

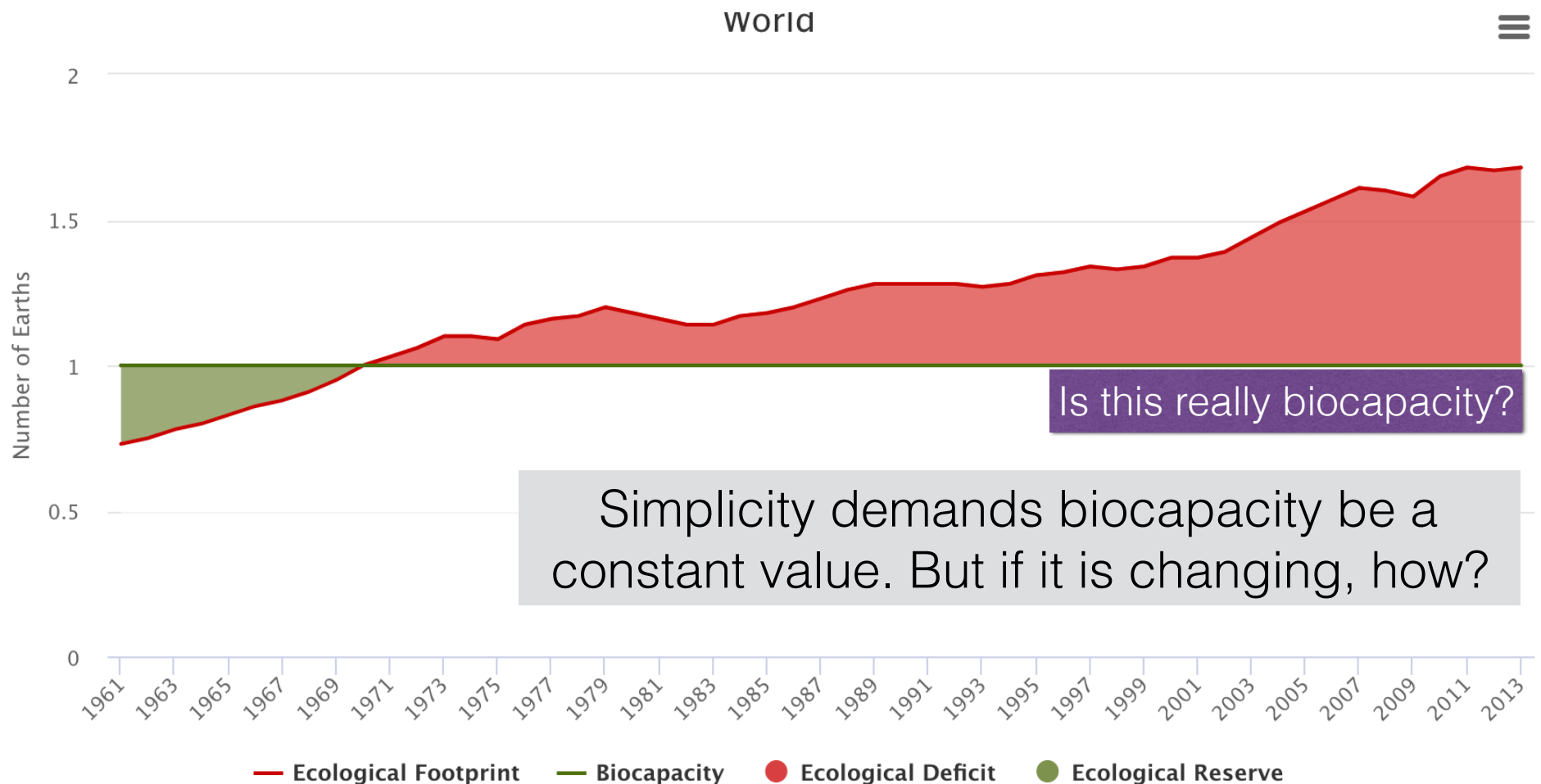
Human Population 2018

Lecture 13
land
biocapacity
impact
modified Lotka-Volterra

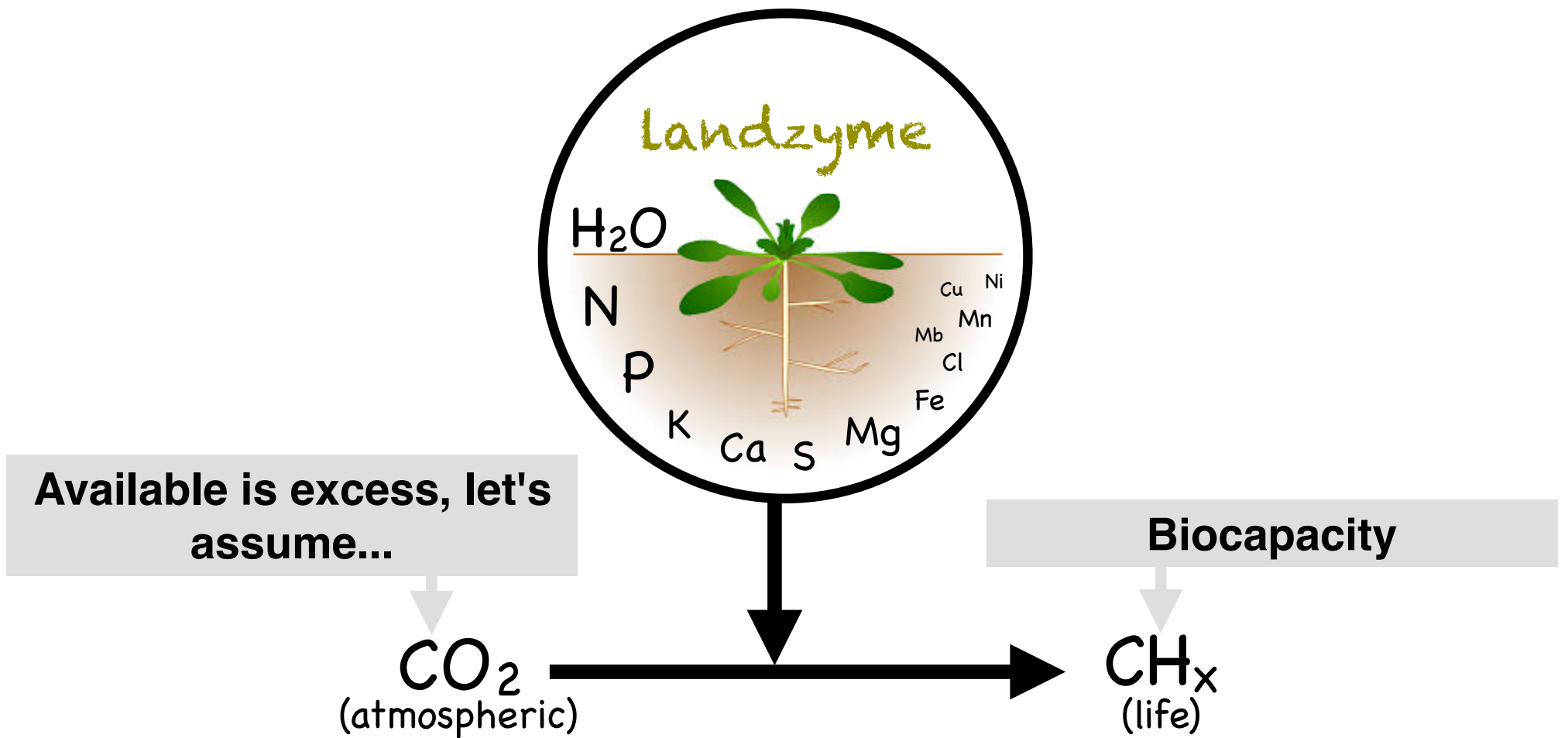
"The environment begins to send signals to the economy"

- How??
 - Diminishing returns in extraction
 - Land regenerates too slowly to keep up with degradation.
 - Food prices, cost of living, increase.
 - Health effects of pollution increase.
 - What else?

Ecological footprint over time is increasing. Biocapacity is not changing?

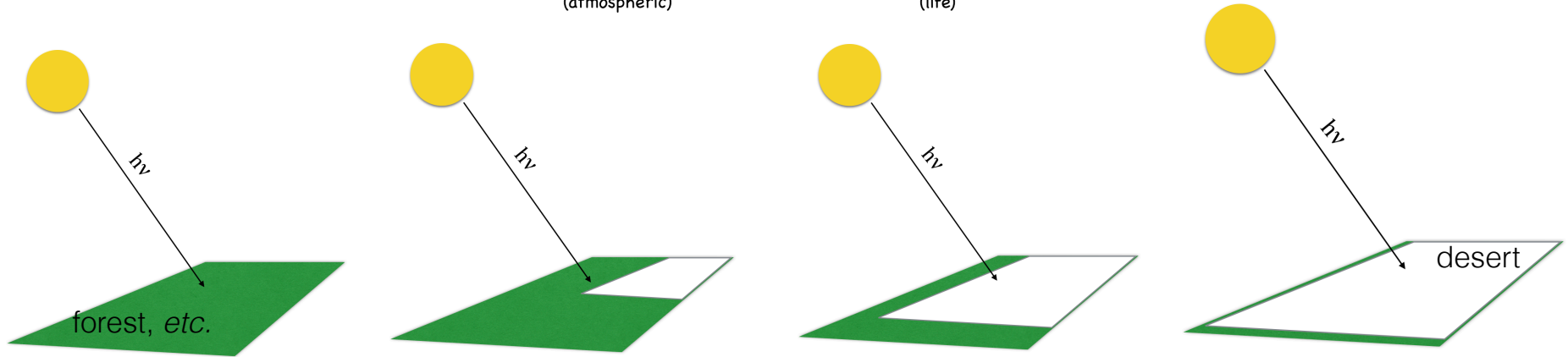
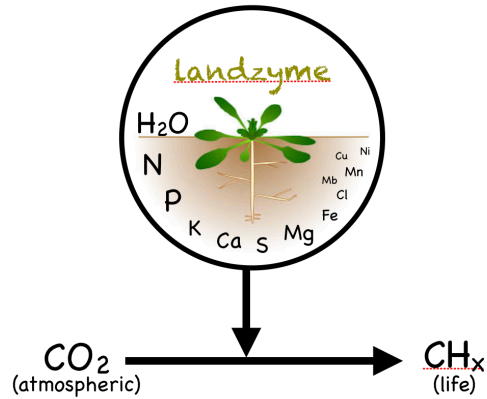


Land use determines the carbon balance.

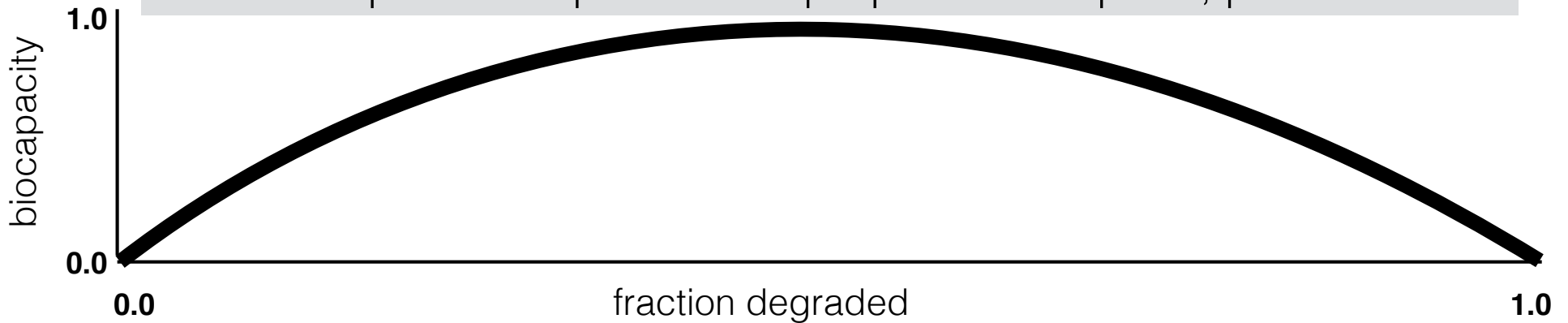


Land model for biocapacity - an inverted parabola

All life comes from plants, which require land and nutrients.



Land produces plant life in proportion to space, plant life.



Plants grow to a saturation point, then stop.

Natural Growth Curve of a Tree

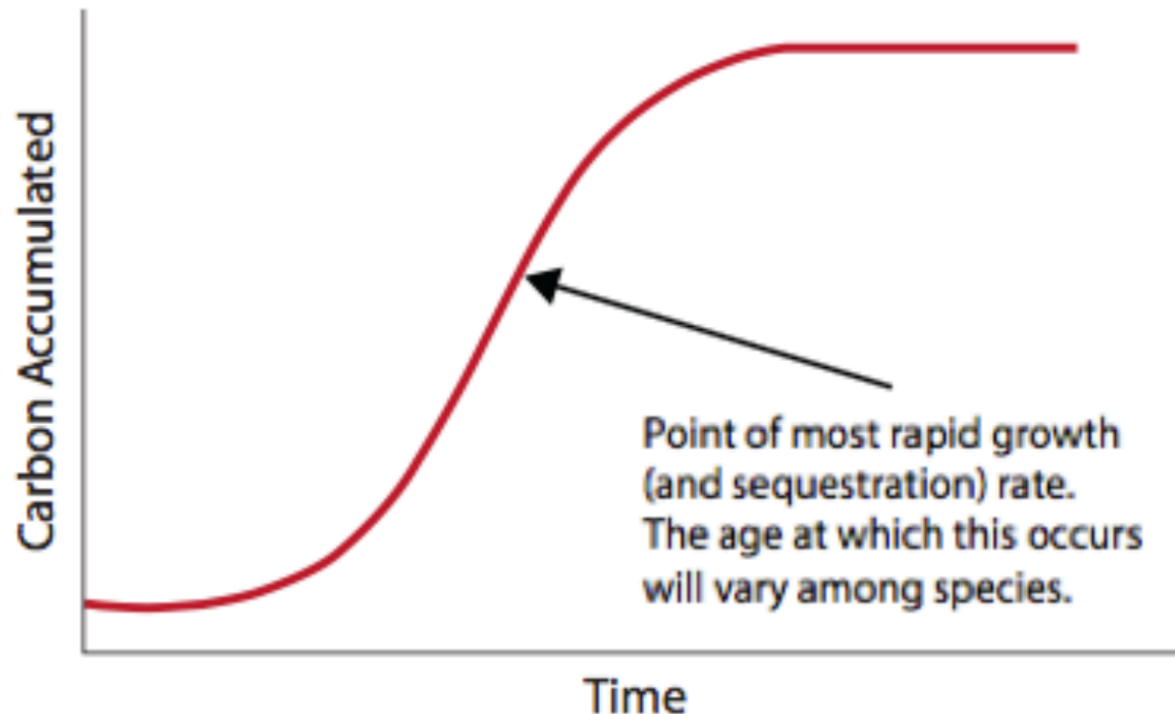
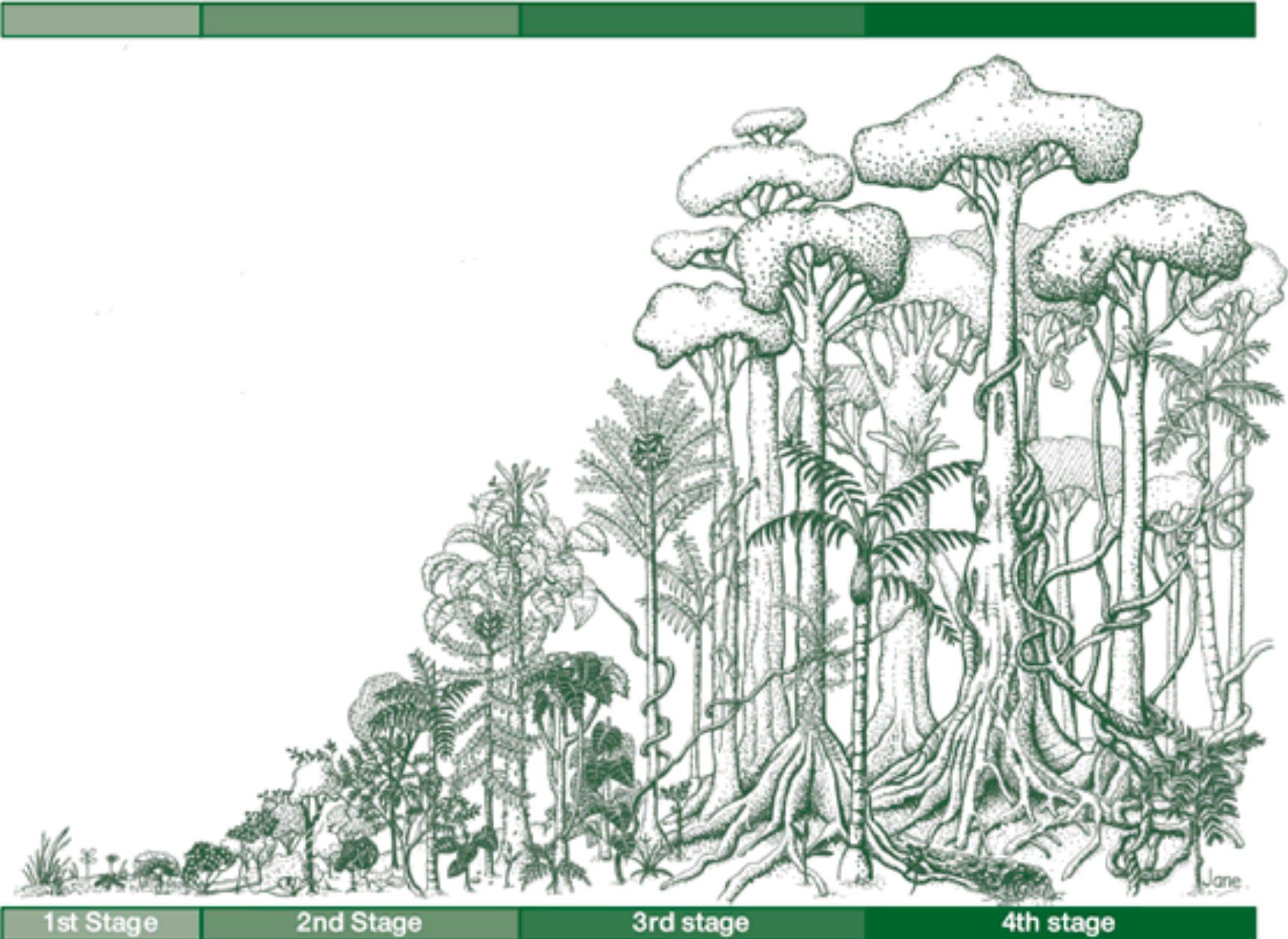


Photo credit: Union of Concerned Scientists.

Forest growth stages



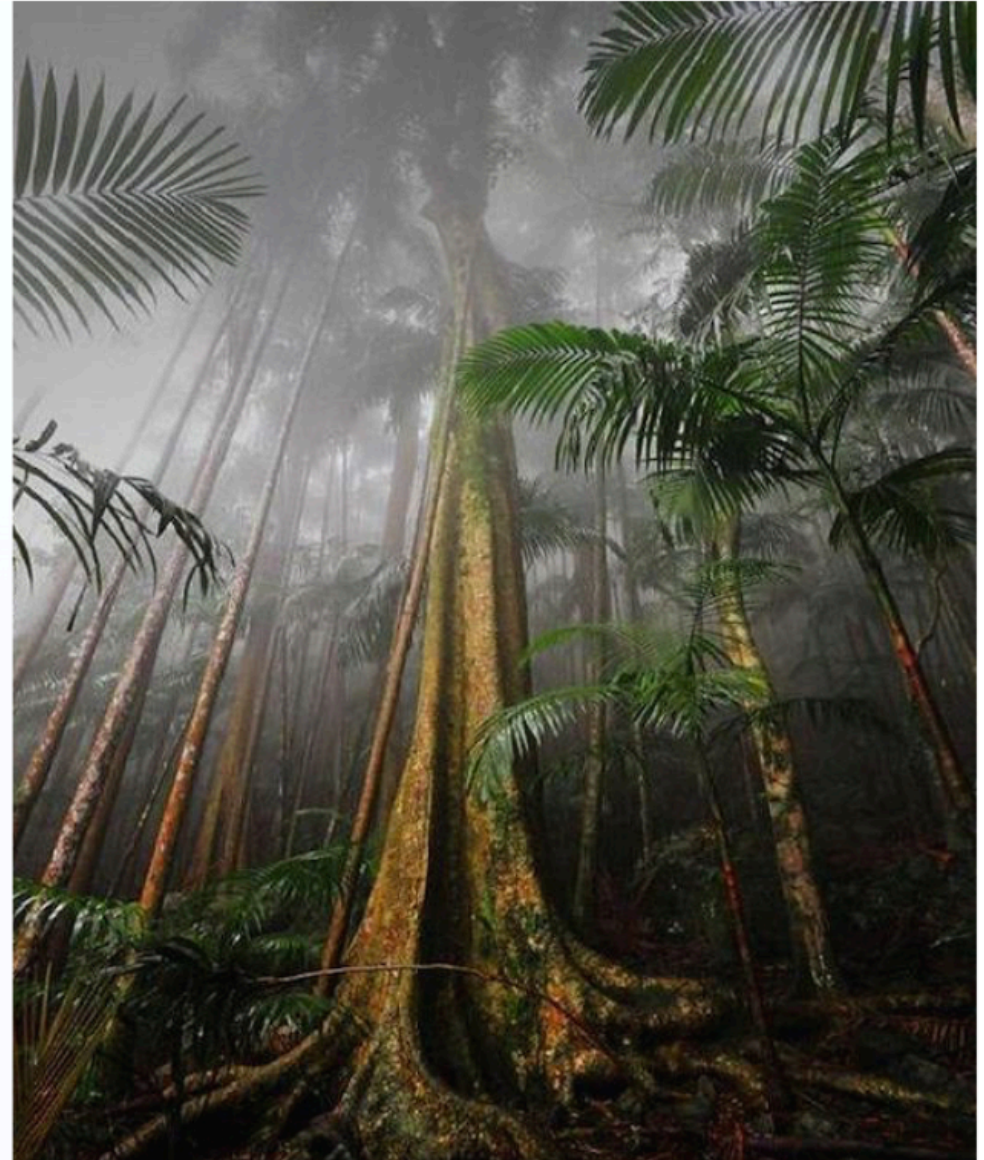
Forest growth stages

- **1st Stage Year 1:** Pioneer seedlings and herbaceous plants colonise the open soil.
- **2nd Stage 10-50 Years:** Pioneers colonise and spread their seeds, eg **bleeding heart**, native peach, and pencil cedar.
- **3rd Stage 50-200 Years:** Secondary species, which are still dependent on pioneers, become established, eg bumpy ash, black bean and native tamarind
- **4th Stage Mature Rainforest 500 Years +:** Longer lived species, eg strangler figs, laurels, pigeonberry ash, are reliant on a nearby seed source for regeneration to climax forest.

Animals are proportional to plants

- **Animals eat plants (or other animals)**
- **Animals grow in proportion to food supply (Lotka-Volterra model)**
- **Therefore, animals are proportional to plants.**
- **If we destroy plants, we also destroy animals, by removing their food supply (and habitat).**

The age of the forest plays a roll A recent study in Nature found that new rainforests grown on degraded lands, known as **secondary forests**, are capable of storing up to **11 times more carbon** than old growth rainforests, where tree growth has largely plateaued.



Rapidly growing secondary forests (left) can absorb up to 11 times more carbon than mature old growth forests (right).
Photo credit: Forru, Pixadus.

Drink more coffee. Save the planet.



While this may look like a natural forest, it's actually a coffee plantation. When coffee trees are cultivated under a canopy of diverse native species, the product is called **shade grown coffee**. These mixed-species plantations are a form of agroforestry and can fall under the umbrella of sustainable forest management.

Rainforest regrowth in abandoned gold mine in Peru

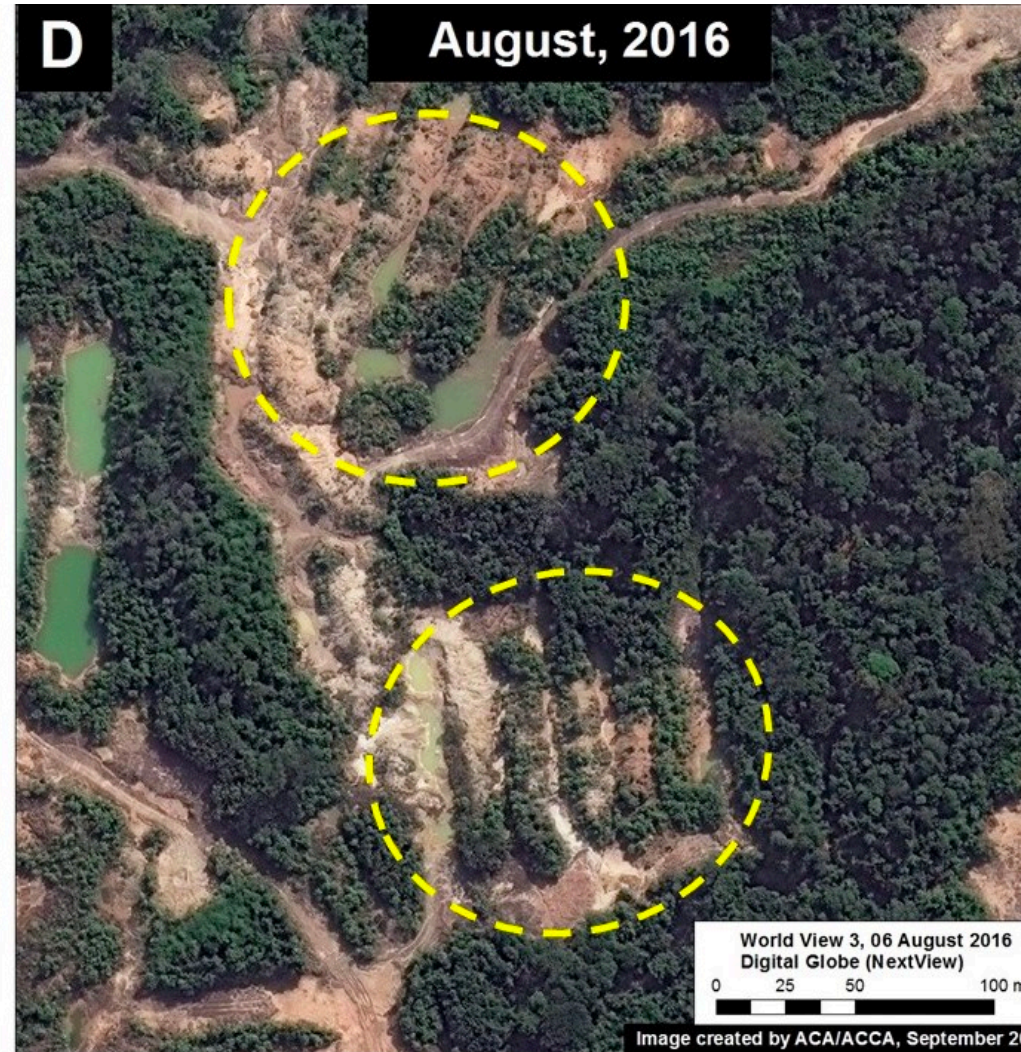
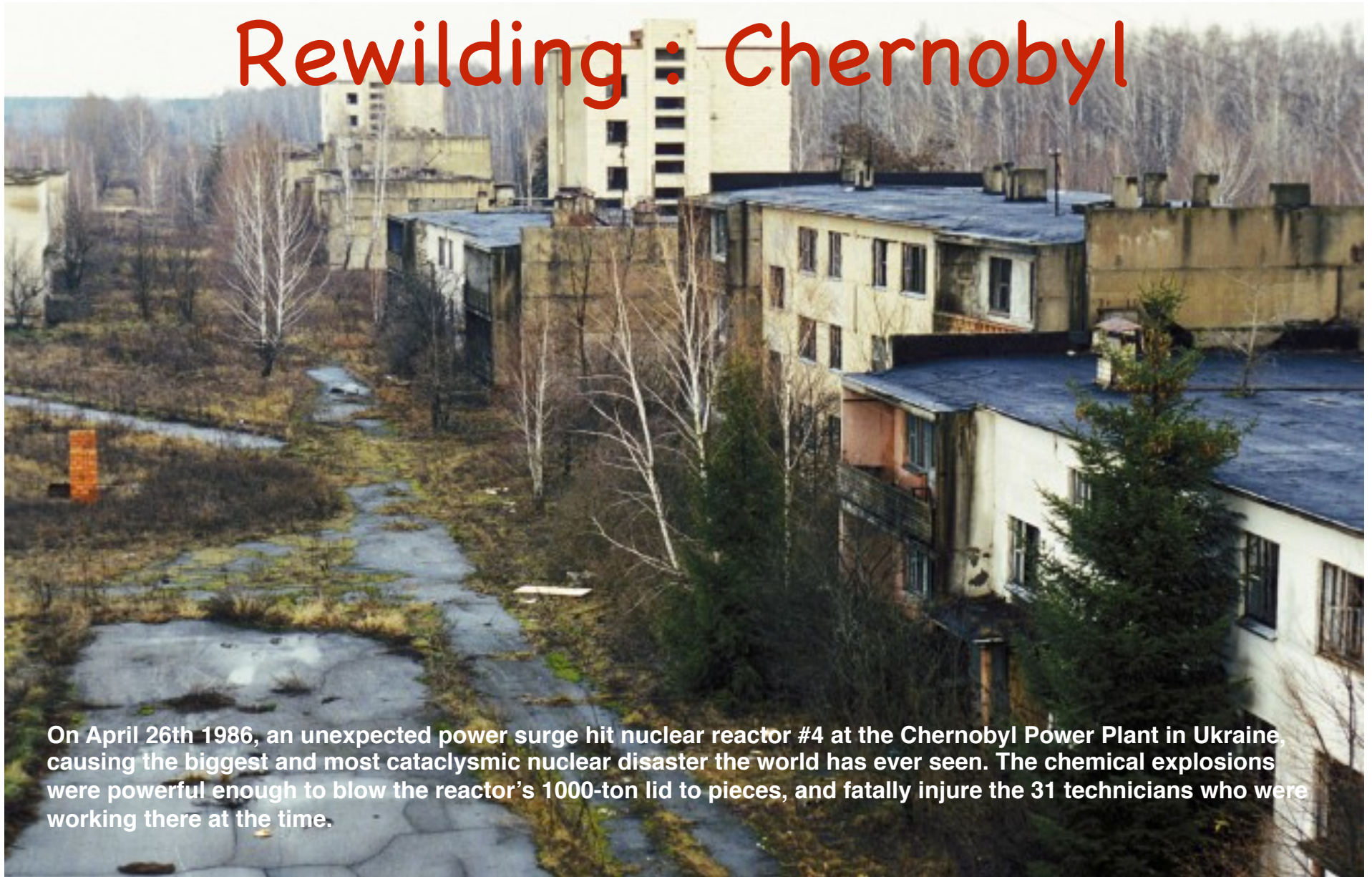


image courtesy of MAAP, with data from Digital Globe (Nextview)

<https://news.mongabay.com/2016/10/signs-of-regrowth-offer-hope-for-peruvian-rainforest-cleared-for-gold/>

Degraded land --> Forest

Rewilding : Chernobyl



On April 26th 1986, an unexpected power surge hit nuclear reactor #4 at the Chernobyl Power Plant in Ukraine, causing the biggest and most cataclysmic nuclear disaster the world has ever seen. The chemical explosions were powerful enough to blow the reactor's 1000-ton lid to pieces, and fatally injure the 31 technicians who were working there at the time.

Rewilding : Chernobyl



<http://www.theguardian.com/environment/2015/oct/05/wildlife-thriving-around-chernobyl-nuclear-plant-despite-radiation>

Rewilding : Chernobyl

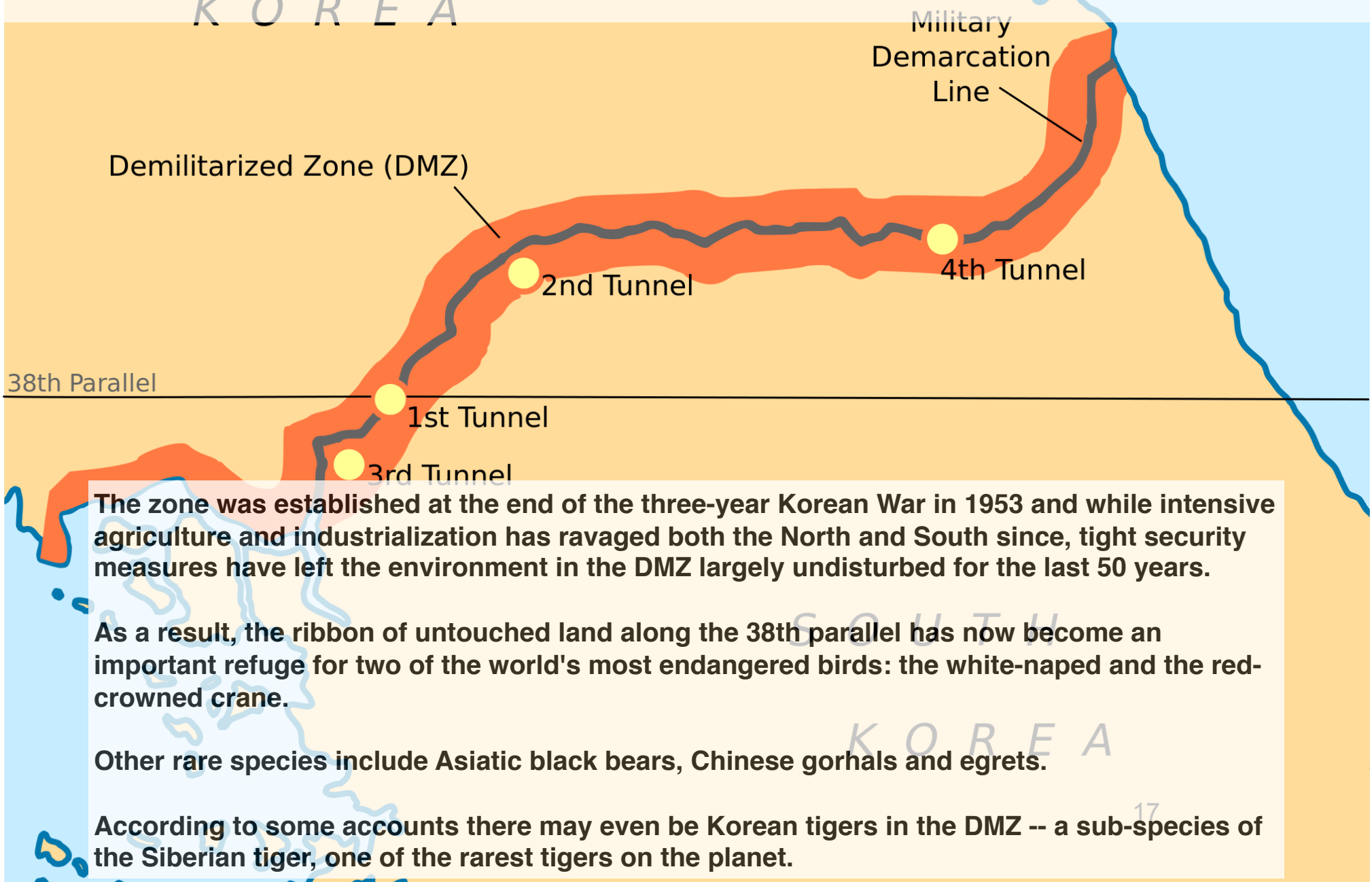


Rewilding : Chernobyl



Degraded land --> Forest

Rewilding : Korean demilitarized zone



The zone was established at the end of the three-year Korean War in 1953 and while intensive agriculture and industrialization has ravaged both the North and South since, tight security measures have left the environment in the DMZ largely undisturbed for the last 50 years.

As a result, the ribbon of untouched land along the 38th parallel has now become an important refuge for two of the world's most endangered birds: the white-naped and the red-crowned crane.

Other rare species include Asiatic black bears, Chinese gorphals and egrets.

According to some accounts there may even be Korean tigers in the DMZ -- a sub-species of the Siberian tiger, one of the rarest tigers on the planet.

Rewilding : Korean demilitarized zone



Rewilding : Korean demilitarized zone

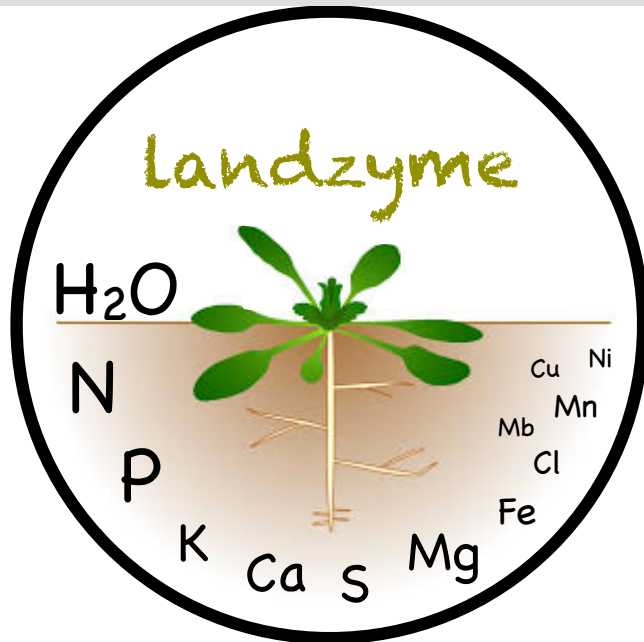


Rewilding : Korean demilitarized zone



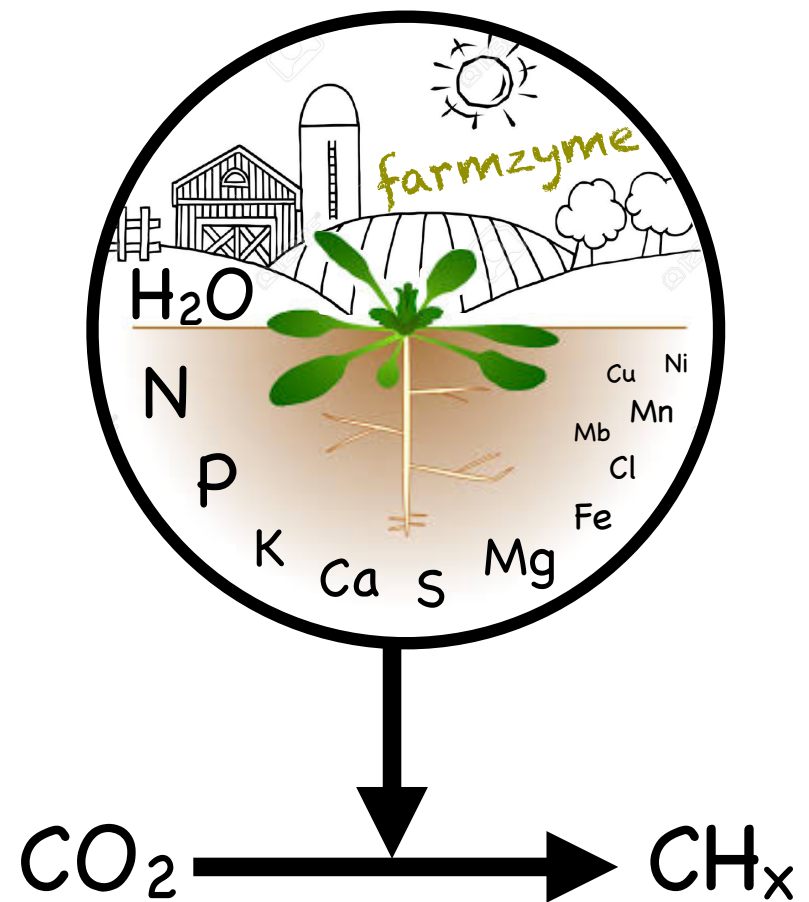
Energy input to Land determines biocapacity.

Land-based plants are a catalyst of CO₂ sequestration



+ Energy =

Energy inputs to the land optimize biocapacity.

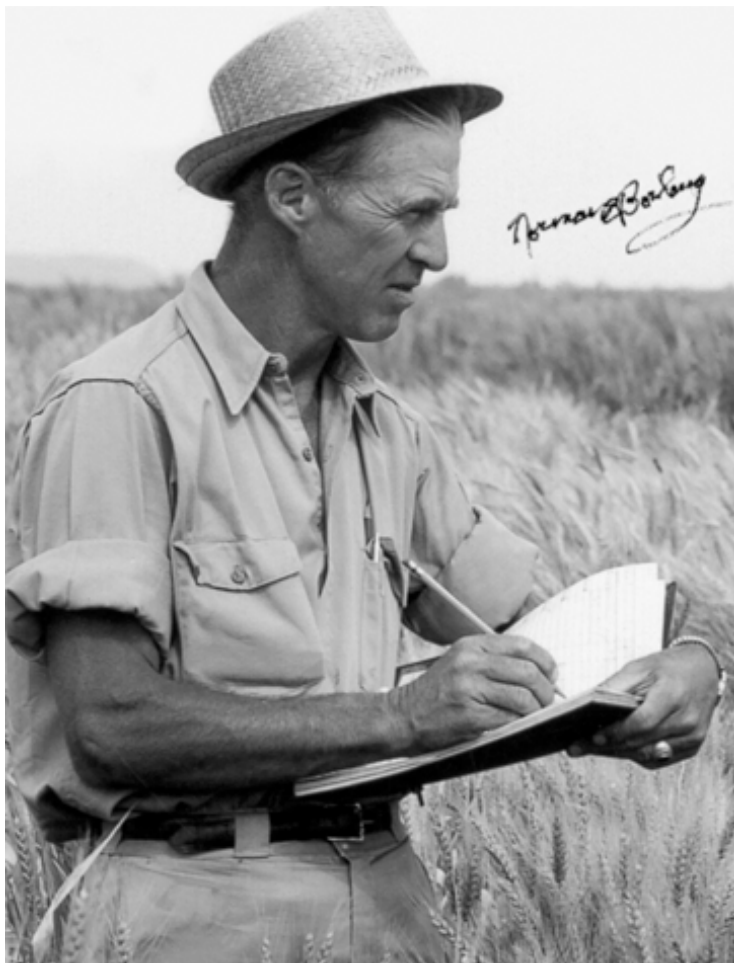


Biocapacity depends on the **land model**, but also on the base productivity of the land. *Farming optimizes the base productivity.*

Increasing farm biocapacity

The Green Revolution — quadruple yields

Norman Borlaug: Father of the Green Revolution. Developed high-yield (dwarf) wheat.



Outstanding in his field

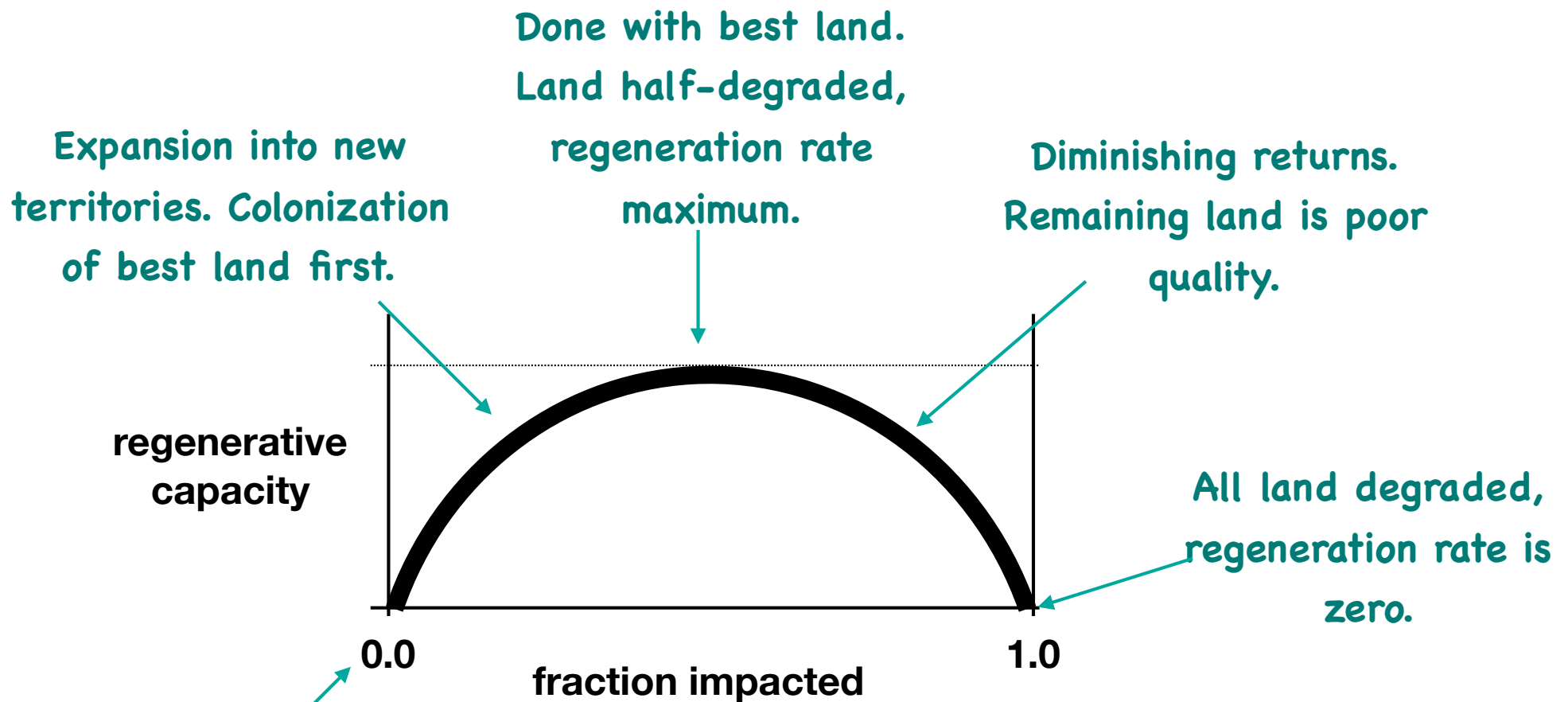


Statue of Norman Borlaug installed at US Capitol, April 1, 2014

"Most people still fail to comprehend the magnitude and menace of the 'Population Monster'"

--Norman Borlaug, father of the "Green Revolution"

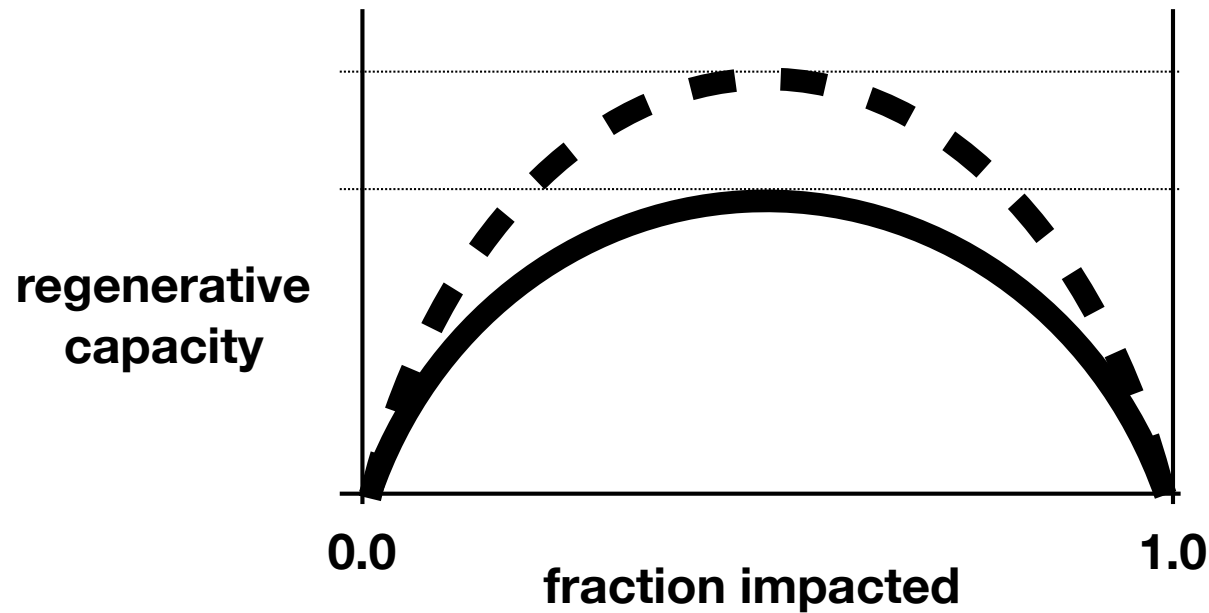
Biocapacity as a function of land use.



No humans. All land is saturated with life, no net regeneration.

In this simple model, 1/2 degraded is optimal for carbon sequestration, but the truth is certainly more complicated!

Biocapacity with energy input.



Farming increases biocapacity! For simplicity we'll say the increase is scalar.

Take home messages

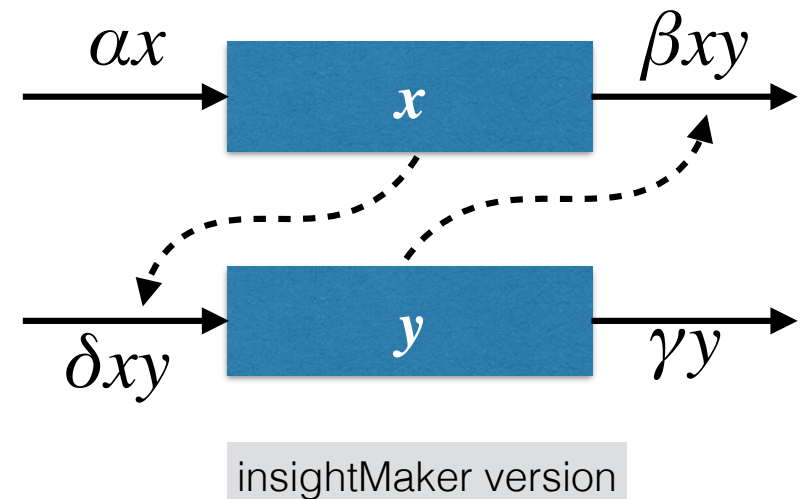
1. Biocapacity is **food supply**.
2. Biocapacity is a **peaked** function of land degradation.
3. **Energy input** (renewable or non-renewable) can raise biocapacity, temporarily.

What happens if we add the land model to the...?

Lotka–Volterra model

$$\frac{dx}{dt} = \alpha x - \beta xy$$

$$\frac{dy}{dt} = \delta xy - \gamma y$$

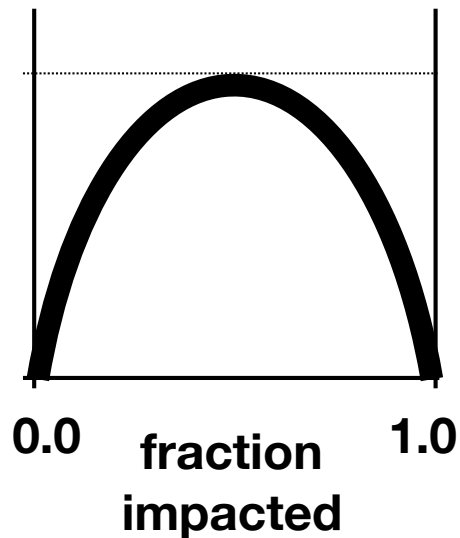


- x is the number of prey (for example, **rabbits**);
- y is the number of some **predator** (for example, **foxes**);
- α and δ represent the instantaneous growth rates of the two populations;
- t represents time; and
- α is the intrinsic growth rate of x (*assumes infinite food*)
- β is the predation rate of y on x
- γ is the intrinsic death rate of y
- δ is the growth rate of y due to *availability of x* .

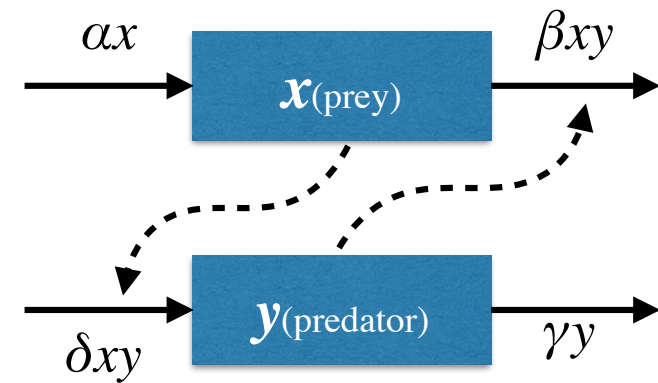
How is "Land" analogous to "Prey"?

Biocapacity is the rate of reproduction of life on Land.

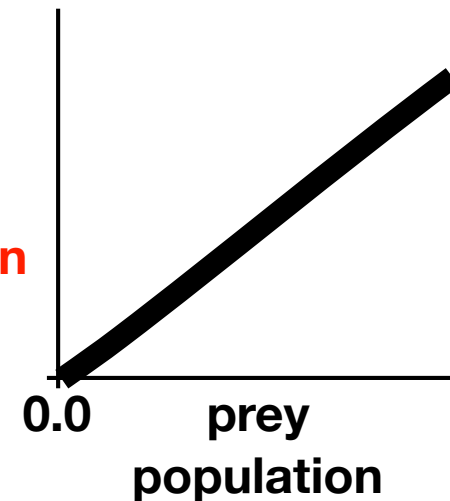
Land
reproduction



Nature (think of forests) grow proportional to biomass, then decrease growth as they reach the point of saturation.

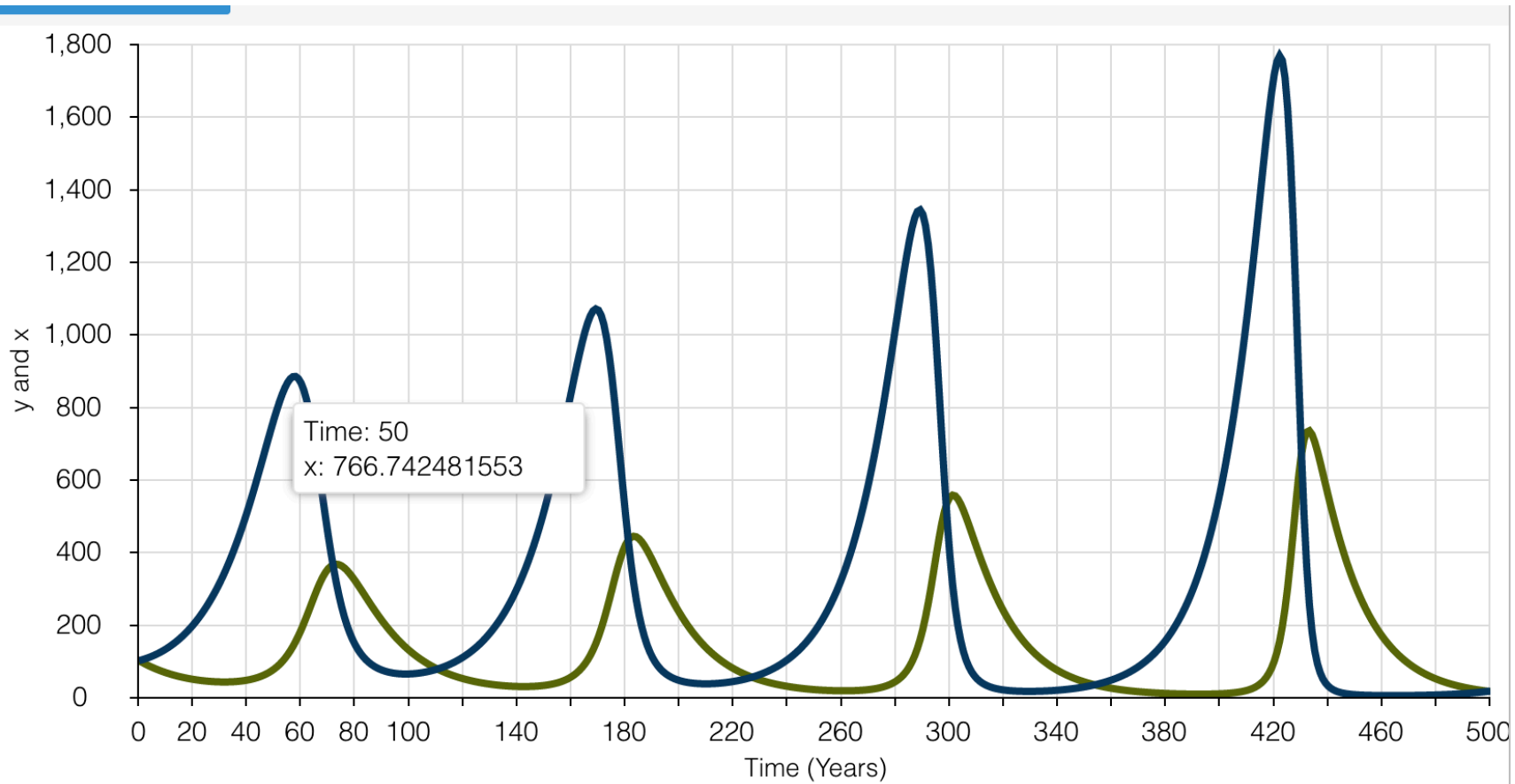


Prey
reproduction



In the L-V model, prey grow in proportion to biomass. Prey do not reach a point of saturation.

Lotka-Volterra produces unstable oscillations.

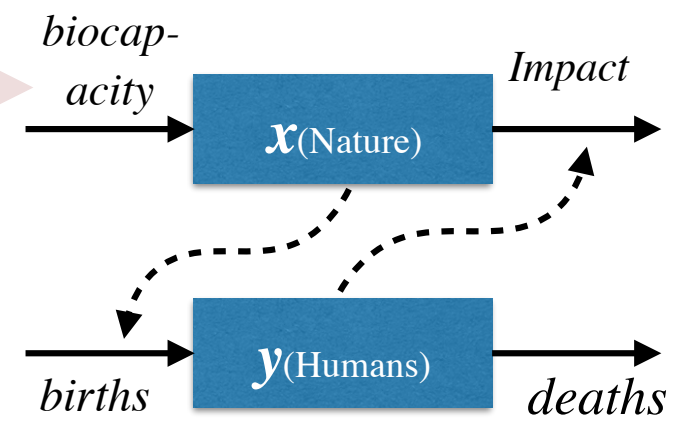
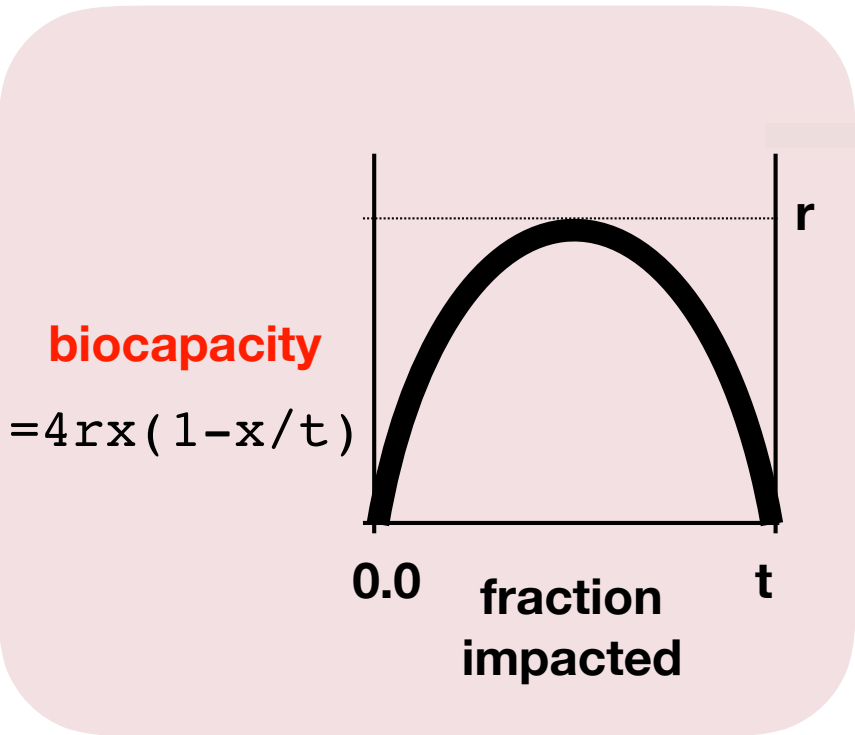


Oscillations diverge. Unstable!

Land model for biocapacity

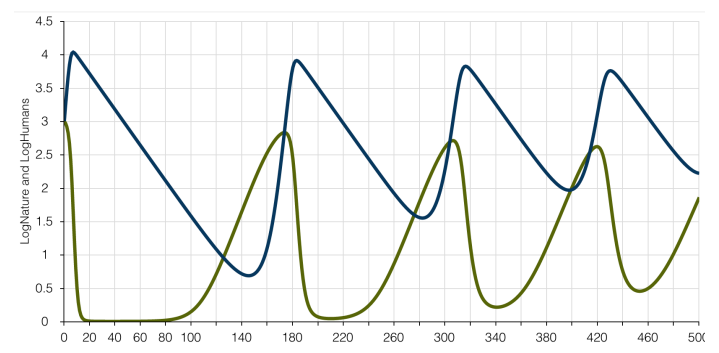
-- oscillations are damped

Nature = amount of life on Land



Humans = predators of Nature

Nature, instead of growing exponentially without limit, grows exponentially with an upper limit. At that limit biocapacity goes to zero.

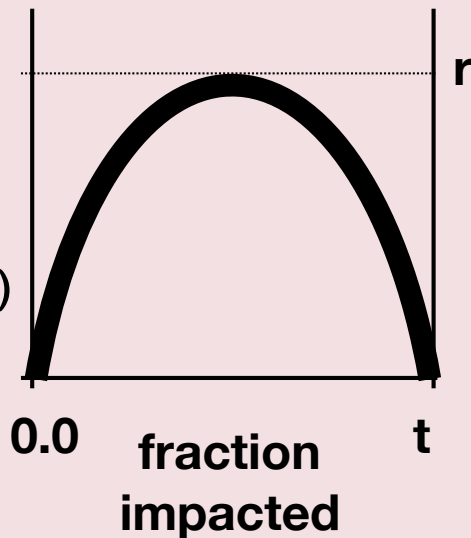


Still oscillates. But oscillations are damped.

Modified Lotka-Volterra

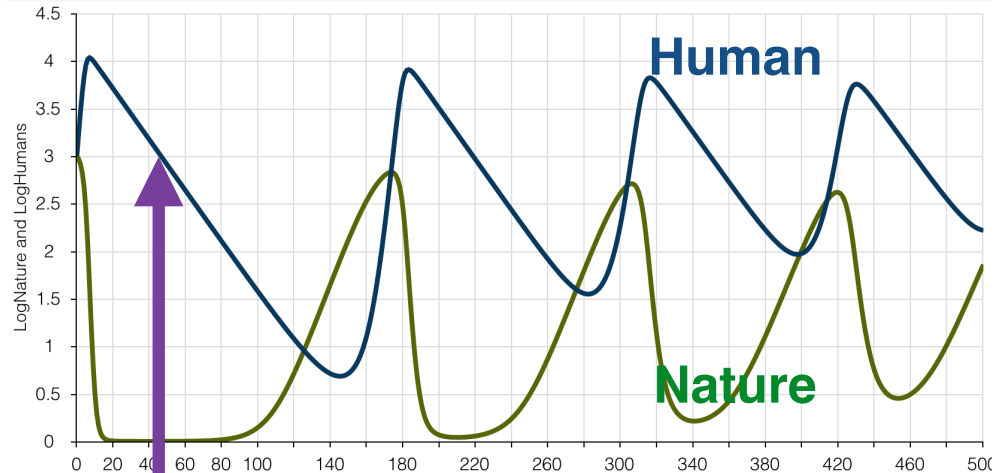
Modeling biocapacity using the **land model** produces slightly damped, but deep oscillations.

biocapacity
 $=4rx(1-x/t)$



Nature (prey) grows to a **maximum**, instead of growing infinitely. Therefore Humans (predators) also grow to a **limit**.

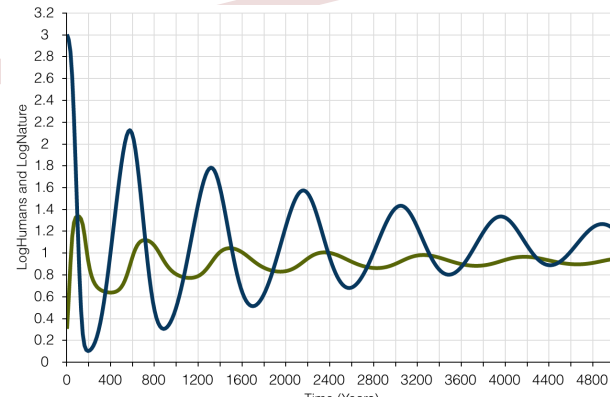
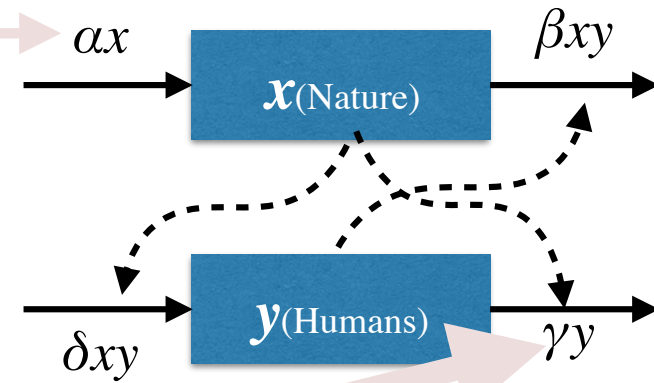
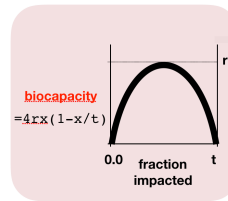
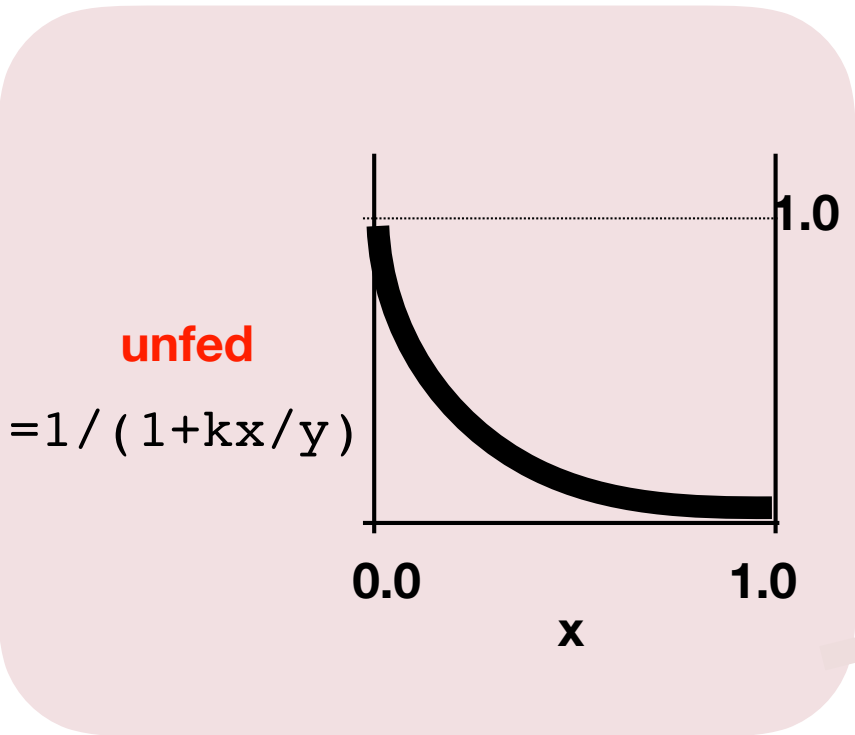
But, is it realistic enough?



Is it realistic to think **unfed predators do not starve** but simply have a higher intrinsic death rate?

Adding starvation...

L-V model

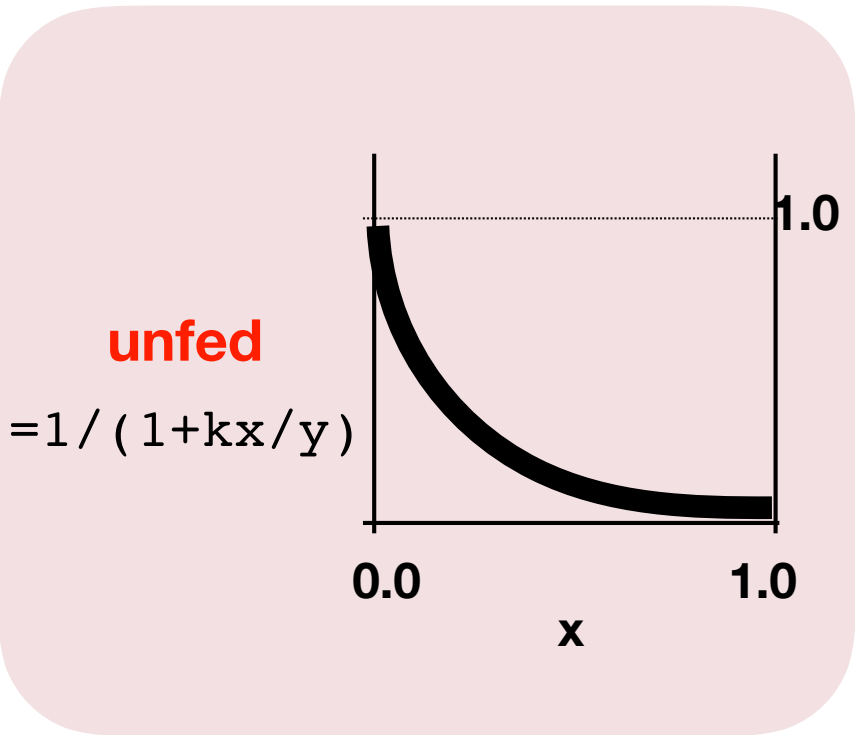


Humans (predators in this model) collapse in population in proportion to the number that are left unfed. Extrinsic death is faster than intrinsic negative exponential growth.

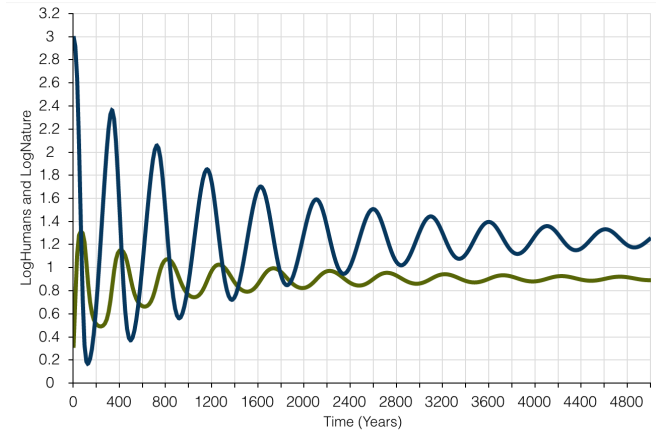
Very damped oscillations. Very stable.

Modified Lotka-Volterra

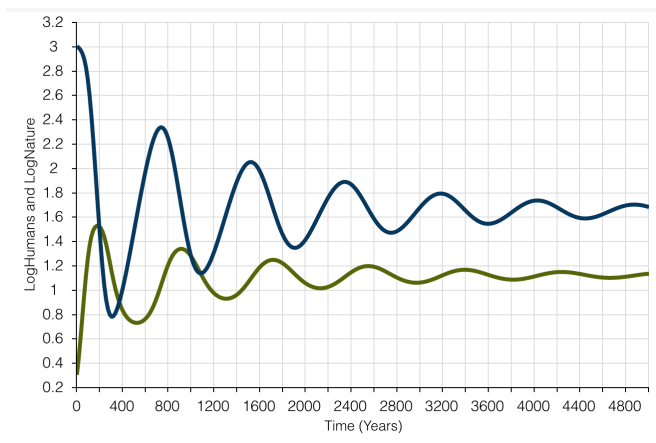
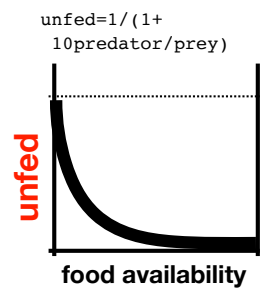
Starvation, faster than exponential decline, catches the carrying capacity as it drops due to overshoot.



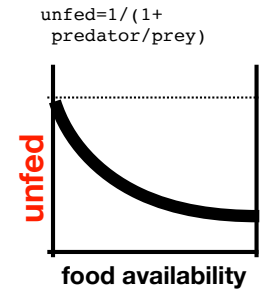
Humans (predators in this model) collapse in population in proportion to **the number that are left unfed**. This is faster than negative exponential growth.



damped. $k=10$

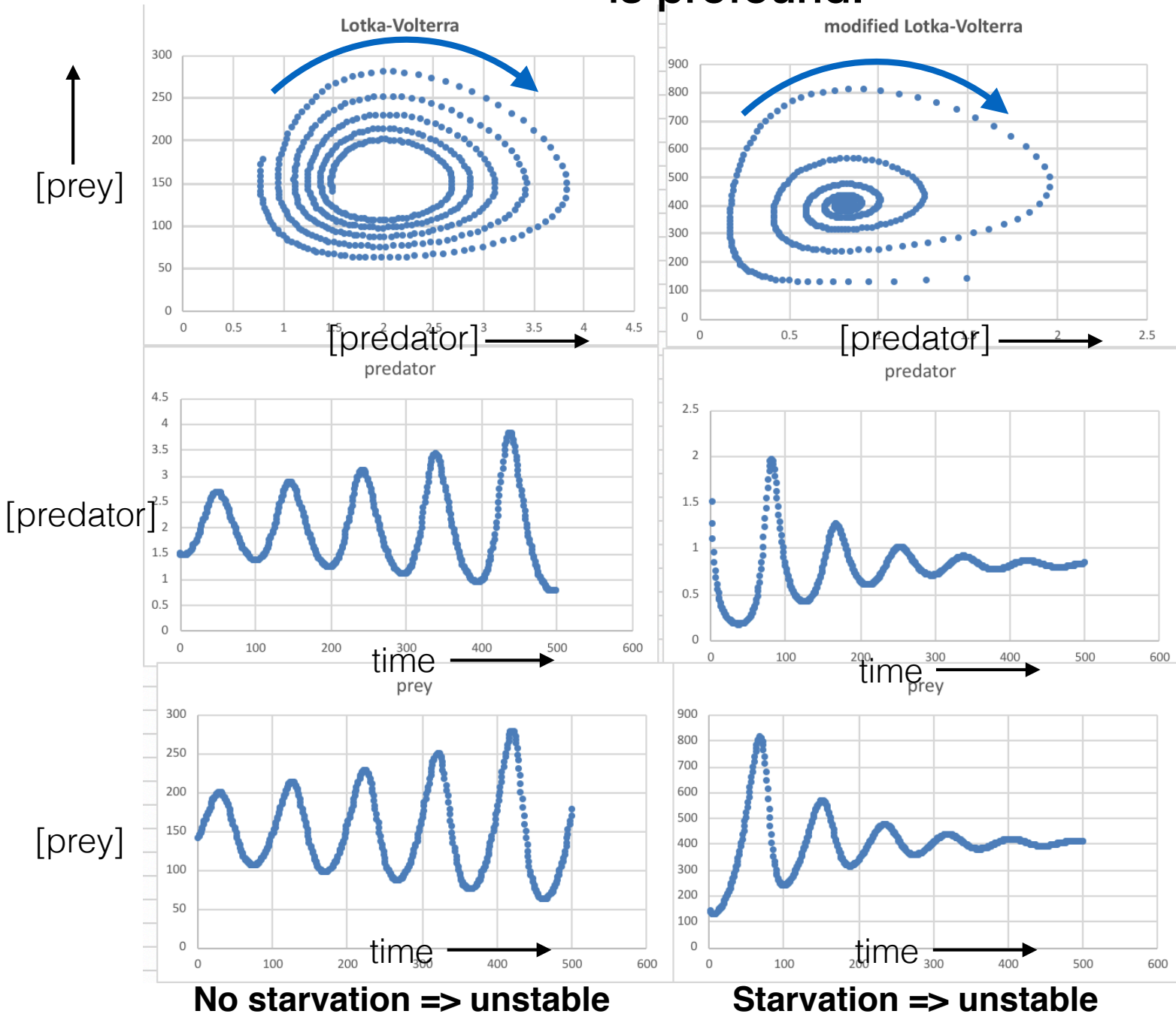


more damped. $k=1$



Modified Lotka-Volterra

The difference between L-V and modified L-V+starvation is profound!



If the correction is slow, oscillations get wider.

If the correction is fast, oscillations are damped.

Take home messages

1. At overshoot, human population decreases due to **food supply**.
2. If decrease were intrinsic (increased death rate, as in classic L-V model) then oscillations would be **unstable**.
3. Decrease is extrinsic (starvation), resulting in **damped oscillations**.

Is the growth rate really a
function of food
availability? For humans?

HUMAN POPULATION NUMBERS AS A FUNCTION OF FOOD SUPPLY

RUSSELL HOPFENBERG^{1,*} and DAVID PIMENTEL²

¹*Duke University, Durham, NC, USA;* ²*Cornell University, Ithaca, NY, USA*

*(*author for correspondence, 105 Autumn Drive, Chapel Hill, NC, USA 27516-7744;
e-mail: RussH100@aol.com; tel.: (919) 431 0085)*

(Received 11 January 2000; accepted 6 March 2001)



Quotes from Hopfenberg & Pimentel

animal studies

Food energy is partitioned into four compartments viz.: maintenance, growth, stored energy, and reproduction.

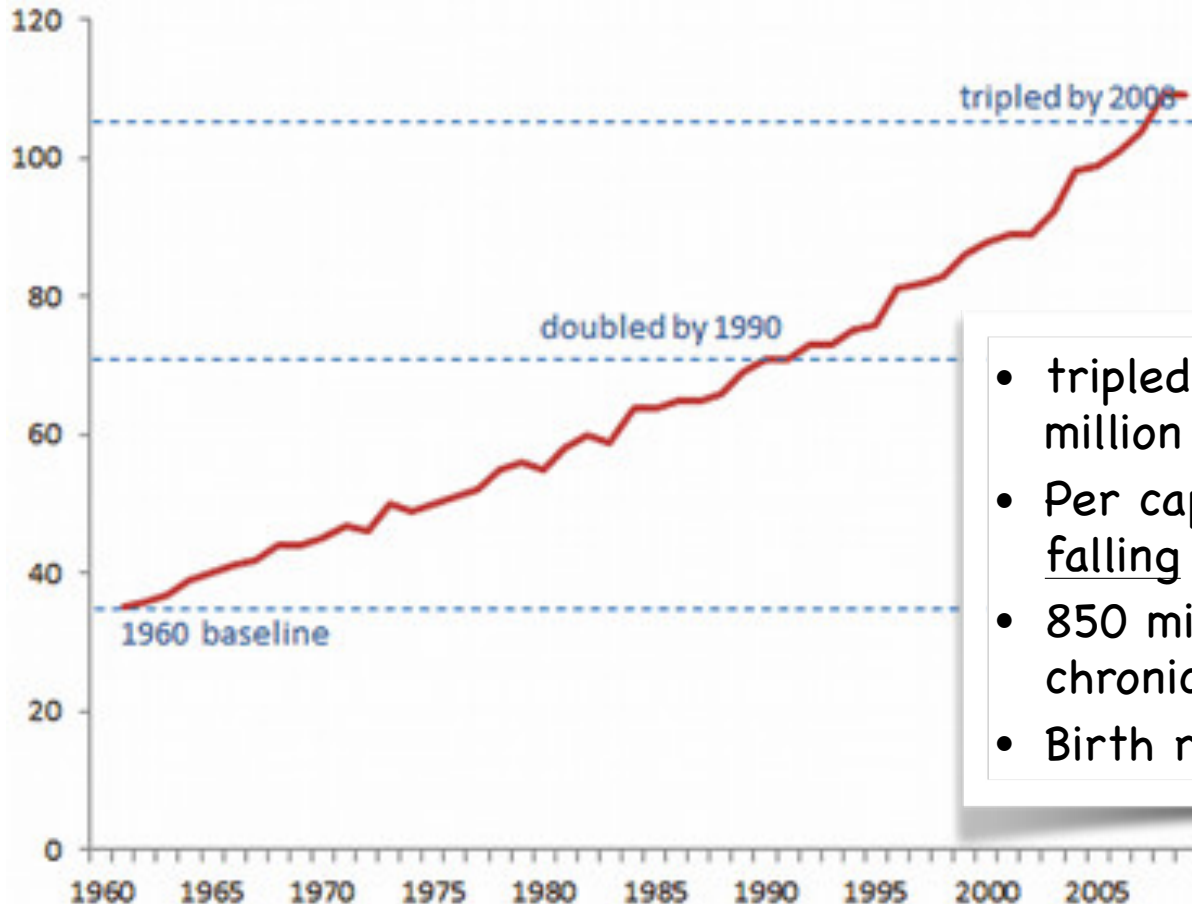
cultural bias in science

Some, like Julian Simon (1991) hold that humans are exempt from the natural laws of physics and biology and that human behavior occurs as a result of metaphysical forces.

thesis statement

Again, the data overwhelmingly establishes that increasing the amount of food available to the population of any species leads to an increase in the population of that species and a decrease in the amount of food leads to a decrease in the size of the affected population (Caceres et al., 1994; McKillup and McKillup, 1994; Angerbjorn et al., 1991; Wayne et al., 1991; Bomford, 1987)

World crop production levels, late 20th early 21st century.



- tripled from 1950 to 2000: 590 - 2000 million metric tons
- Per capita grain production has been falling since 1985
- 850 million are "undernourished", chronically hungry.
- Birth rates are falling.

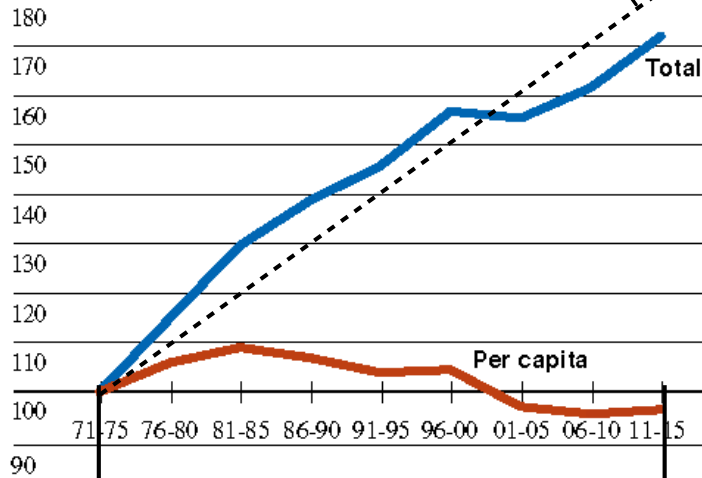
(Source: FAOStat 2011)

According to Hopfenberg, fertility should go up, but....

grain per capita is decreasing, parallels fertility

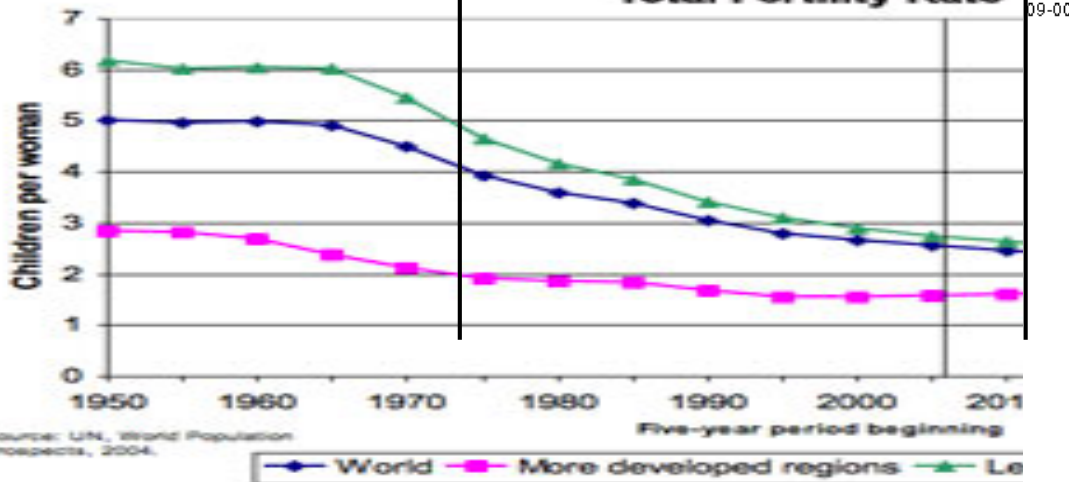
Global Grain Production: 1971-2015

Index: 1971-75=100



Sources: International Food Policy Research Institute, October 1999, US Bureau of the Census, and CIA.

Total Fertility Rate



Source: UN, World Population Prospects, 2004.

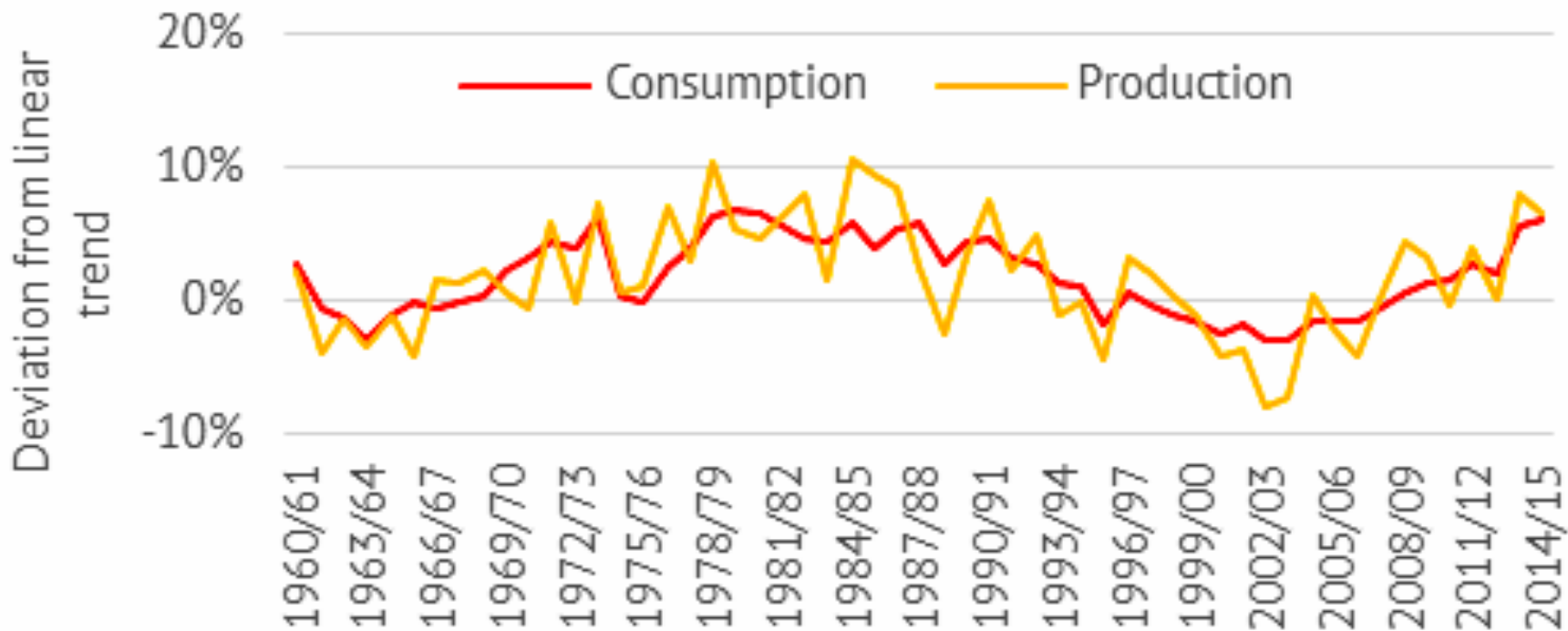
population increase

Total food production has been constantly increasing.

But, per capita food is decreasing.

Fertility is also decreasing.

total world grain consumption mirrors total world grain production



- Consumption of grains mirrors production, although production fluctuates more than consumption.
- There is no apparent delay in the production/consumption curves.
- We eat what's on our plate!

Source: USDA analysed Inside Track
<http://www.insidetrack.org.uk/264/>

Food limitations to growth

in Yeast

$$\mu = \frac{\mu_{\max}}{\sum_n \left(1 + \frac{k_n}{x_n}\right)} + \varepsilon, n \in \{C, N, P, U\} \quad (5)$$

Growth rate is attenuated by nutrient deficiency.

Boer, Viktor M., et al. "Growth-limiting intracellular metabolites in yeast growing under diverse nutrient limitations." *Molecular biology of the cell* 21.1 (2010): 198-211.

Are Humans smarter than Yeast?

Food limitations to growth

in Mouse

Infant mortality rate increases with nutrient deficiency.
Intraspecific strife increases with increased population density.

Bendell, J. F. "Food as a control of a population of white-footed mice, *Peromyscus leucopus noveboracensis* (Fischer)." *Canadian Journal of Zoology* 37.2 (1959): 173-209.

Do humans behave like mice?

Wilmsen, Edwin N. "Diet and fertility among Kalahari Bushmen." (1979).

- The 1st category of births (bush food dependent) displayed a marked peak in March-April when 32% of all reported births occurred. Conceptions which led to these births would have occurred in June-August when calorie-protein intake was highest, and individual weights were at their peak. Births to women whose diets included large amounts of milk and maize meal were more evenly distributed throughout the year, - See more at: <http://www.ponline.org/node/460468#sthash.1kV7BFly.dpuf>

Are Humans smarter than Yeast?

- Can we control our reproductive rate?
- Or do we let biocapacity control us?
- What will happen in each case?