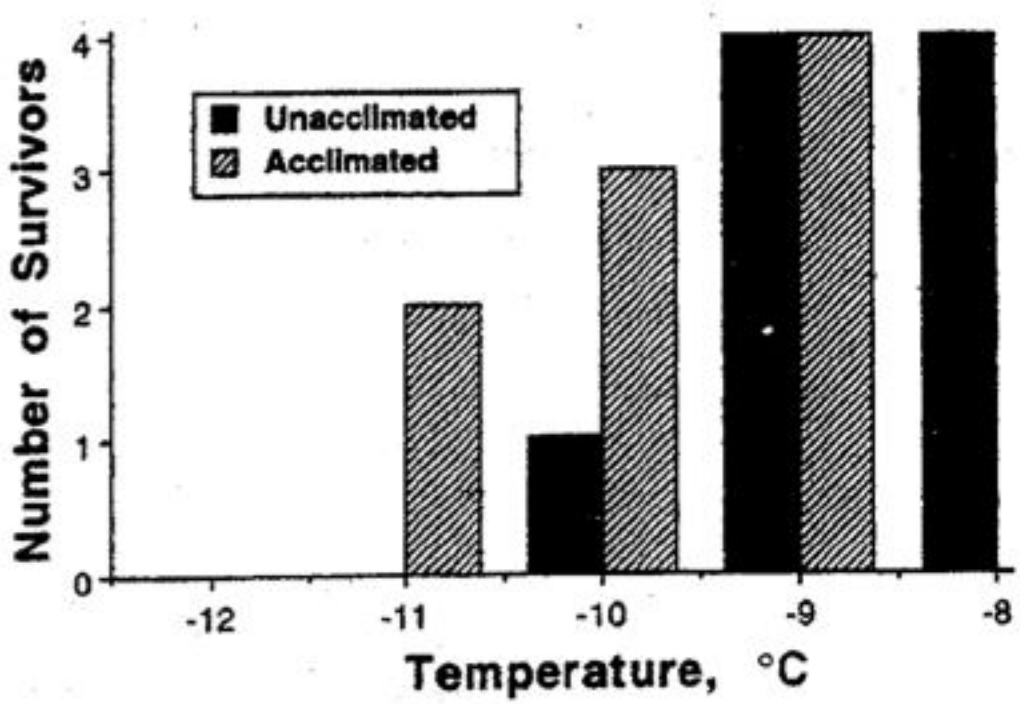


Fig. 3. Survivorship of *Ixodes scapularis* nymphs chilled for 2 h at sub-zero temperatures. Nymphs were either unacclimated, or were acclimated by exposure for 7 weeks to 4°C and LD 10:14 h.

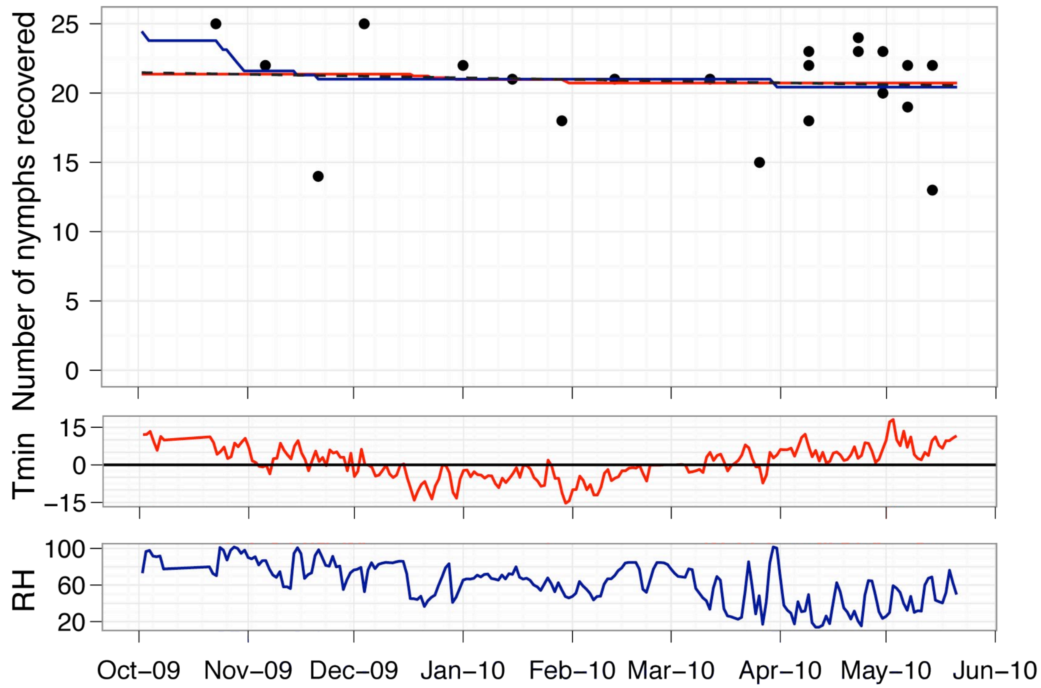
But ticks *exposed to ice* died at
-3° to -4°C !

--> direct chilling injury

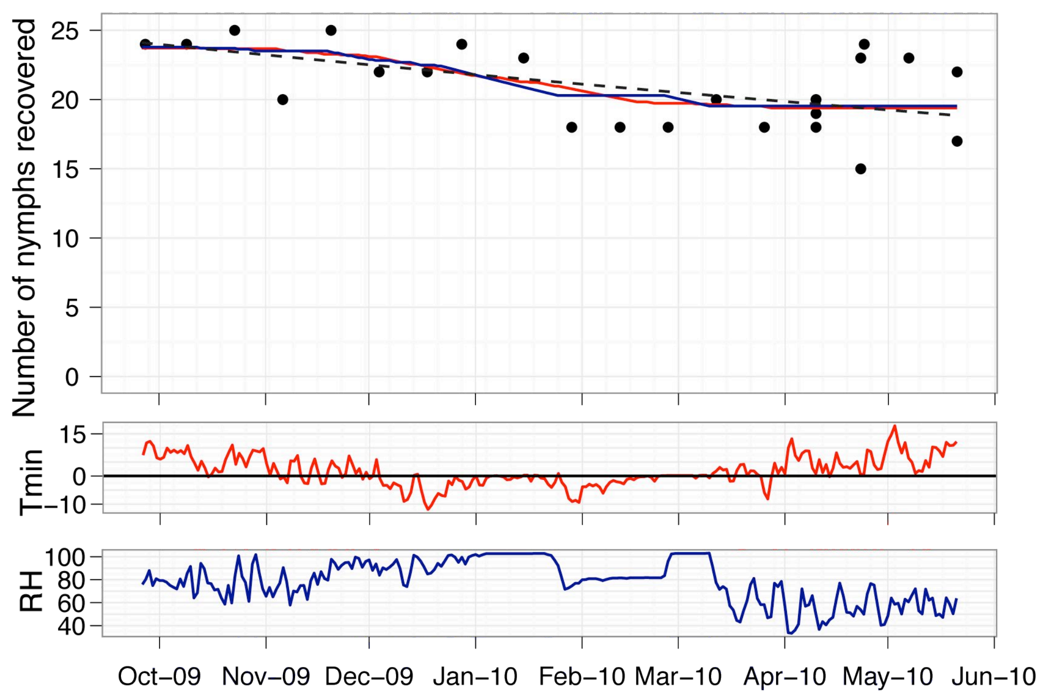
Overwintering survival of newly molted nymphs

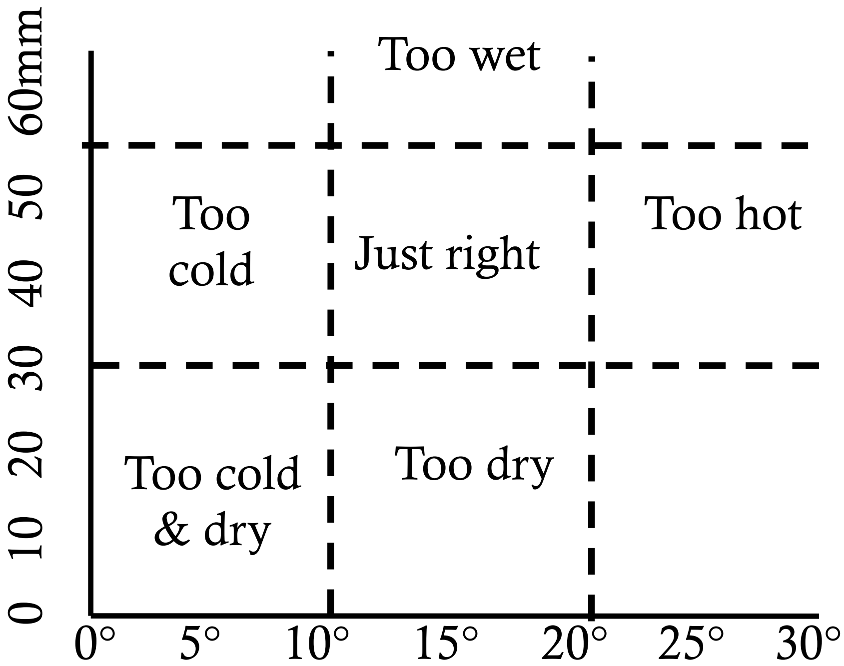
Placed ticks in soil cores in organdy mesh bags

The next spring dug them up and counted surviving nymphs

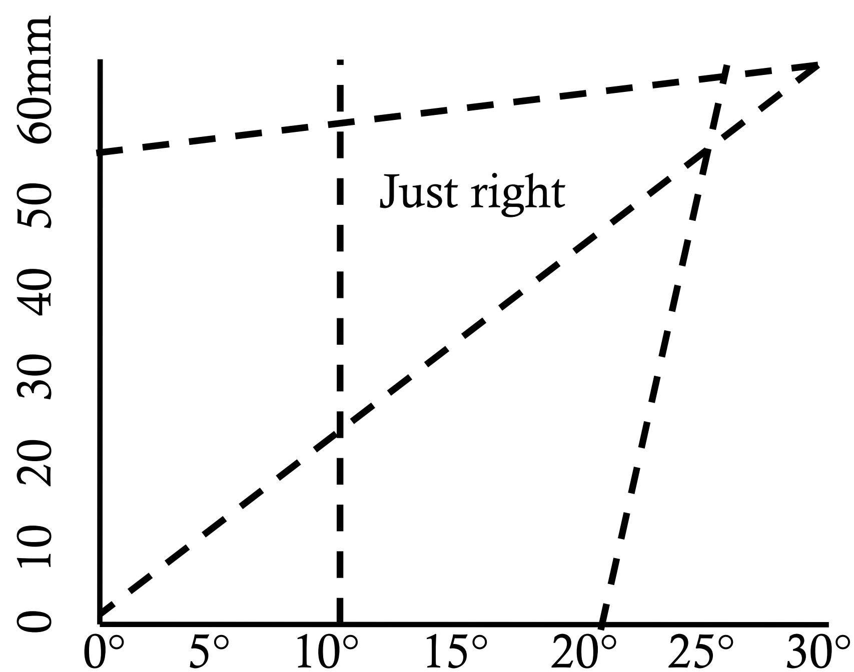


It got quite cold (and wet), well beyond their lethal limits, but ticks survived
Presumably they found *somewhere* to hide to avoid freezing

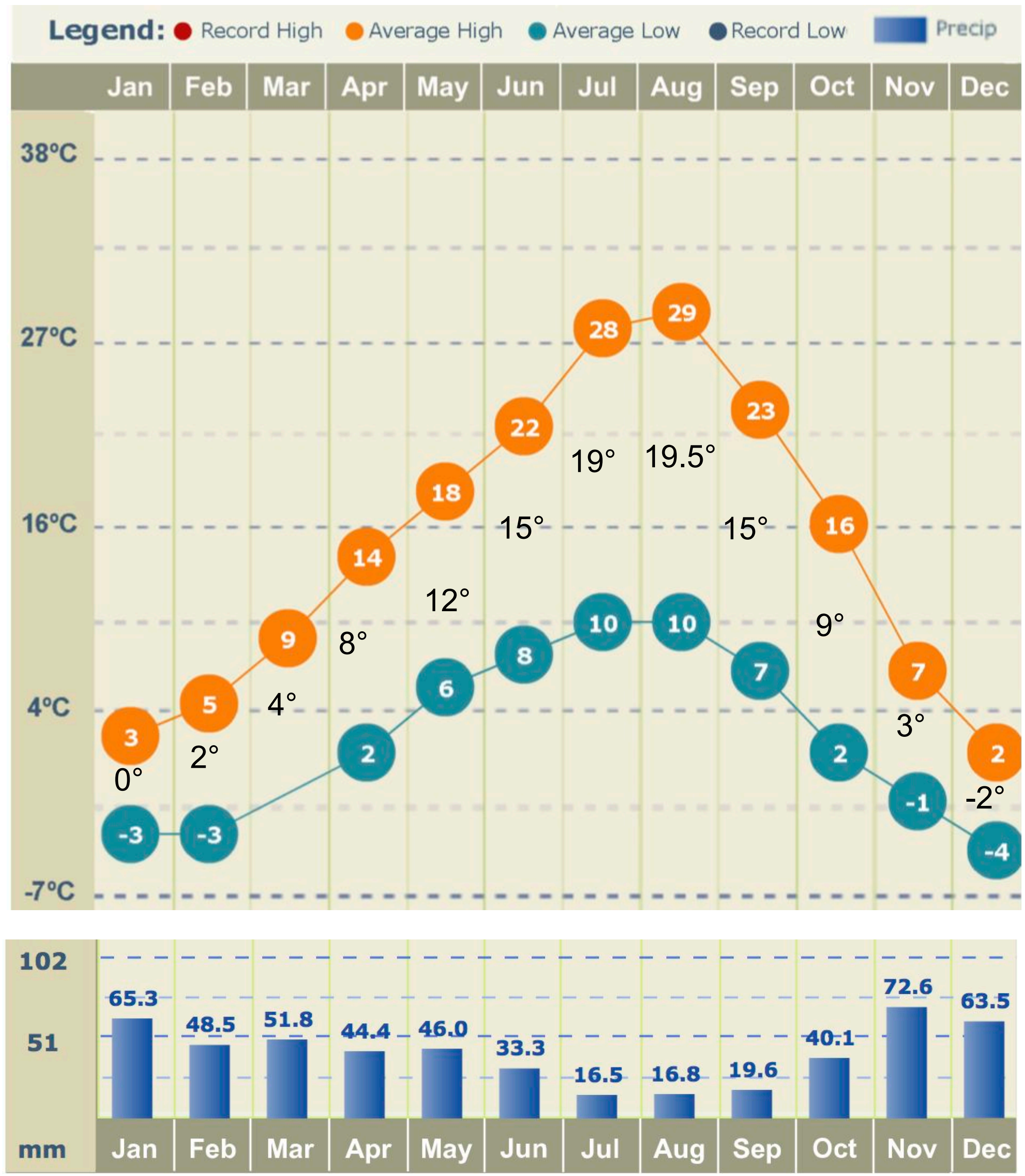




There are often *many* conditions that matter

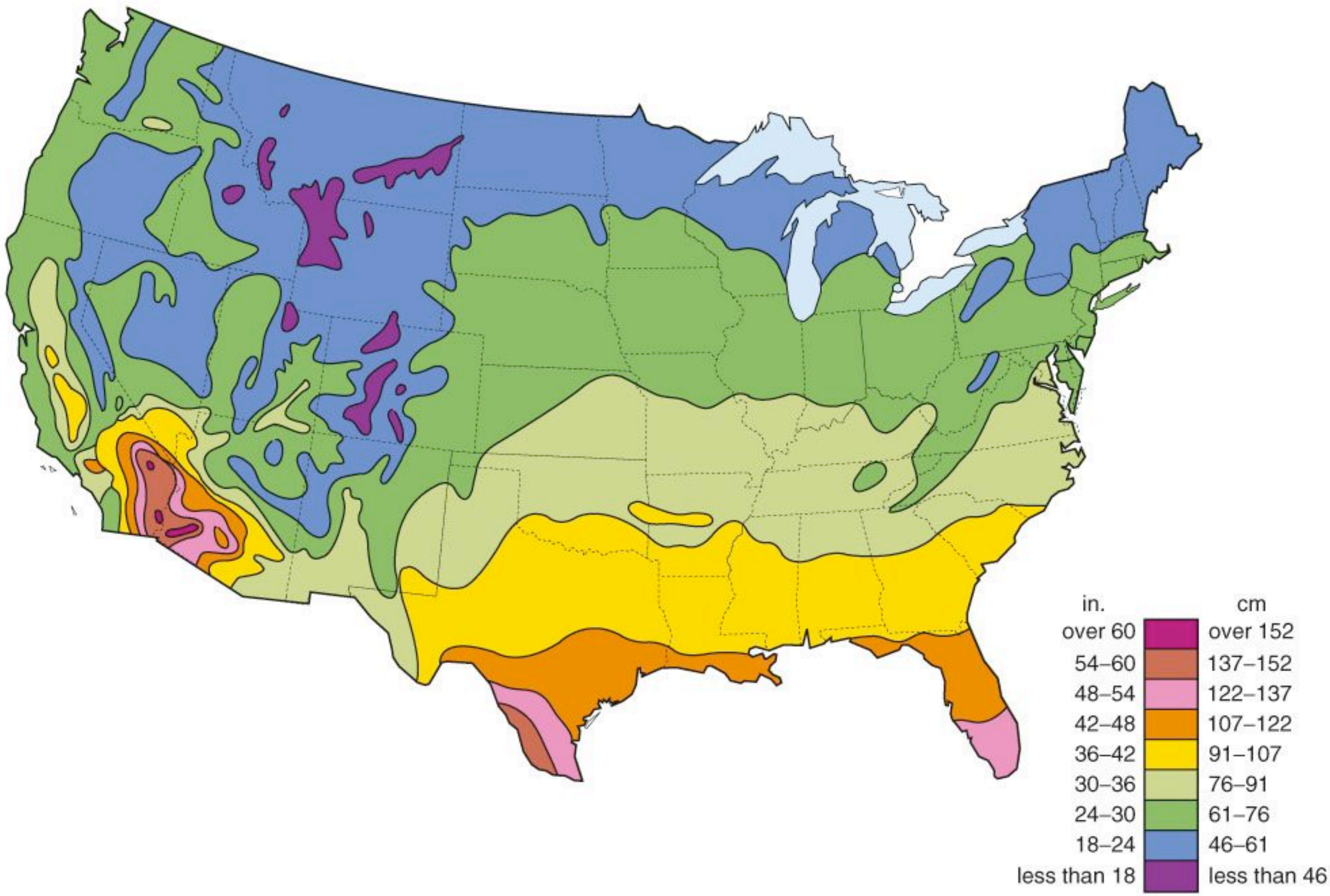


Tolerances are not independent of one another



Legend: Record High Average High Average Low Record Low Precip
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
38°C
27°C
16°C
4°C
-7°C
3 5 9 14 18 22 28 29 23 16 7 2
0° 2° 4° 8° 12° 15° 19° 19.5° 15° 9° 3° -2°
-3 -3 2 6 8 10 10 7 2 -1 -4
102
51
mm
65.3 48.5 51.8 44.4 46.0 33.3 16.5 16.8 19.6 40.1 72.6 63.5
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec

Potential evapotranspiration



http://www.geogrify.net/GEO1/Lectures/Weather/Humidity.html

Law of the minimum (Justus von Leibig)

Growth and reproduction are limited by the scarcest resource

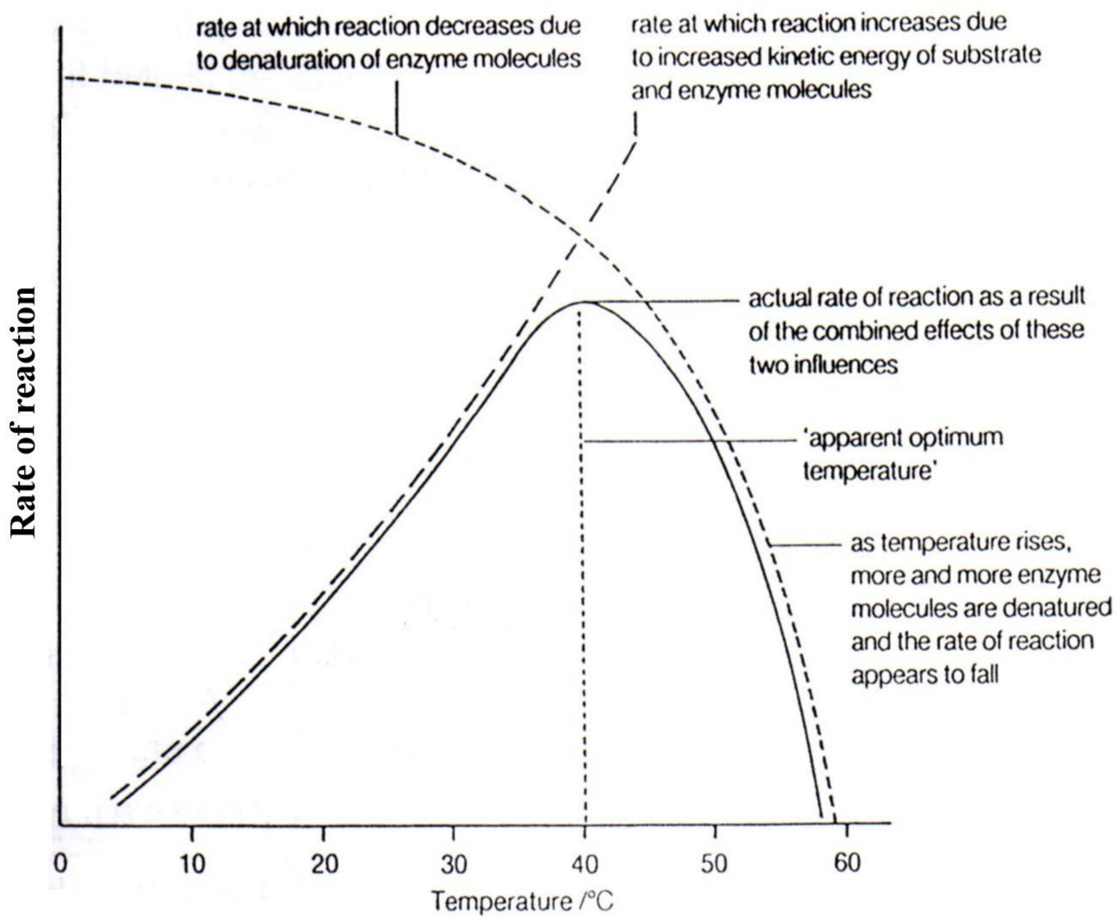
Law of tolerances (V.E. Shelford)

What is limiting in one place (e.g., leads to an edge of the range) may be unimportant elsewhere.

Q10 = (rate @ temp T) / (rate @ temp T - 10°C)

The increase in the rate at which an enzymatic reaction rate or physiological process with a 10°C increase in temperature

Q10 ≈ 2 (i.e., doubles w/ 10°C) up to 3, usually

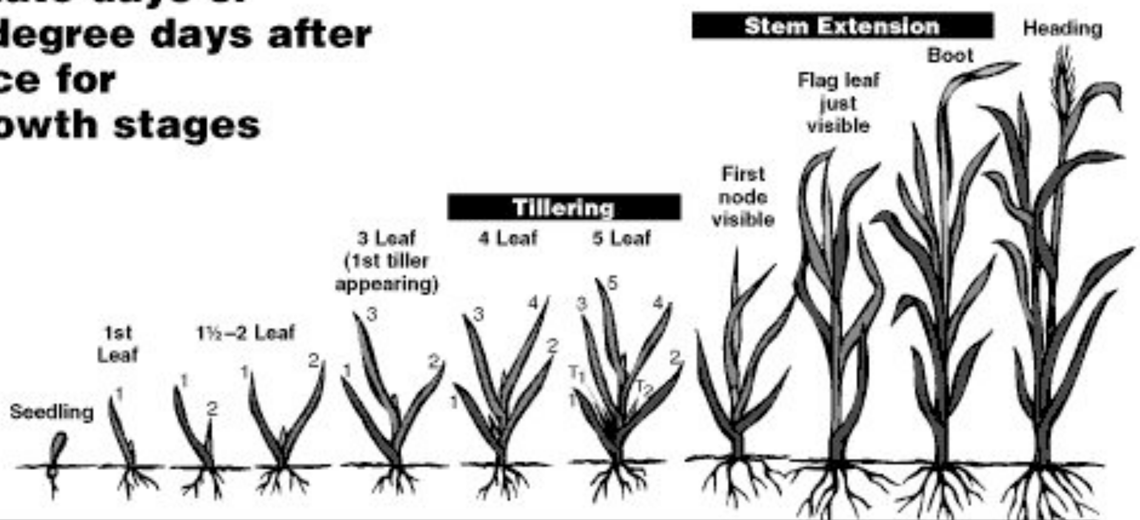


http://library.thinkquest.org/C005053/factors.htm

- Over most ecologically relevant temperature ranges, this can be approximated by a linear relationship
- Never increases forever (degradation or other lethal effects)
- Accumulation of "growing degree days" is often useful for measuring developmental time

Growing degree days = days * temperature > 0°C

Approximate days or growing degree days after emergence for wheat growth stages



	1st Leaf	1½–2 Leaf	3 Leaf	4 Leaf	5 Leaf	First node visible	Flag leaf just visible	Boot	Heading
Early Planting (days)	7-8	14-16	20-22	26-28	31-33	34-36	44	53	58
Late Planting (days)	6-7	11-13	16-18	21-23	25-27	28-31	38	45	49
Growing Degree Day* (units)	72	144-215	358	501	644	715	1075	1359	1500

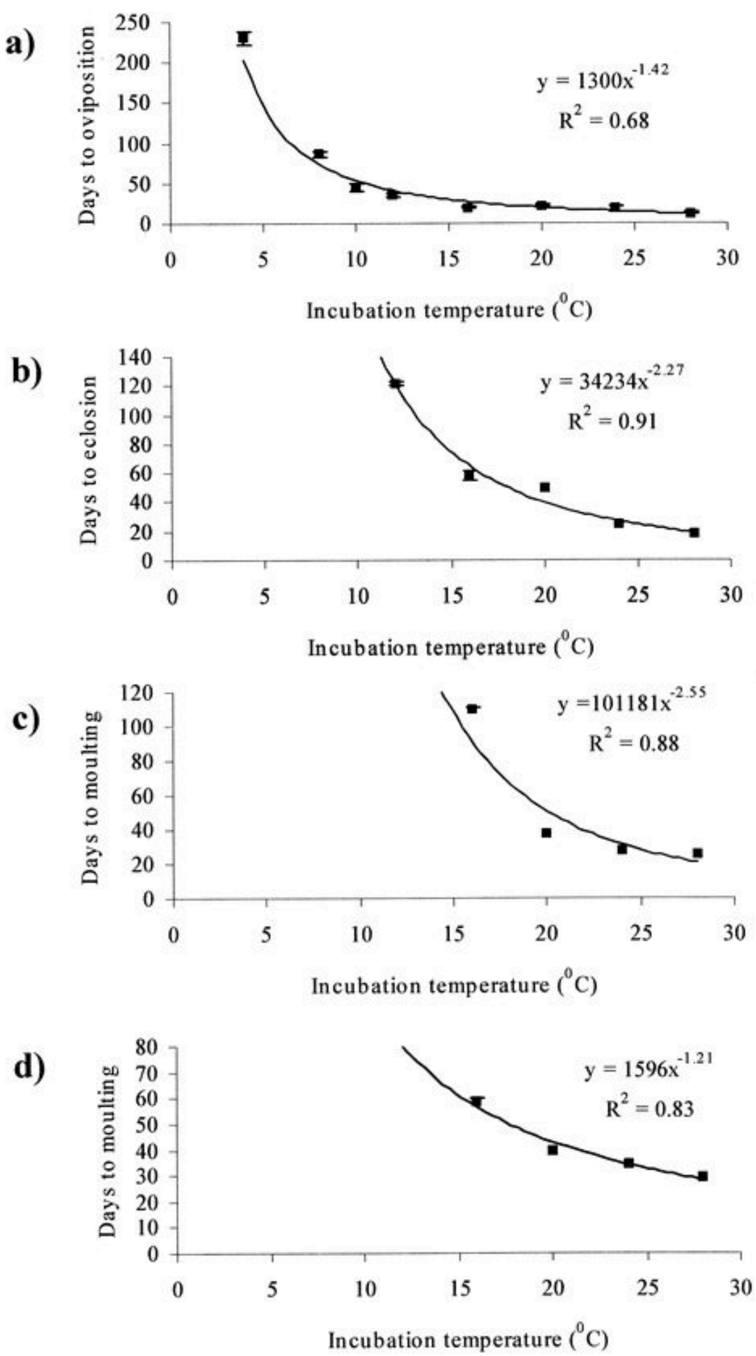
← Although these are in °F

The lettering on the drawing represents the following: 1=1st leaf on the main stem of the plant; 2=2nd leaf on the main stem; 3=3rd leaf on the main stem; 4=4th leaf on the main stem; 5=5th leaf on the main stem and T=Tiller – not counted as a leaf when determining leaf stages.

*Growing Degree Day Units = $\frac{\text{(Maximum Day Temperature + Minimum Day Temperature)}}{2} - 32$

See extension circular EB-37, Use of Growing Degree Days to Determine Spring Wheat Growth Stages, for details about what development and use of growing degree day units.

Why does this work?



Investigation of Relationships Between Temperature and Developmental Rates of Tick *Ixodes scapularis* (Acari: Ixodidae) in the Laboratory and Field

N. H. OGDEN,[1, 2, 3] L. R. LINDSAY,[4] G. BEAUCHAMP,[1] D. CHARRON,[2] A. MAAROUF,[5] C. J. O'CALLAGHAN,[6] D. WALTNER-TOEWS,[7] AND I.K. BARKER[8]

J. Med. Entomol. 41(4): 622–633 (2004)

Duration of development for I. scapularis ticks held at different temperatures in the laboratory.

(a) Preoviposition period of engorged adult females.
(b) Preeclosion period for egg masses.
(c) Premolt period of engorged larvae.
(d) Premolt period of engorged nymphs.

A dynamic population model to investigate effects of climate on geographic range and seasonality of the tick *Ixodes scapularis*

N.H. Ogden[a,b,*], M. Bigras-Poulin[a], C.J. O'Callaghan[c], I.K. Barker[d], L.R. Lindsay[e], A. Maarouf[f], K.E. Smoyer-Tomic[g], D. Waltner-Toews[h], D. Charron[b]

International Journal for Parasitology 35 (2005) 375–389

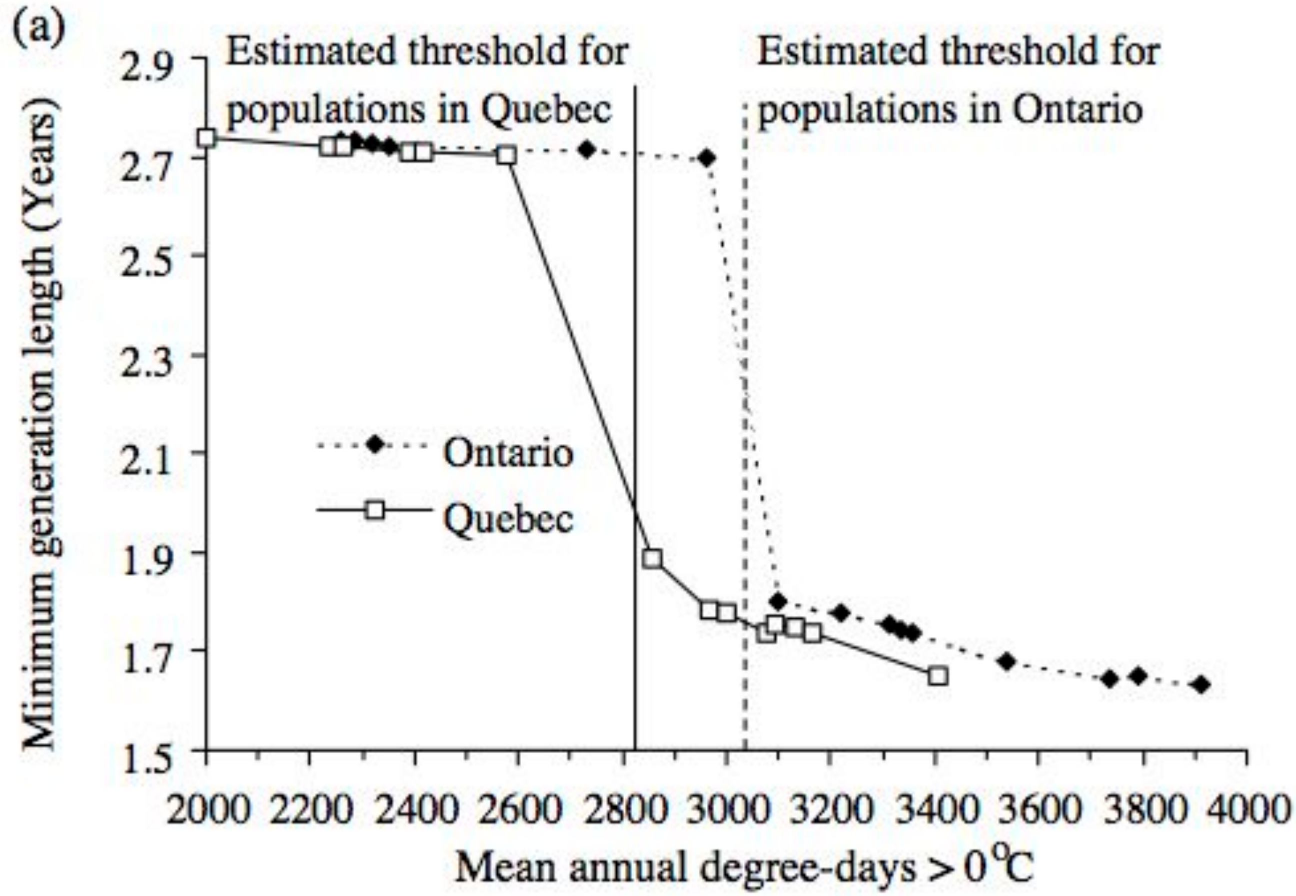
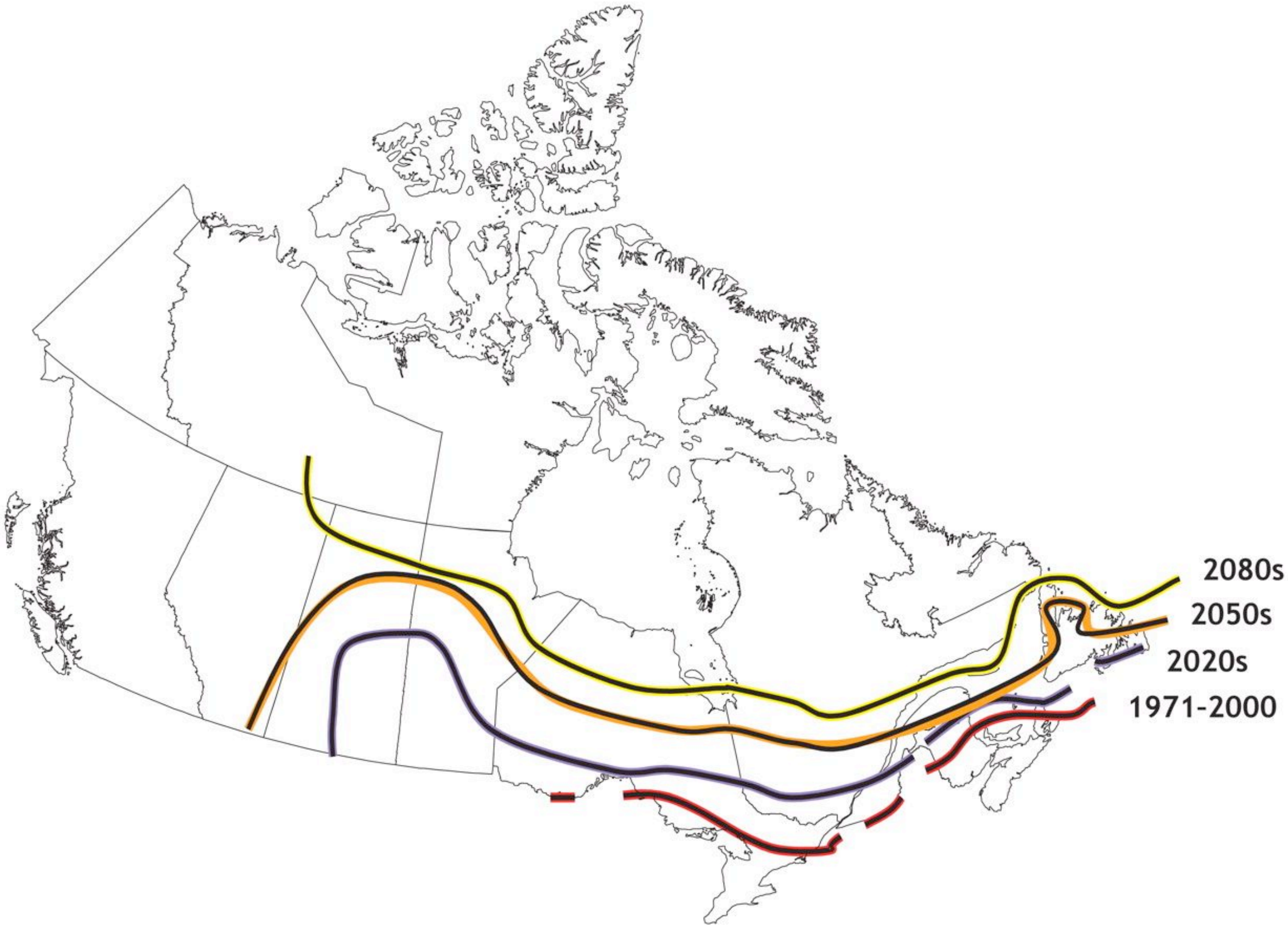


Figure 2: Upper temperature limits for Ixodes scapularis establishment in Canada, based on mathematical models.



Greer, Amy et al. CMAJ 2008;178:715-722

CMAJ·JAMC

Mountain pine beetle

(*Dendroctonus ponderosae*)
Coleoptera: Curculionidae, Scolytinae

Native to North America

Infests all species of pines within their range (but especially ponderosa, lodgepole, western white, sugar, and limber pines)

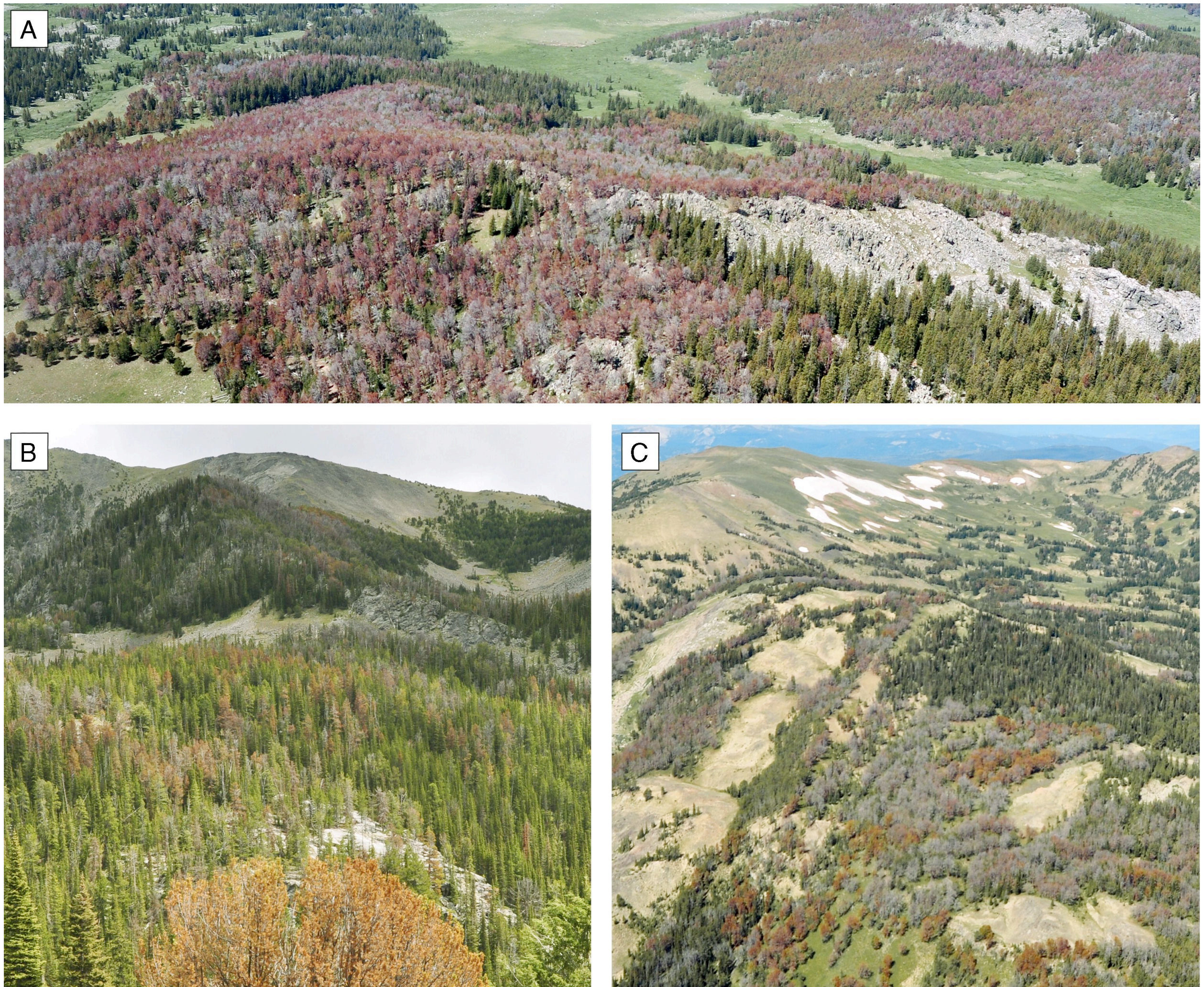
Attacking beetles introduce spores of several fungi, which alters resin and water flow, preventing tree response

Girdles trees

Large outbreaks can affect ≥80% of trees in a stand

www.fs.fed.us/rm/landscapes/Solutions/Pinebeetlebrood.shtml

www.uwyo.edu/uwag/News/May2011/pine-beetle-devastation.jpg



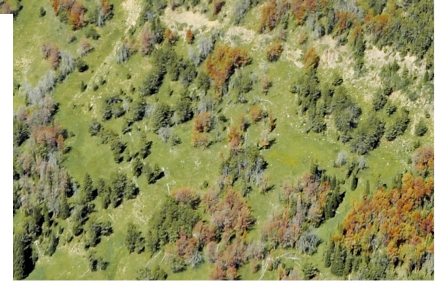


Plate 1. In these photographs, the trees with red needles were killed during the previous summer; the gray “ghost trees” remain after the needles drop, beginning the second summer after the tree is killed: (A) near Union Pass, Gros Ventre Range, Bridger-Teton National Forest, south-central GYE (Greater Yellowstone Ecosystem, USA); (B) Wisconsin Creek, Tobacco Root Range, Beaverhead National Forest, northwest GYE; (C) two miles southwest of Electric Peak, Gallatin Range, Yellowstone National Park, north-central GYE. Photo credits: W. W. Macfarlane.

Ecological Applications, 20(4), 2010, pp. 895–902

Whitebark pine vulnerability to climate-driven mountain pine beetle disturbance in the Greater Yellowstone Ecosystem

Jesse A. Logan,[1,4] William W. Macfarlane,[2] and Louisa Willcox[3]

[1]*USDA Forest Service, Box 482, Emigrant, Montana 54927 USA*
[2]*GeoGraphics, Incorporated, 90 West Center Street, Logan, Utah 84321 USA*
[3]*Natural Resources Defense Council, Box 70, Livingston, Montana 59047 USA*

Cold hardening in Mountain Pine Beetles

- Habitat within the bark can drop below –35°C
- MPB are not freeze tolerant!
- Lower their supercooling point (SCP), the temp at which ice crystals spontaneously form

Steps:

1. rid body of ice-nucleating agents such as food in gut, large proteins in hemolymph (lowers SCP by 10–20°C!)
2. Accumulate cryoprotectants (e.g. glycerol) and antifreeze proteins (lowers SCP by an additional 10°C)

This is a process of *acclimation*, so early cold snaps = bad news

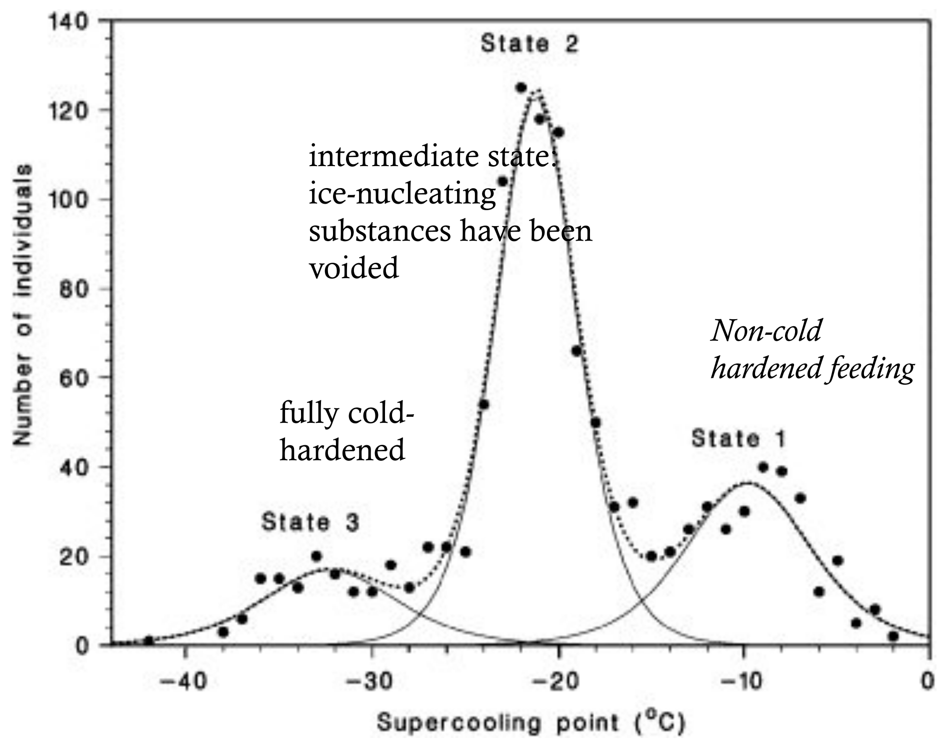


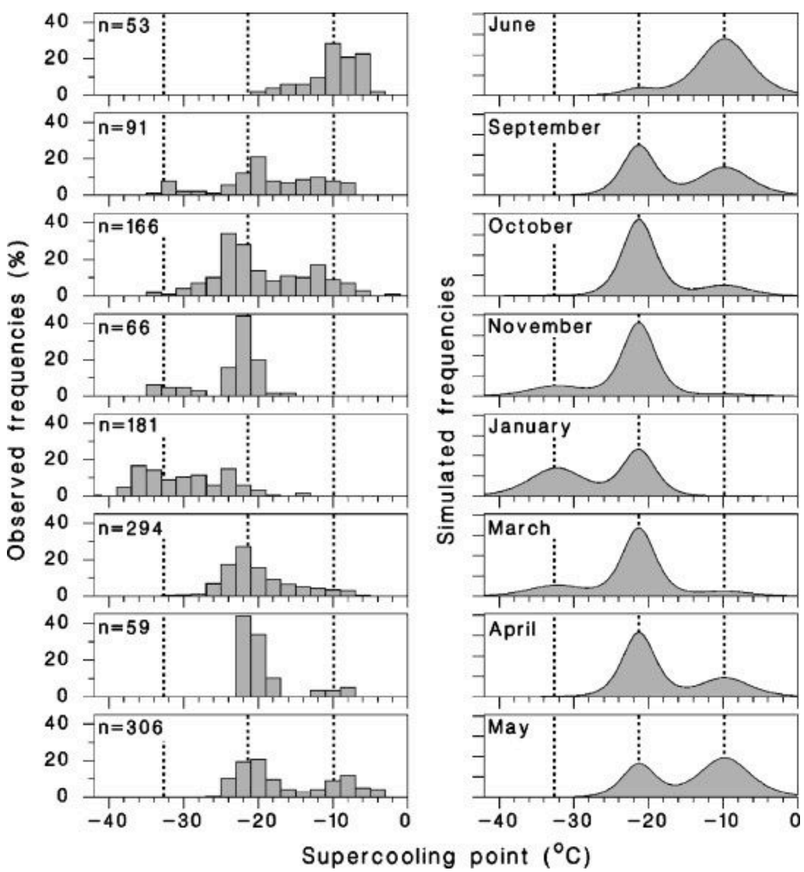
Fig. 3. Pooled frequency of all larval SCP (1 °C classes). Eq. (1) (solid lines: for each state; dotted line: combined) fitted by non-linear logistic regression to pooled observations of SCP among *Dendroctonus ponderosae* larvae (●).

Available online at www.sciencedirect.com
ScienceDirect
Journal of Insect Physiology 53 (2007) 559–572
Journal of Insect Physiology
www.elsevier.com/locate/jinsphys

Modeling cold tolerance in the mountain pine beetle, *Dendroctonus ponderosae*

Jacques Régnière[a,*], Barbara Bentz[b]

[a]*Natural Resources Canada, Canadian Forest Service, Laurentian Forestry Centre, PO Box 10380, Stn. Sainte-Foy, Quebec, QC, Canada G1V 4C7*
[b]*USDA Forest Service, Rocky Mountain Research Station, 860 N 1200 E, Logan, UT 84321, USA*



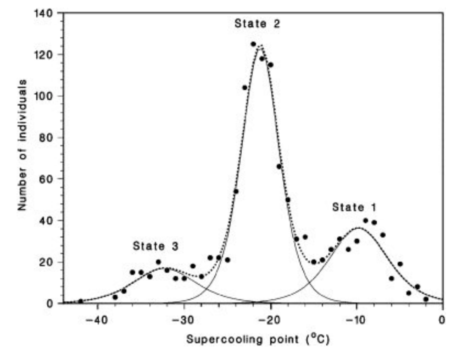
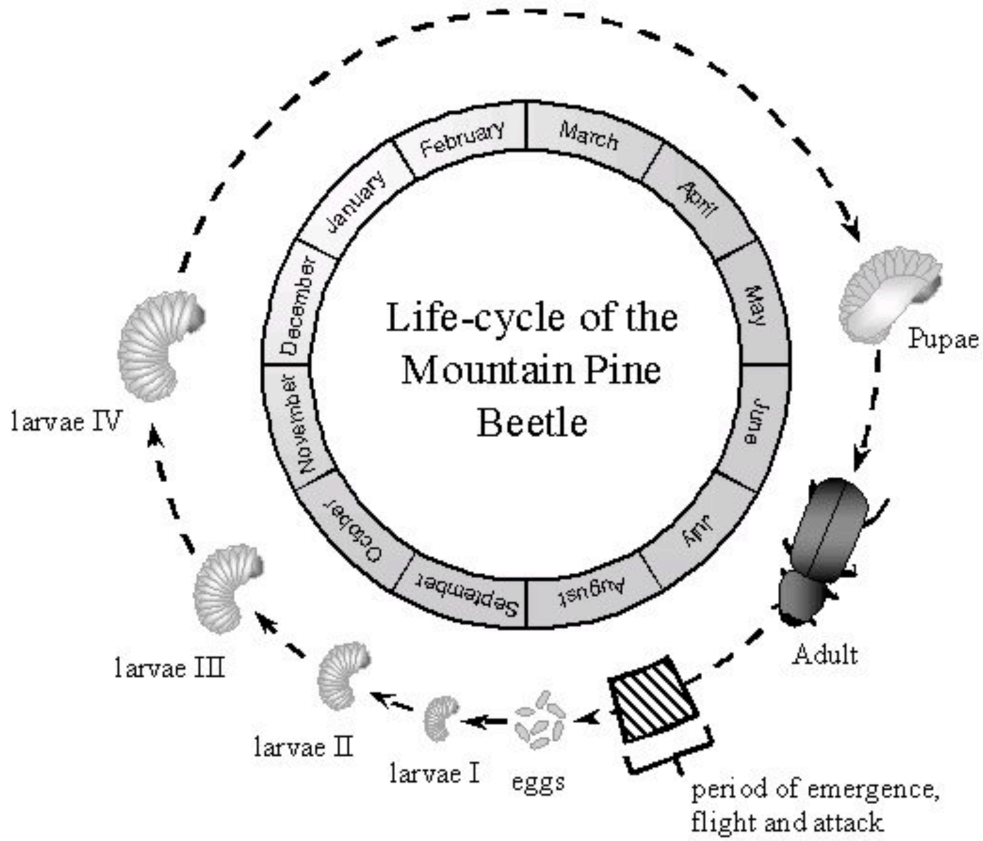


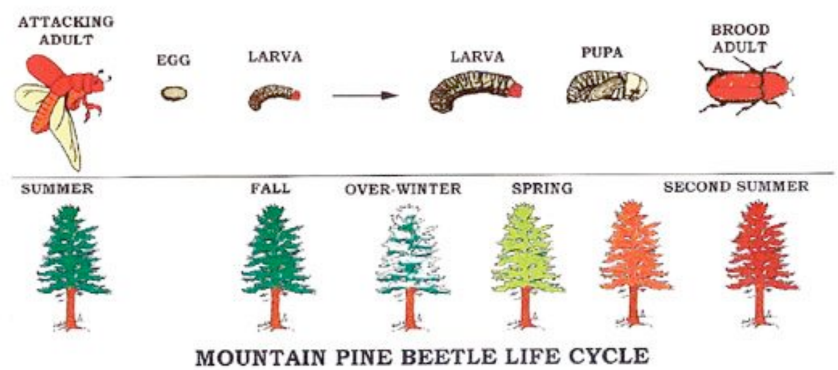
Fig. 1. Left column: frequency histograms of observed supercooling points (2 °C classes) among mountain pine beetle larvae collected at various times of the year from 7 locations in Utah and Wyoming in 1992–93 and 1994–95 (data of Bentz and Mullins, 1999). Right column: average monthly simulated distribution of SCPs at the same locations (from 1971 to 2000 normals). Vertical dotted lines indicate the median SCP in each of three different cold-tolerance states distinguished by the model.



www.realclimate.org/index.php/archives/2010/10/seeing-red/

- All but a few days that are spent flying and attacking trees MPB are in inner bark and phloem
- Adults bore into tree, mate, and lay eggs
- Generally has a one year life cycle at low elevations, maybe two at higher elevations

Note: mass attacks are much more successful, so synchronous emergence is important



csfs.colostate.edu/images/graphics/barkbeetlefadergraphic.jpg

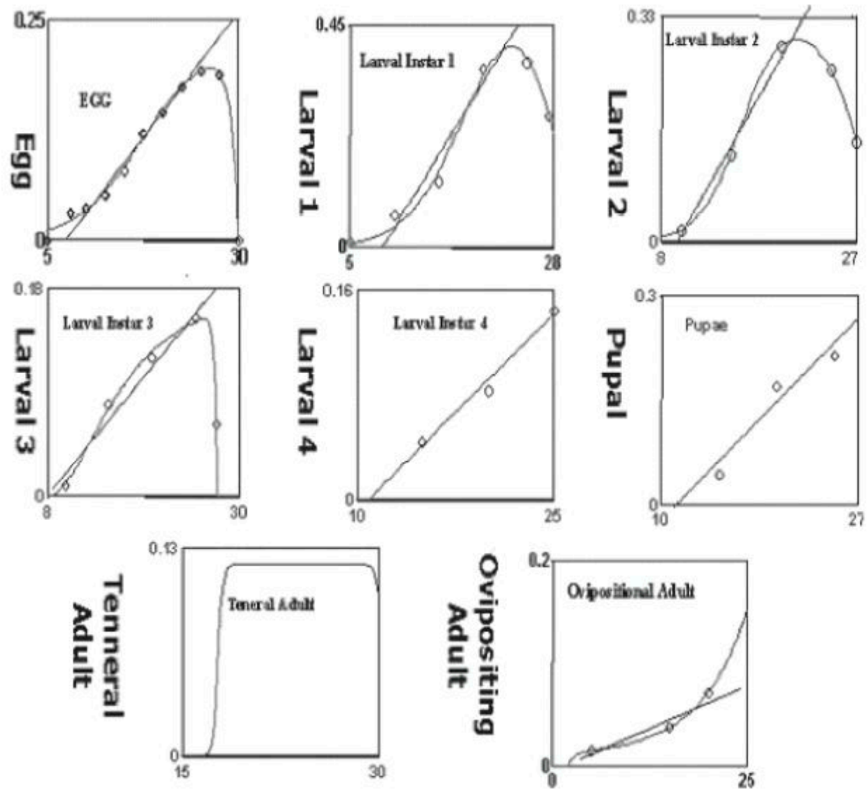


Figure 1. Rate curves for the mountain pine beetle. In all curves, the vertical axis is measured in development/day and the horizontal axis is temperature in centigrade. Data points determine rearing at controlled temperatures are depicted as open circles.

Modelling Mountain Pine Beetle Phenological Response to Temperature

Jesse A. Logan[1] and James A. Powell[2]

[1]USDA Forest Service, Rocky Mountain Research Station, Logan, Utah USA
[2]Department of Mathematics and Statistics, Utah State University, Logan, Utah USA

In T.L. Shore, J.E. Brooks, and J.E. Stone, editors. Mountain Pine Beetle Symposium: Challenges and Solutions, October 30-31, 2003, Kelowna, British Columbia, Canada. Natural Resources Canada, Canadian Forest Service, Pacific Forestry Centre, Victoria, British Columbia, Information Report BC-X-399. 298 p

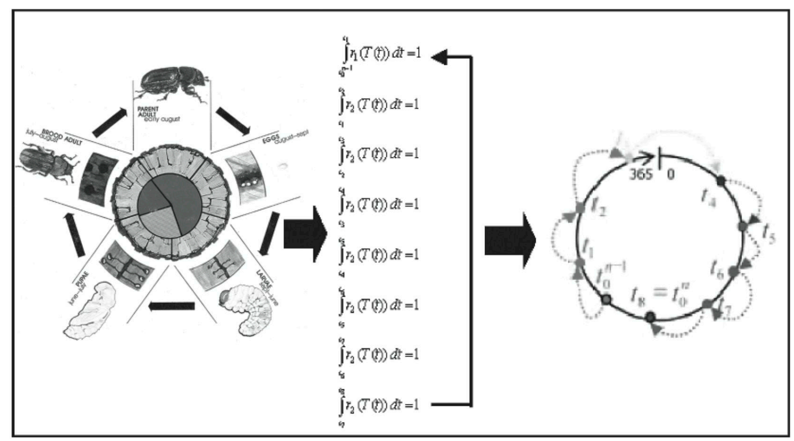


Figure 2. Schematic diagram of the mountain pine beetle model. Development for each life stage is accumulated according to the stage specific development rate curves in Fig. 1. Completion of the final life stage signals the initiation of the first life stage in the next generation. This process is mathematically represented as a circle map, analogous to the cycles of the natural world.

Ecological Applications, 20(4), 2010, pp. 895–902

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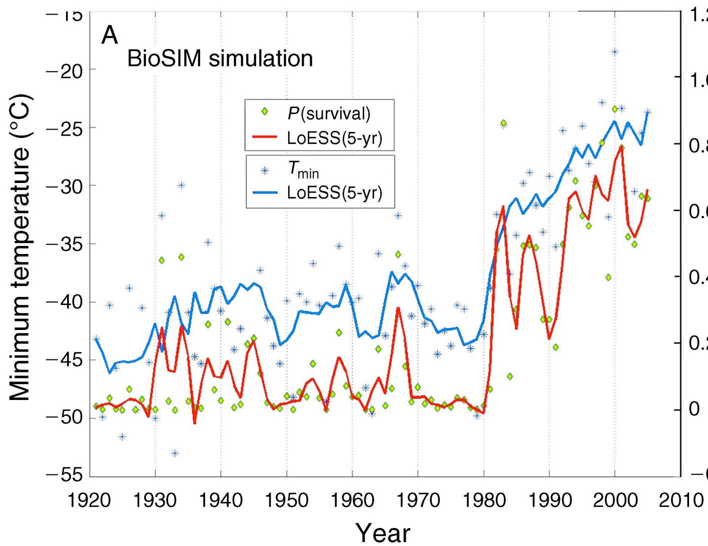
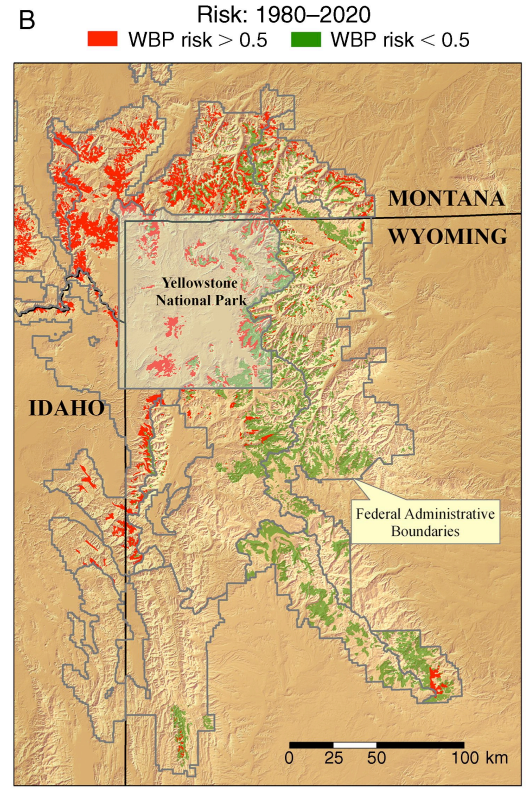
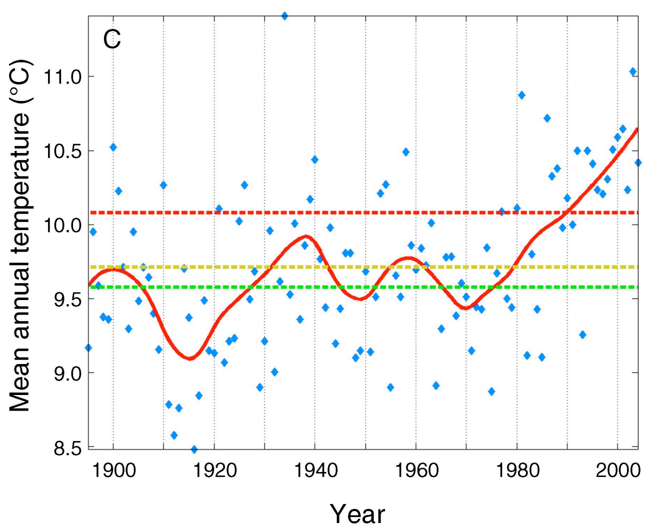


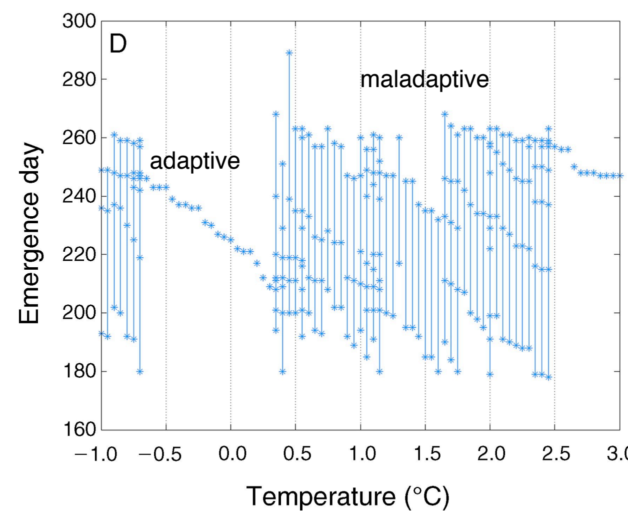


c) Mean annual temp for the 11 Western state

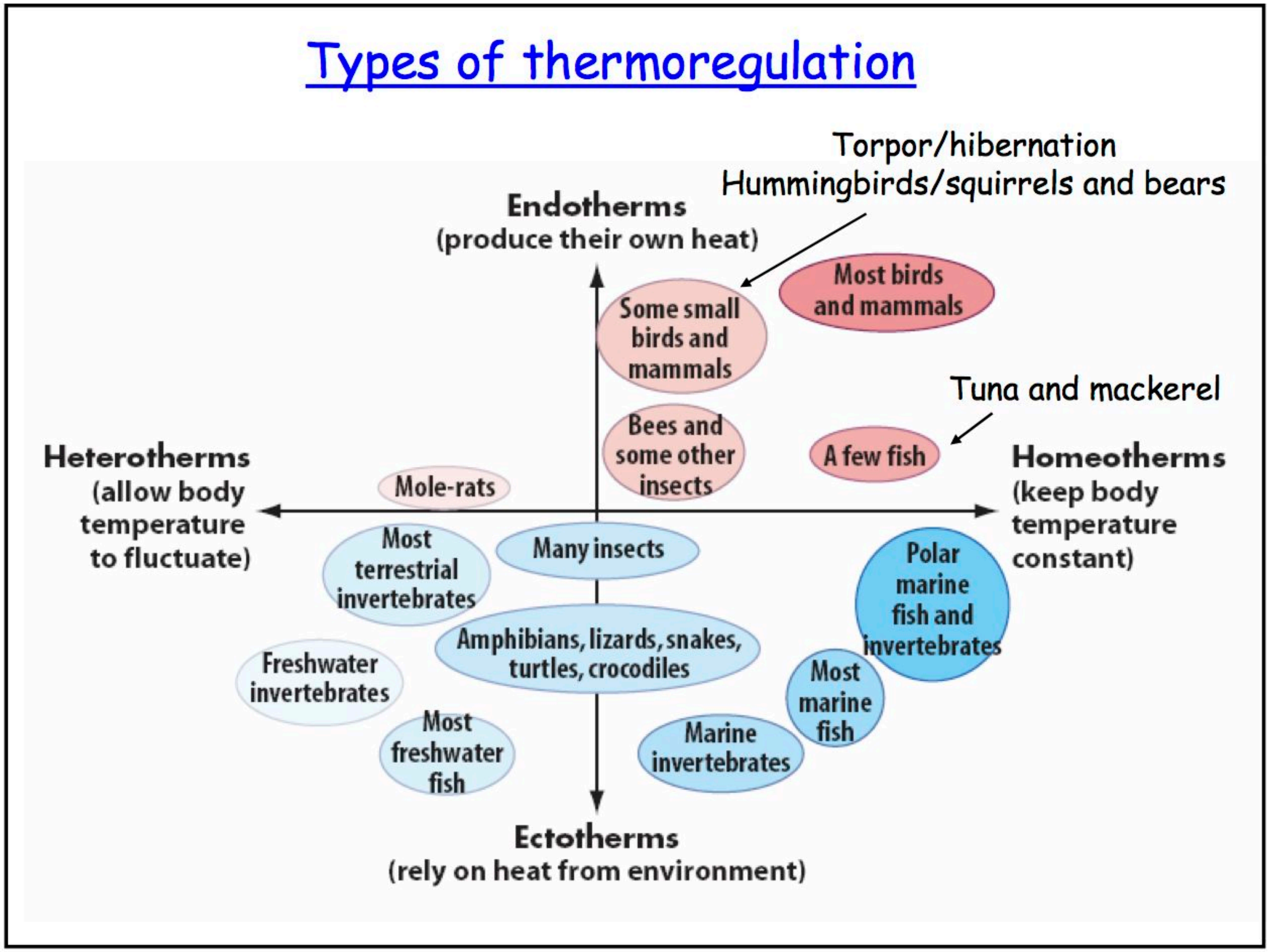
Grand mean ≥ 1976

Grand mean < 1976

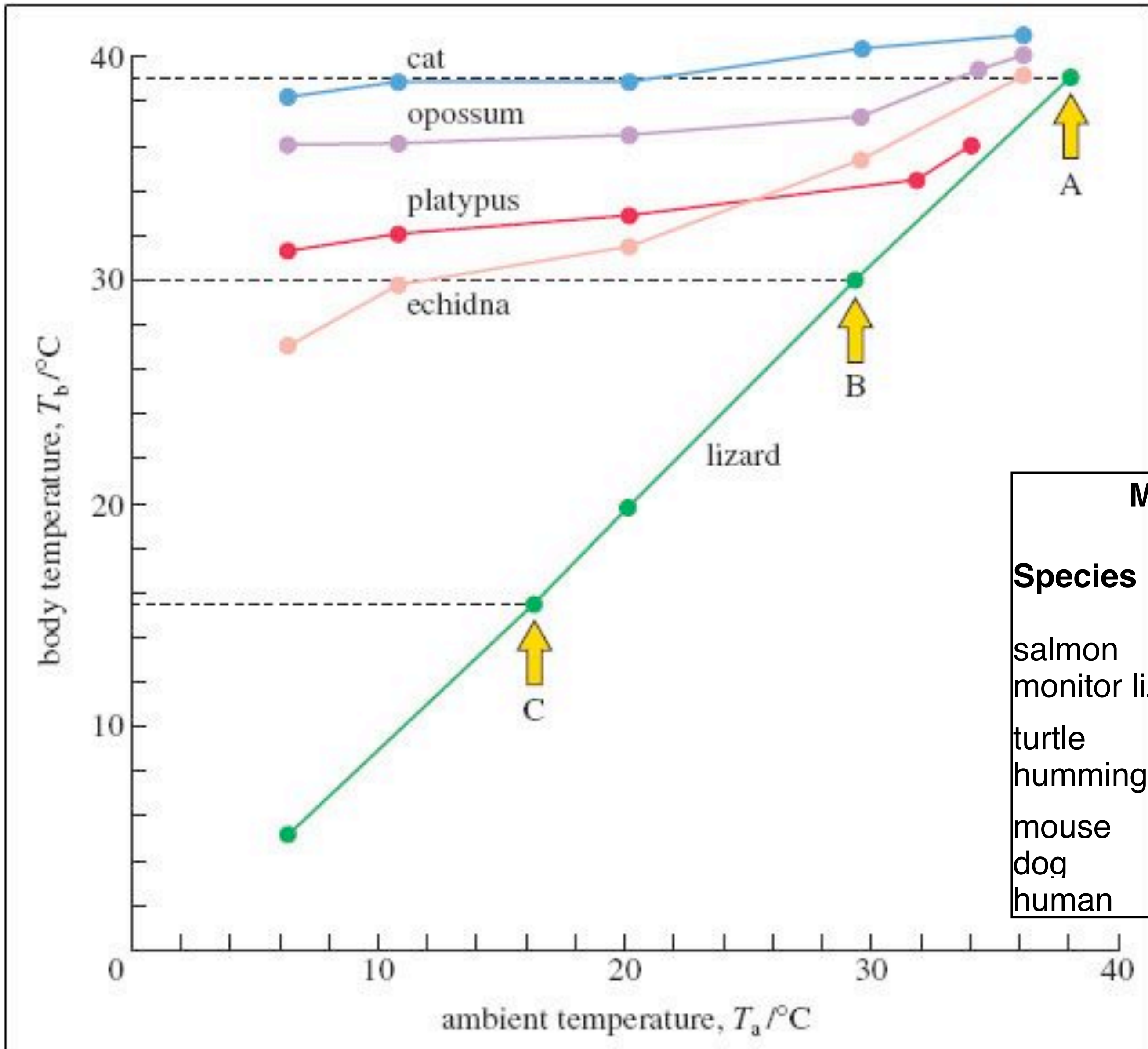




Homeostasis ~ maintaining relatively constant internal conditions in the face of a varying environment



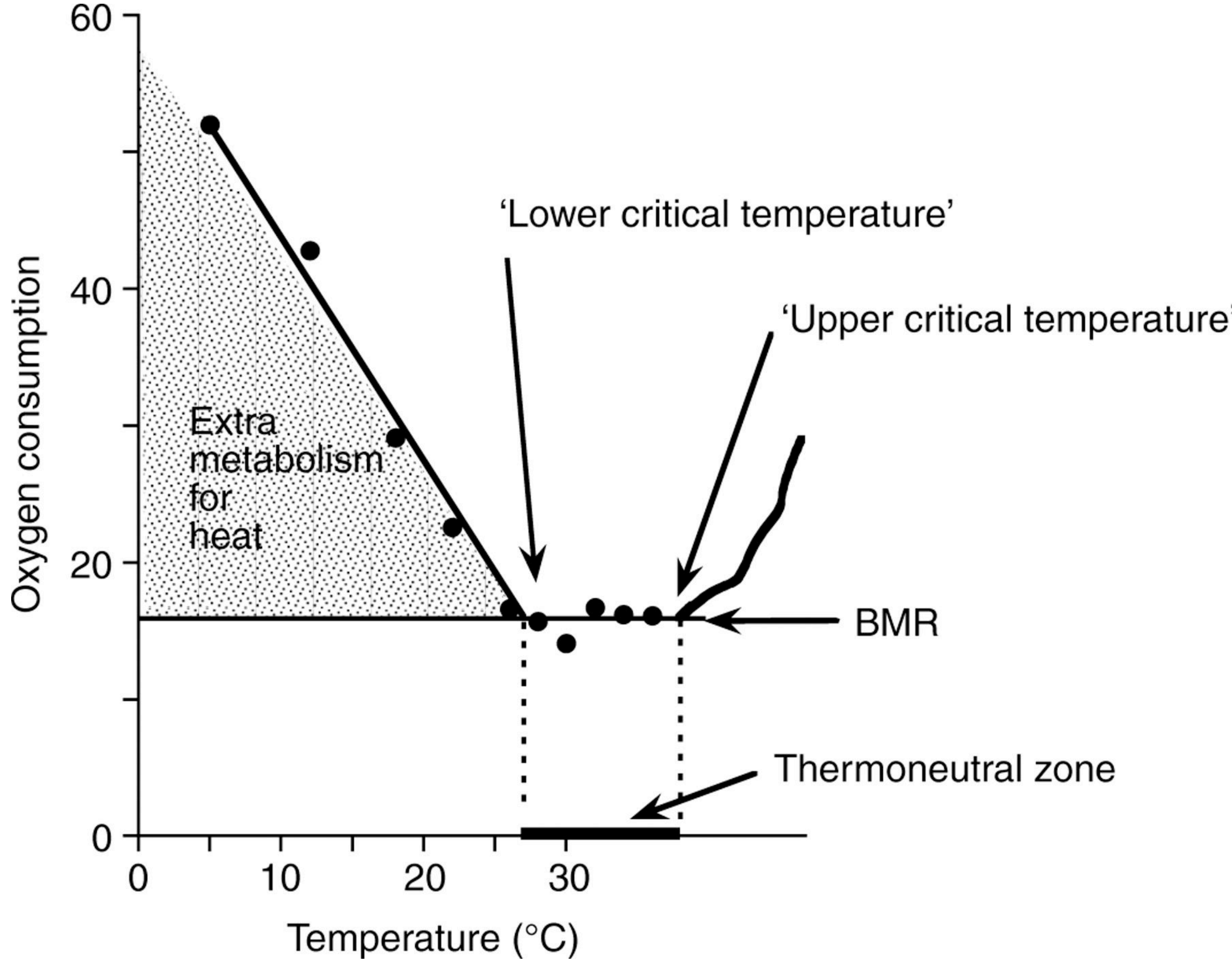
http://www.calpoly.edu/~bio/EPL/pdfs/SampleLectureBIO162.pdf



Metabolic rate/cm³ O_2 g^{-1} h^{-1}		
Species	**at rest**	**at peak activity**
salmon	0.08	0.6
monitor lizard	0.08	0.38
turtle	0.03	0.64
humming-bird	2.8	42
mouse	2.5	20
dog	0.33	4.02
human	0.23	3.2

http://open.jorum.ac.uk/xmlui/bitstream/handle/123456789/919/Items/S182_1_section7.html

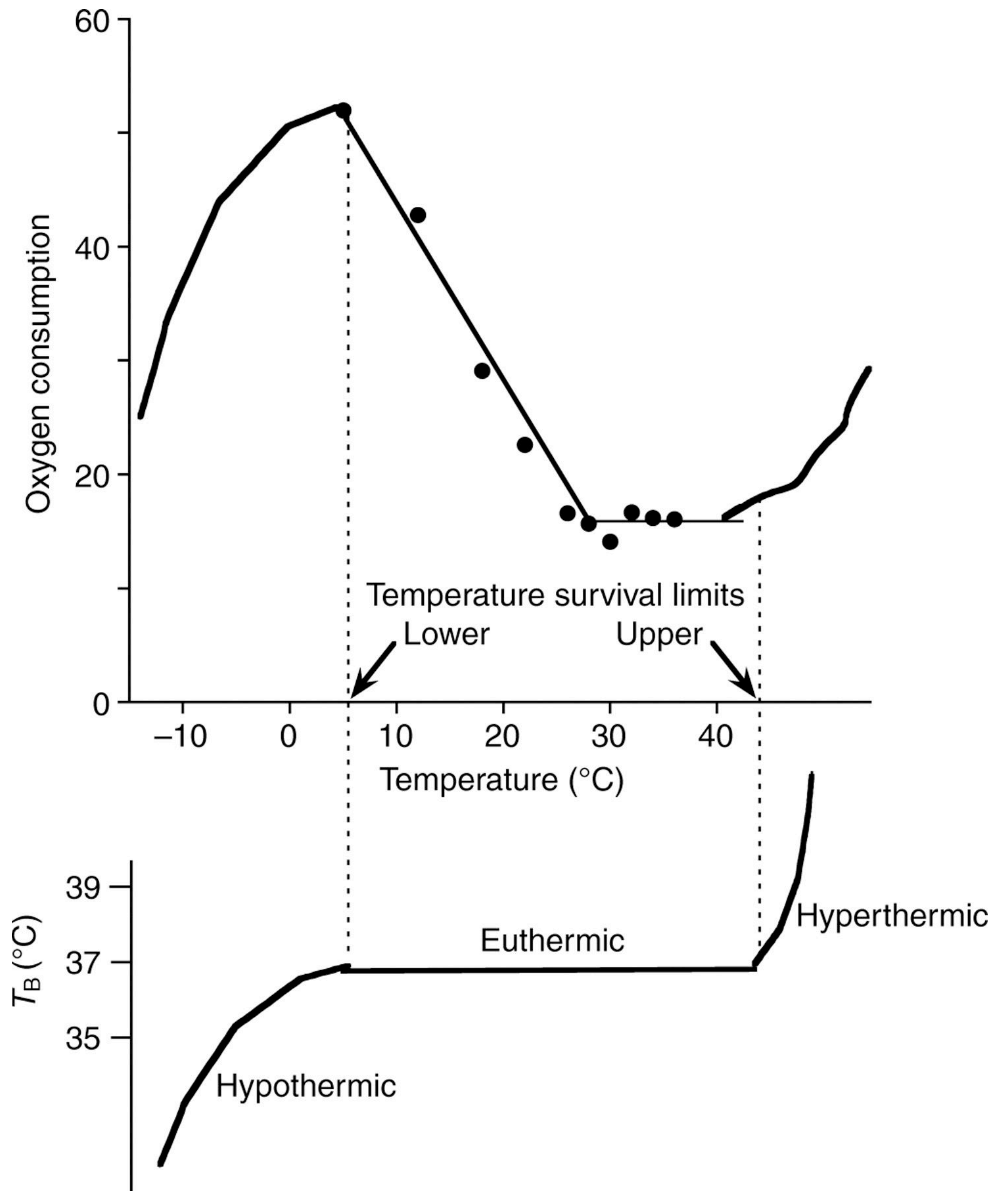
The energetic consequences of different ambient temperatures.



Cannon B , Nedergaard J J Exp Biol 2011;214:242-253

The Journal of Experimental Biology

The effects of exceeding the ambient temperature survival limits.



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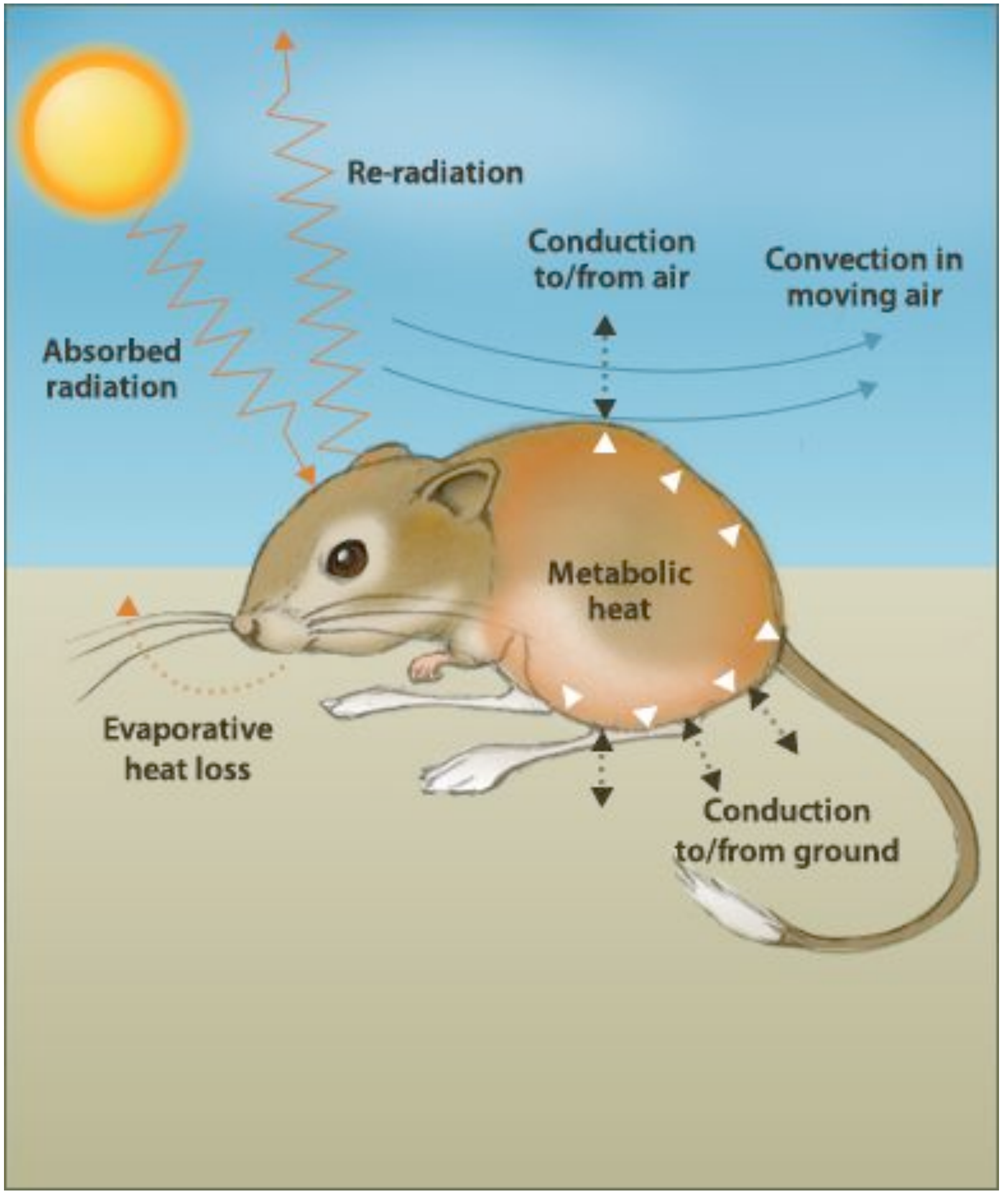
The Journal of Experimental Biology



1) **absorbed radiation**
= exposed SA x solar radiation x absorption

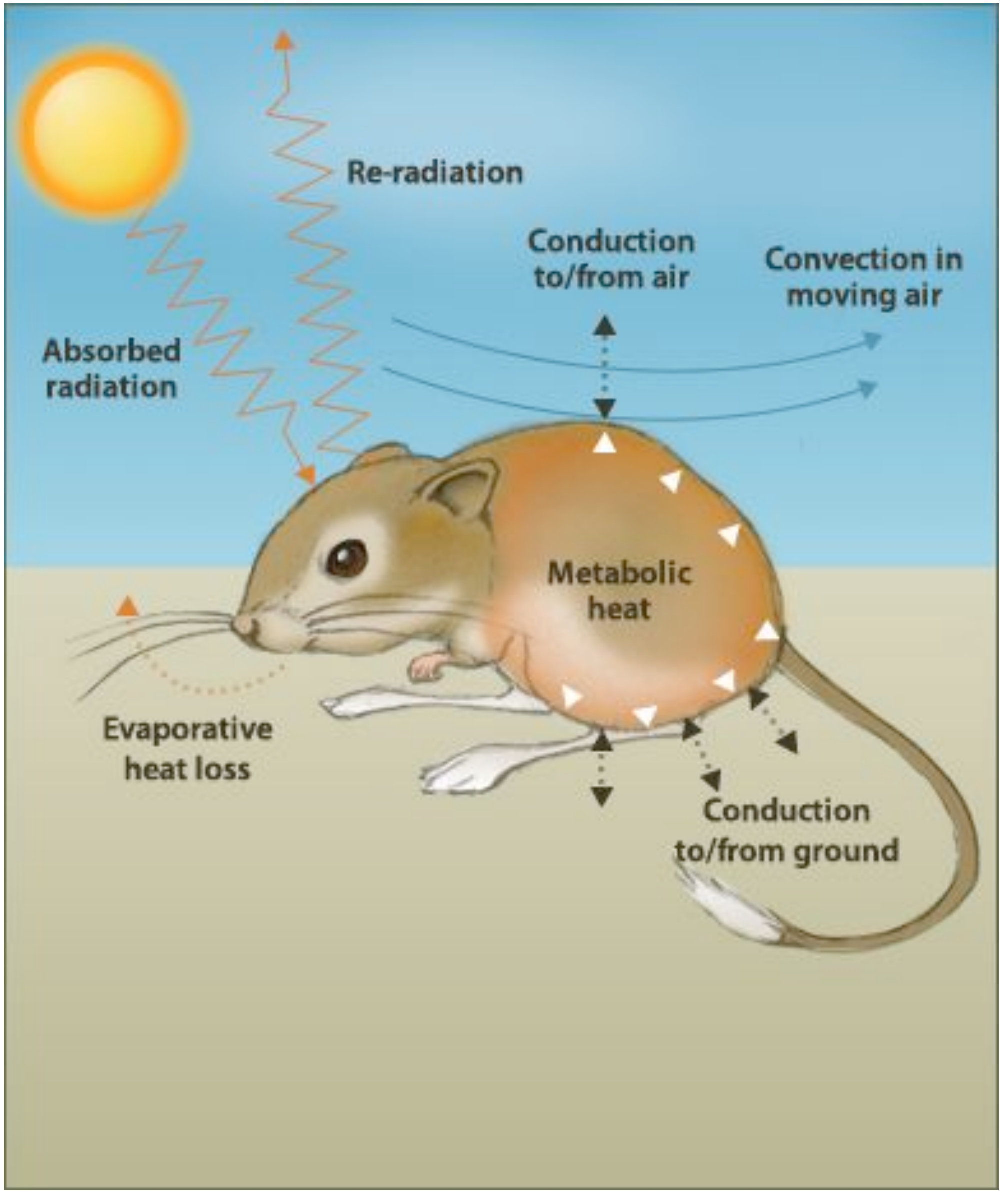
2) **metabolic heat** @ rest
= 0.03 x $Mass^{0.7}$

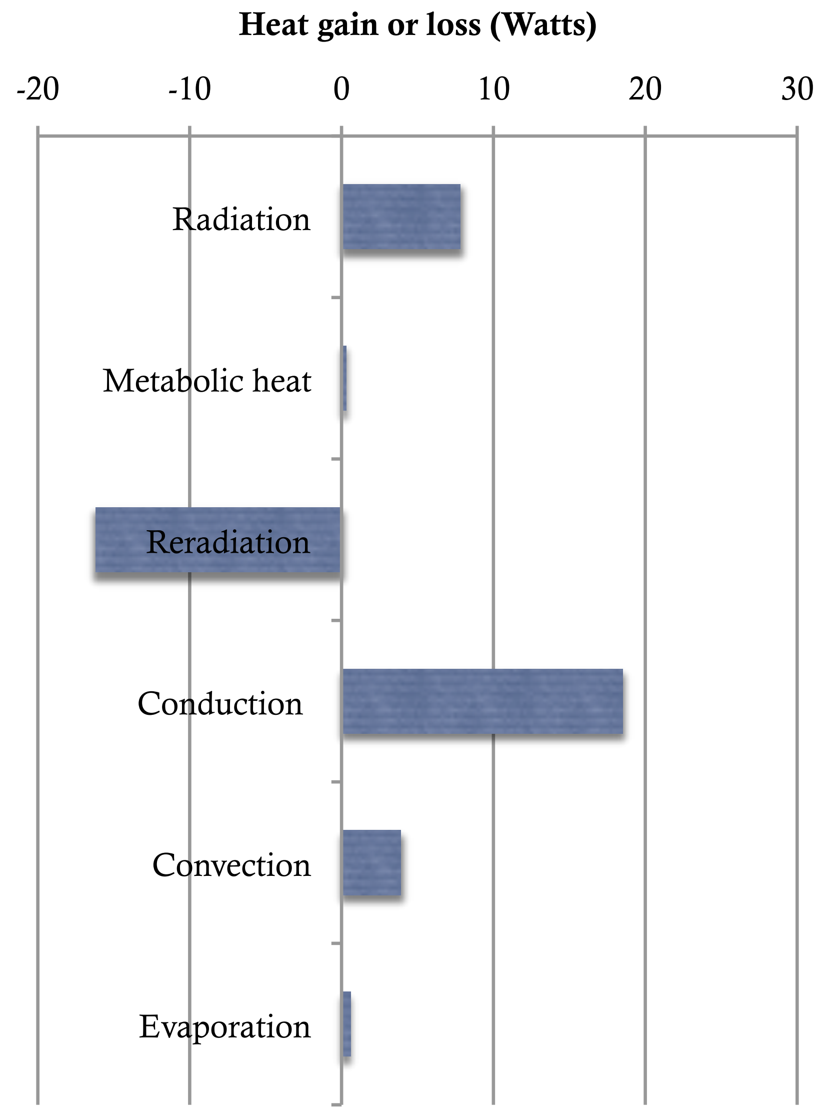
3) **re-radiating**

4) **conduction** to ground or air
= Conductivity x TempDifference x SA

5) **convection** in airflow

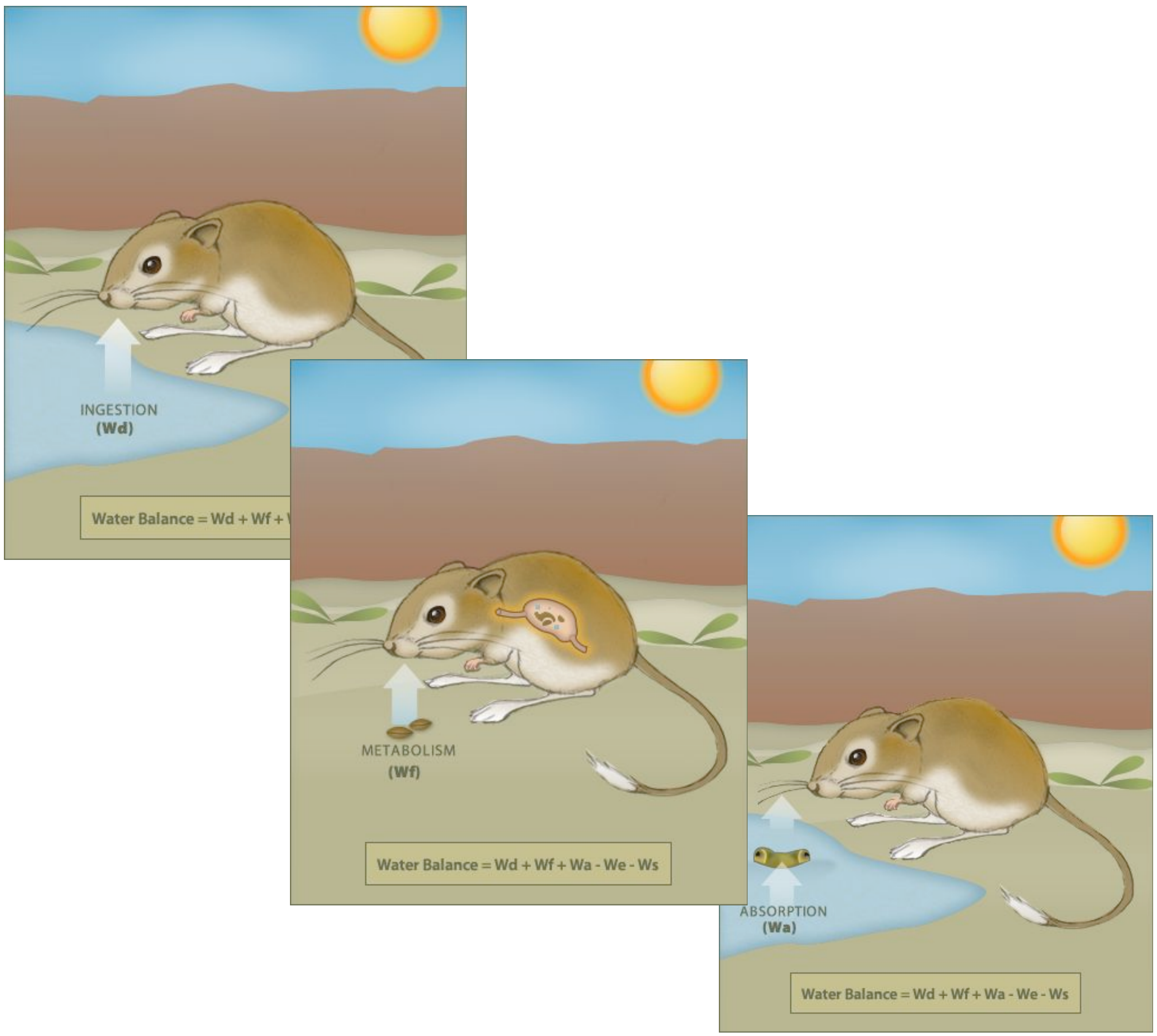
6) **evaporative** cooling

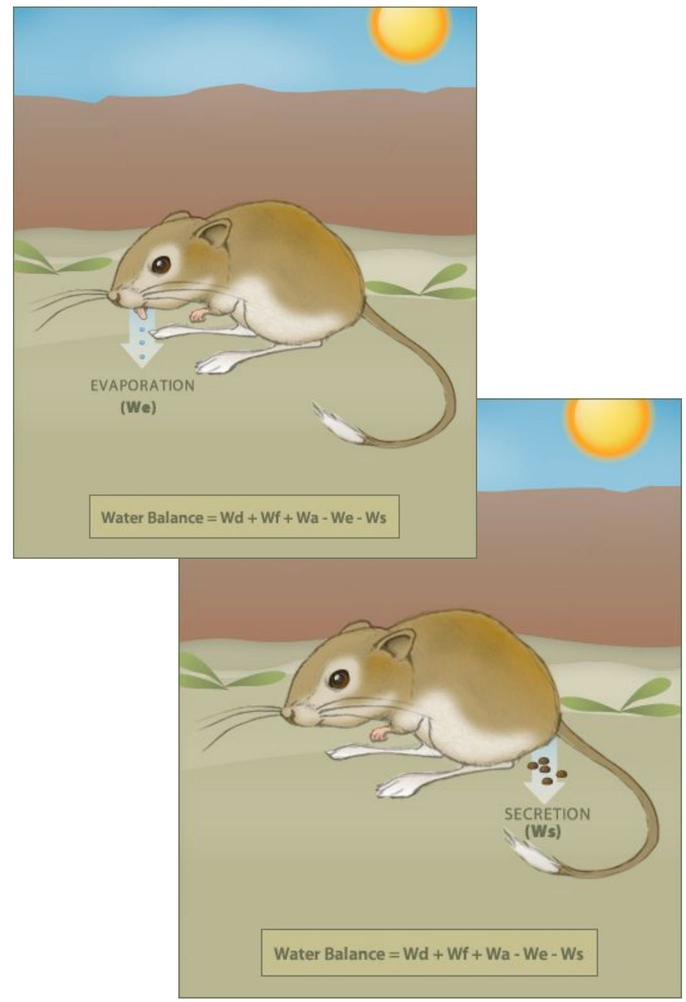

Re-radiation
Conduction to/from air
Convection in moving air
Absorbed radiation
Metabolic heat
Evaporative heat loss
Conduction to/from ground

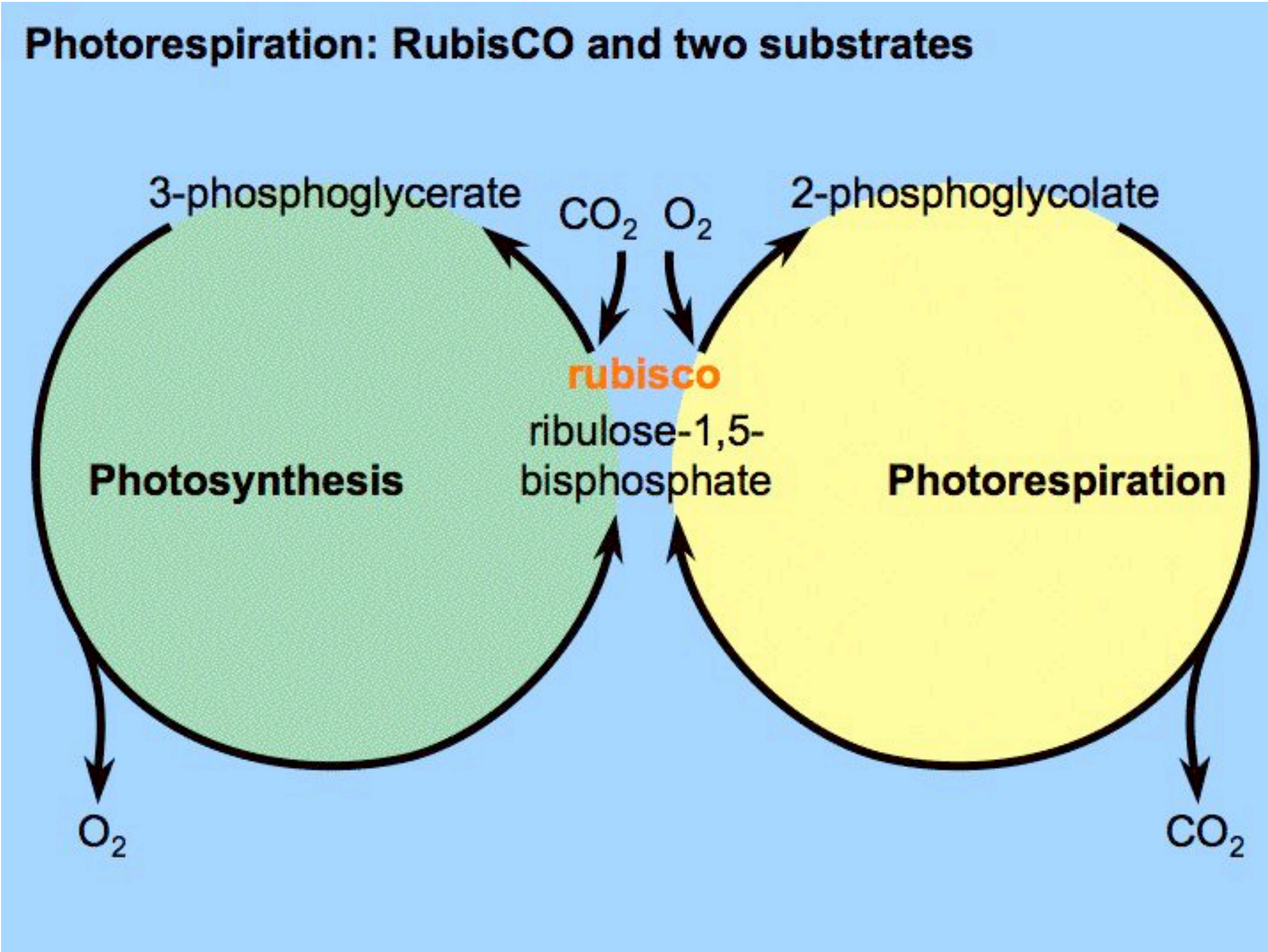

Heat gain or loss (Watts)
-20
-10
0
10
20
30
Radiation
Metabolic heat
Reradiation
Conduction
Convection
Evaporation

Water balance =

$$W_{d\ [ingestion]} + W_{food\ [metabolism]} + W_{absorption} - W_{evaporation} - W_{secrete}$$





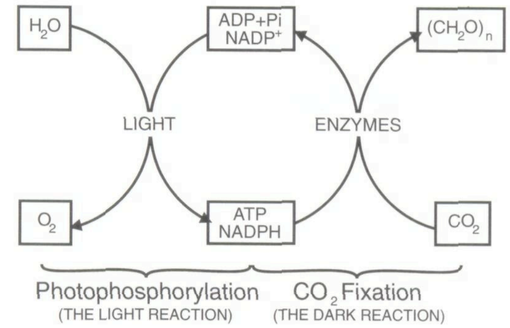


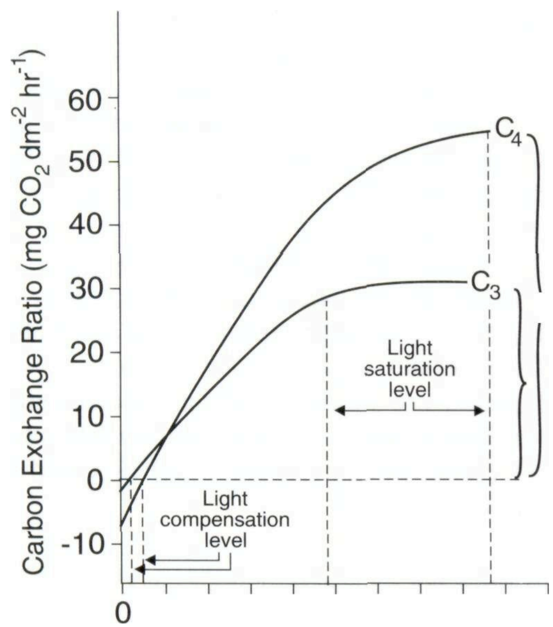
http://plantphys.info/plant_physiology/photoresp.shtml

	C_3	C_4	CAM
	cool season grass (wheat, oats, rye) dicots: legumes, tobacco, potato	warm season grasses (maize, sugarcane) dicots:no major crops, but some weeds	About 10 families (e.g.: pineapple, agave, opuntia)
Taxon. diversity	Very wide	Many grasses No/very few trees	Very few species
Anatomy			
Chloroplast	*Not* in vasc. sheath	Present in vasc. sheath	
CO_2 fixed: (enzyme)	RuBP carboxylase	PEP carboxylase	in night; energy from glycolysis
Habitat	no pattern	open, warm, saline	open, warm, saline
Photorespiration	high	low	low
Light sat. point (lux)	65000	> 80000	like C_3
Max P.S. ($mg\ dm^{-2}\ h^{-1}$)	30	60	3
Max. growth rate ($g\ dm^{-2}\ d^{-1}$)	1	4	0.02
WUE* ($g\ H_2O\ gCO_2^{-1}$)	600	300	50
CO_2 comp. point (ppm)	50	5	2 (in dark)
Stomates:			
day	open	open	closed
night	closed	closed	open

* Water use efficiency.

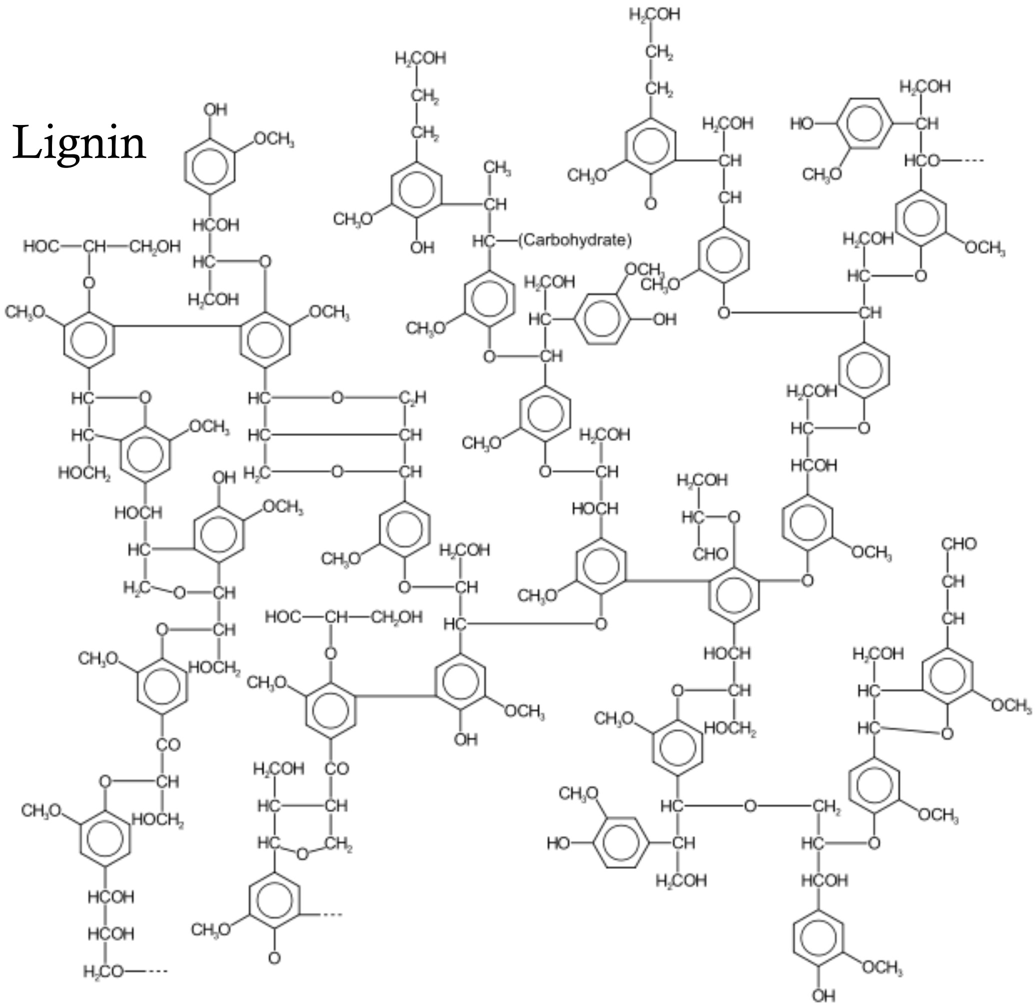
http://www.worldagroforestry.org/units/Library/Books/Book%2032/an%20introduction%20to%20agroforestry/html/11_1_photosynthesis.htm



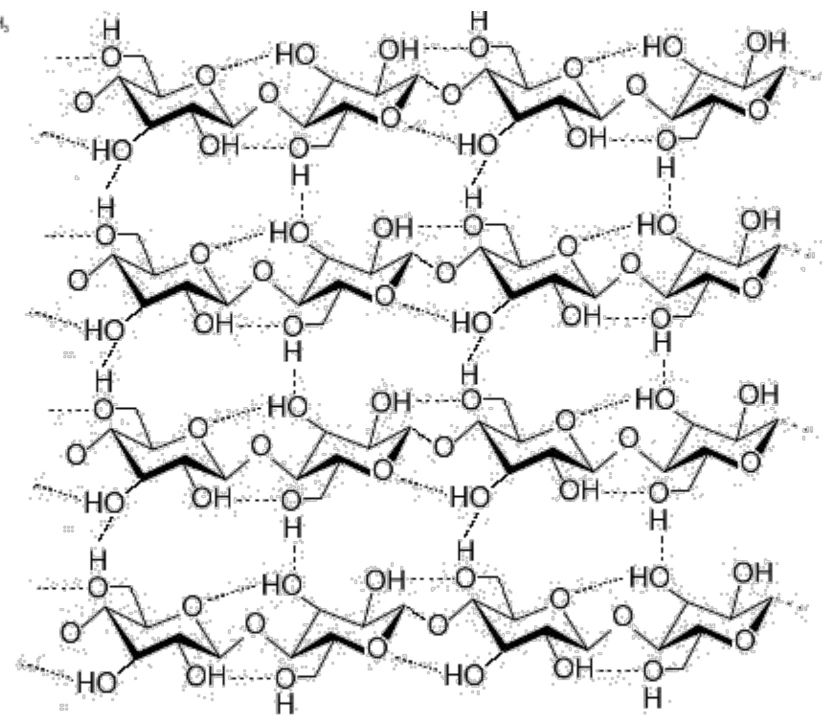


Adapted from Gardner et al. (1985).

Lignin



Cellulose



Element	**Structure/function**
Nitrogen	Nucleic acids (RNA/DNA) Amino acids (protein)
Phosphorus	ATP! Nucleic acids (RNA/DNA) Phospholipids (membranes) Bones
Potassium	Osmotic balance Basis of charge gradients (ATP production, action potentials in animals) Activates enzymes
Calcium	Cell walls Bones & exoskeletons Signal transduction (within cells, between neurons)
Sulfur	Amino acids methionine & cysteine Many enzymes, cofactors, and catalysts Sulfur metabolism
Iron	Ion donor/acceptor (redox reactions, electron transport) O2 transport

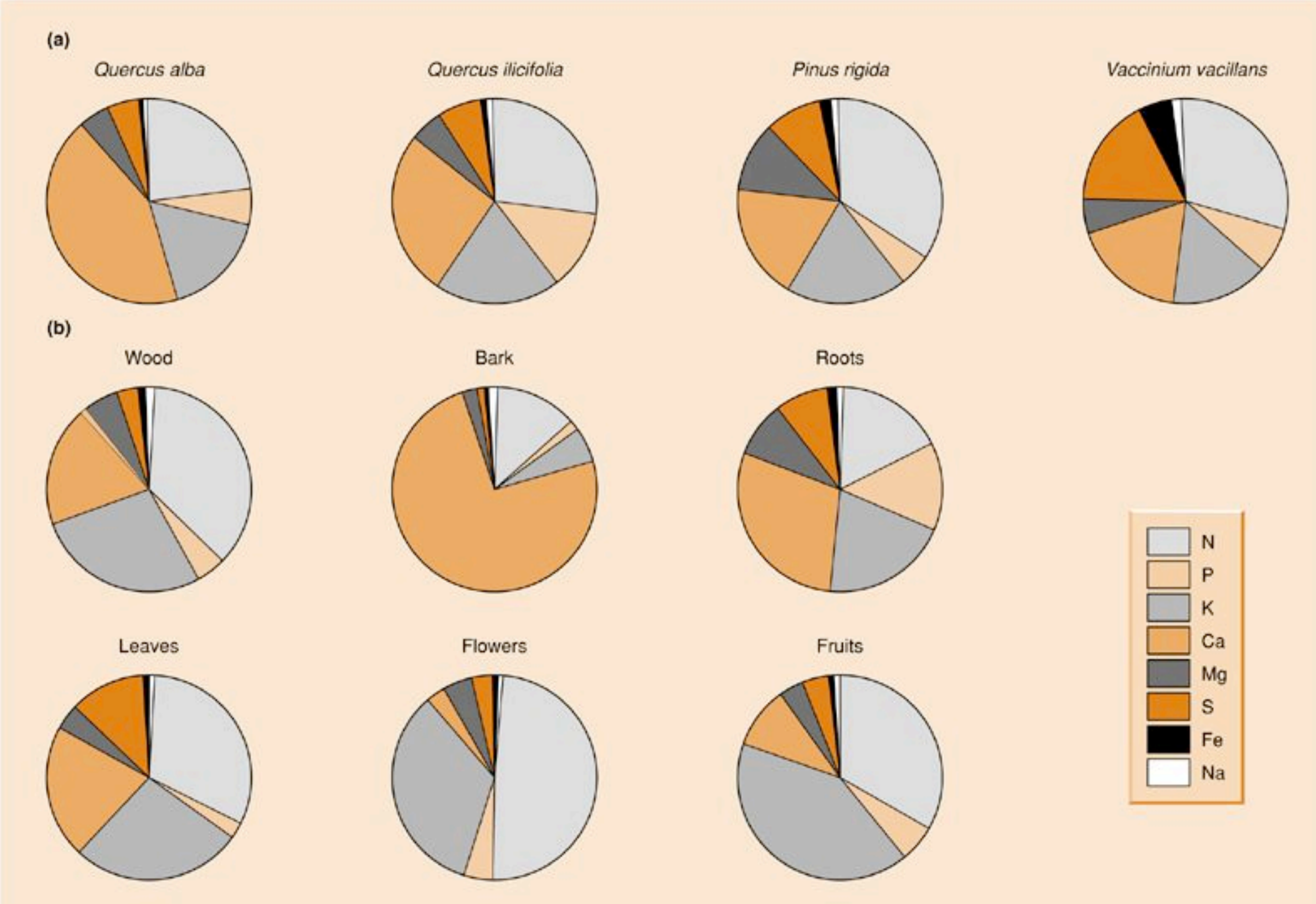


Figure 3.19 (a) The relative concentration of various minerals in whole plants of four species in the Brookhaven Forest, New York. (b) The relative concentration of various minerals in different tissues of the white oak (*Quercus alba*) in the Brookhaven Forest. Note that the differences between species are much less than between the parts of a single species. (After Woodwell *et al.*, 1975).

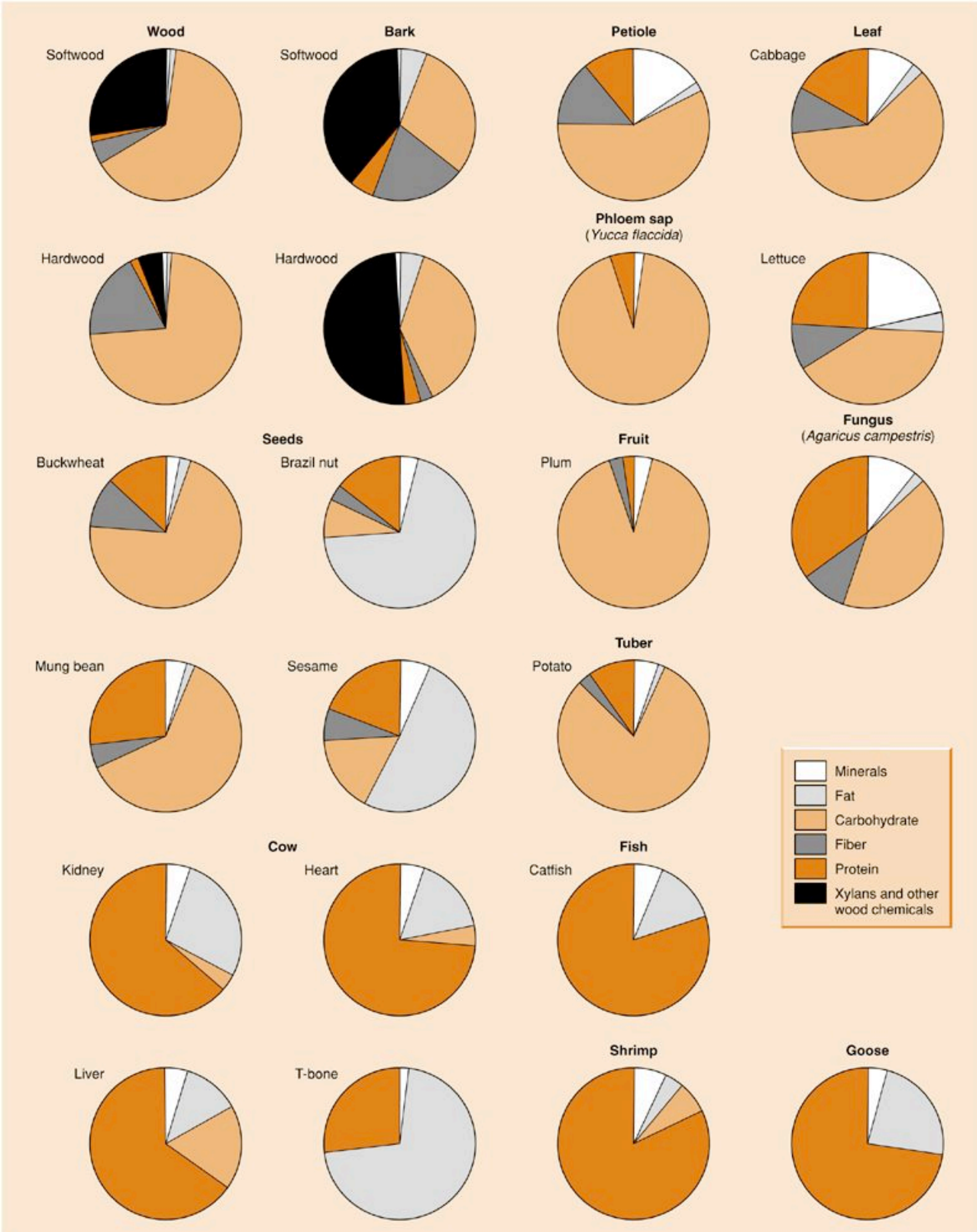
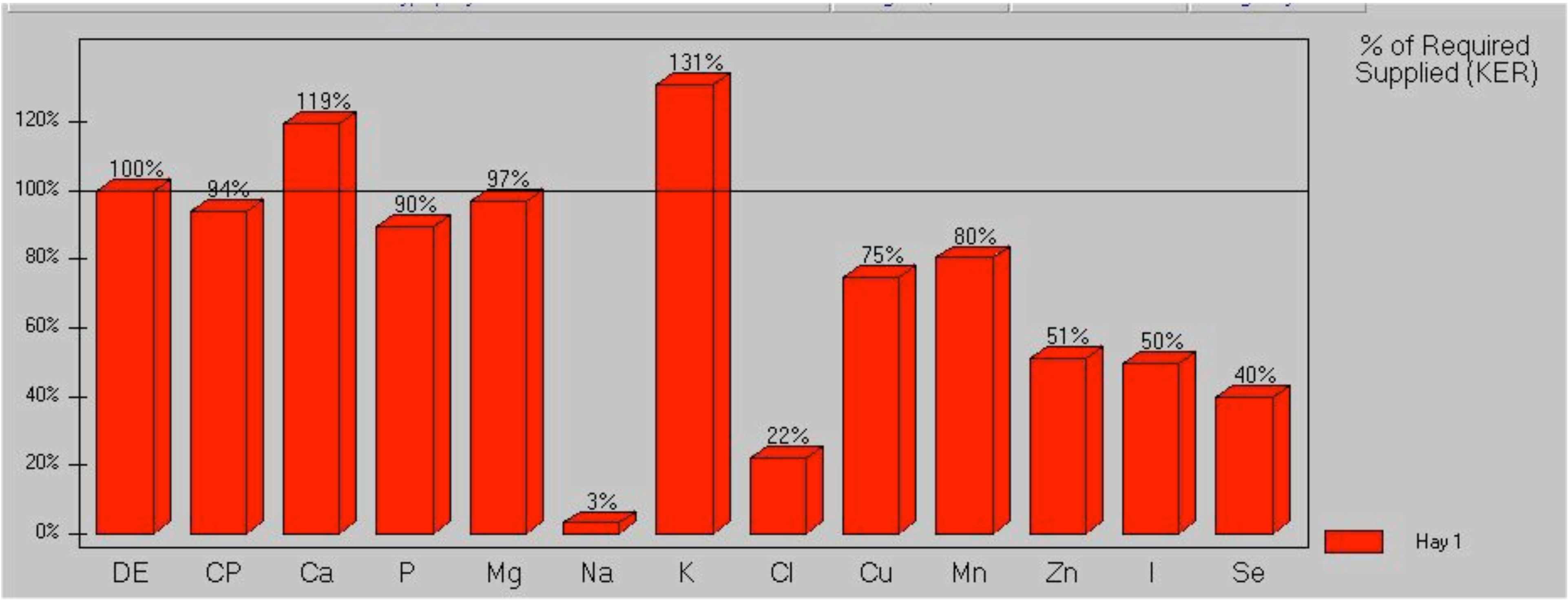


Figure 3.23 The composition of various plant parts and of the bodies of animals that serve as food resources for other organisms. (Data from various sources.)



http://www.extension.umn.edu/horse/components/hays/hay1detailed.html

Table 2.3. Expected range of crude protein (CP), digestibility (DMD), and phosphorus (P) content in warm and cool season forages from native and improved pastures throughout the world.

Forage Class	Pasture Type	Growing Season	Life Form	CP%	DMD%	P%
Grass	Native	Warm	Annual	—	50–73	—
			Perennial	2–15	20–65	.08–.28
		Cool	Annual	2–25	60–95	.03–.48
			Perennial	3–25	42–94	.05–.35
	Improved	Warm	Annual	4–18	46–69	—
			Perennial	2–25	36–68	.05–.35
		Cool	Annual	3–30	50–91	—
			Perennial	5–30	30–76	.08–.28
Forbs				4–23	42–91	.10–.46
Browse (shrubs)				4–32	14–74	.08–.54

http://cnrit.tamu.edu/rlem/textbook/Chapter2.htm