Human Population 2017

Lecture 14
modeling

A <u>foundational</u> model

- Includes undisputed functional forms and feedbacks.
- Models system behavior qualitatively, not quantitatively.
- Models sensitivities qualitatively, not quantitatively.
- A work in progress. Incomplete, but not necessarilly incorrect.
- You **build** on it.

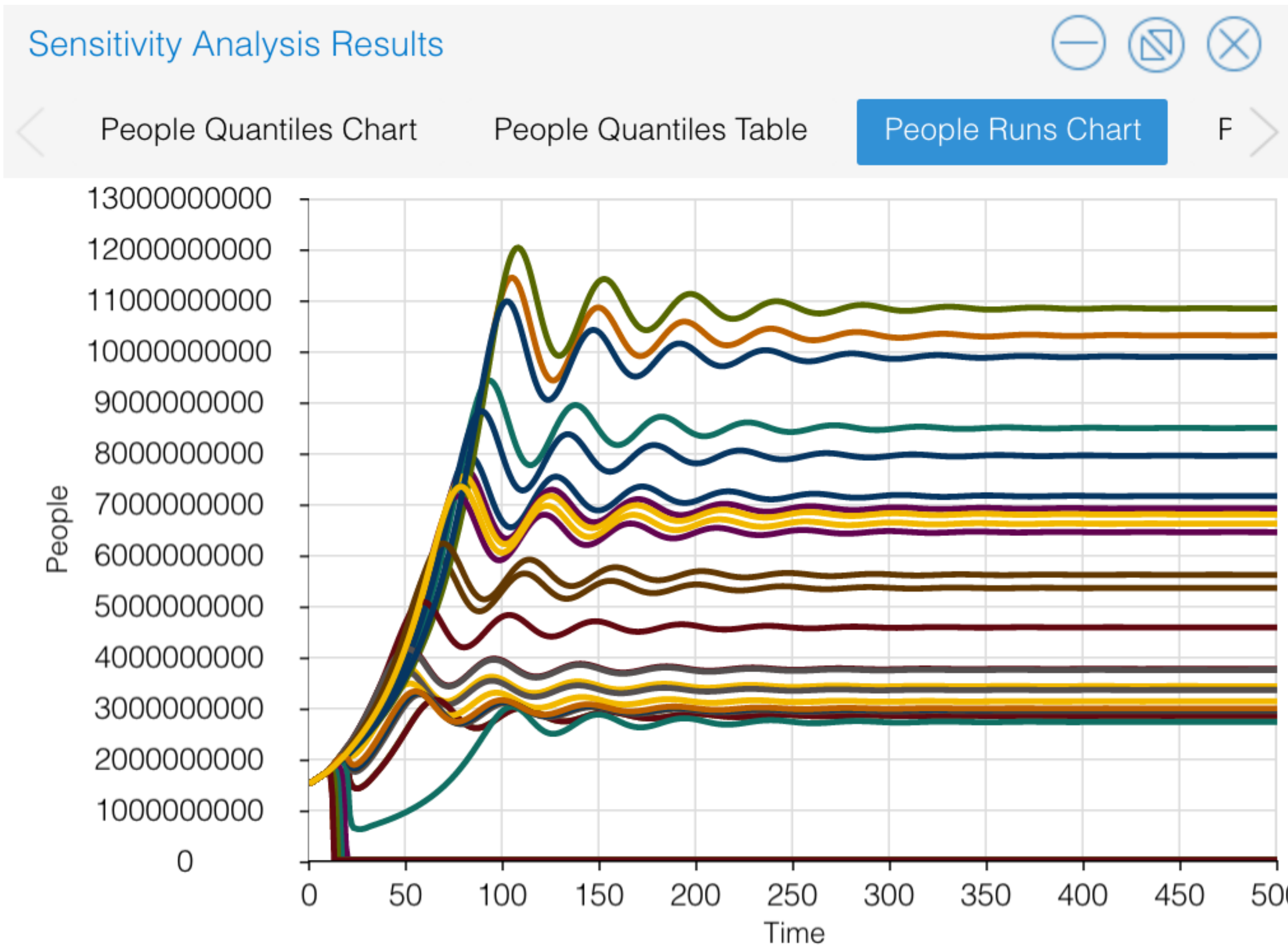
Our foundational model

assumptions

- Population grows or shrinks **exponentially** depending on death rate, birth rate.
- Birth rate and death rate have **linear relationships with Affluence**.
- Environmental **Impact** is proportional to **Population, Affluence and Technology**
- **Biocapacity** cancels, balances **Impact**.
- **Biocapacity** depends **Ecological Capital** which depends on **Impact**.
- **Biocapacity** has a peak at moderate **Impact**.
- Constant **Impact** > peak **Biocapacity** leads to ecosystem collapse.
- Decreased **Ecological Capital** leads to **rationing**, decreased **Affluence**, increased **death rate** (or increased infact mortality)

Technology

sensitivity

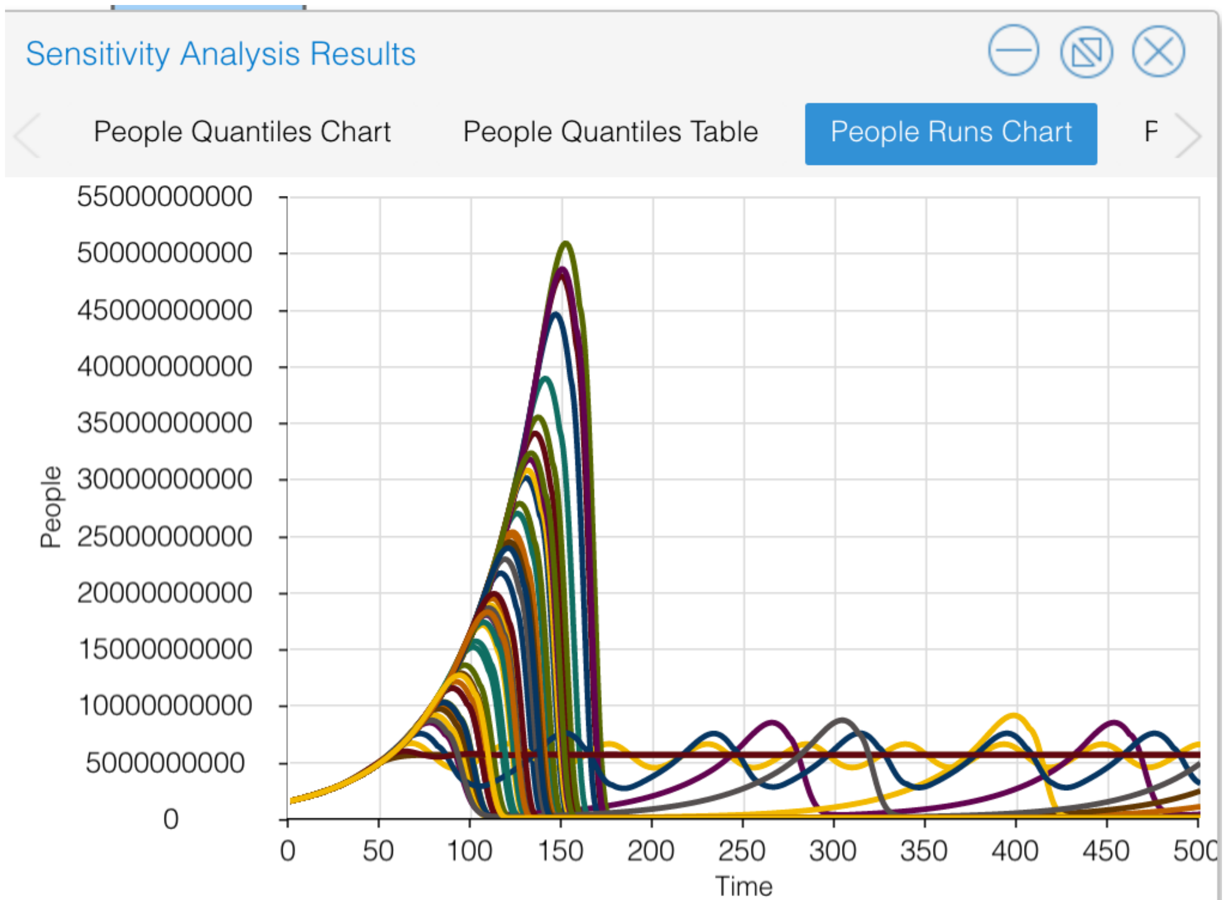


I=PAT

Below a certain cutoff, plateau population depends on decr. Technology factor. Lower mean higher Pop.

Delay =years needed to adapt to rationing

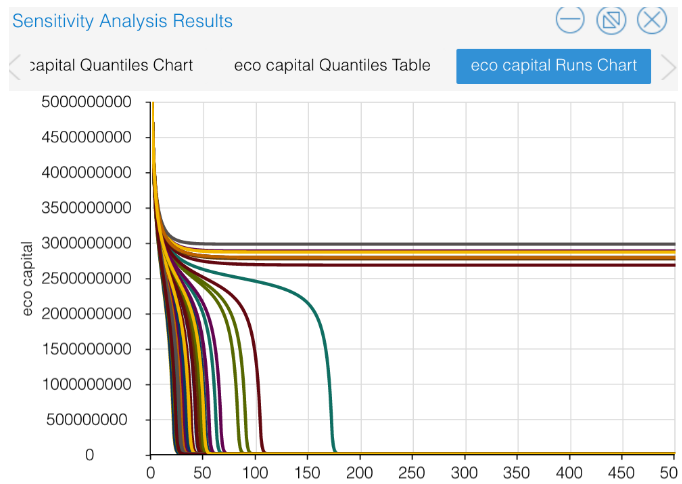
```
x <- Delay([rationing],[delay],[QOL])
```

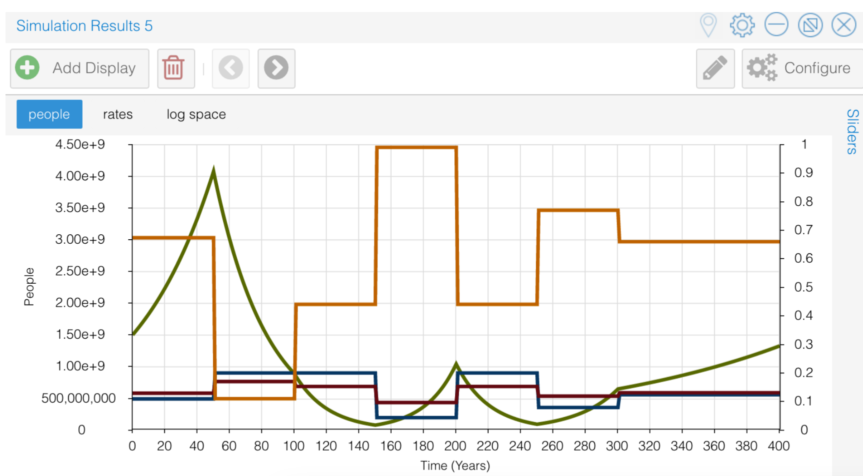


sensitivity

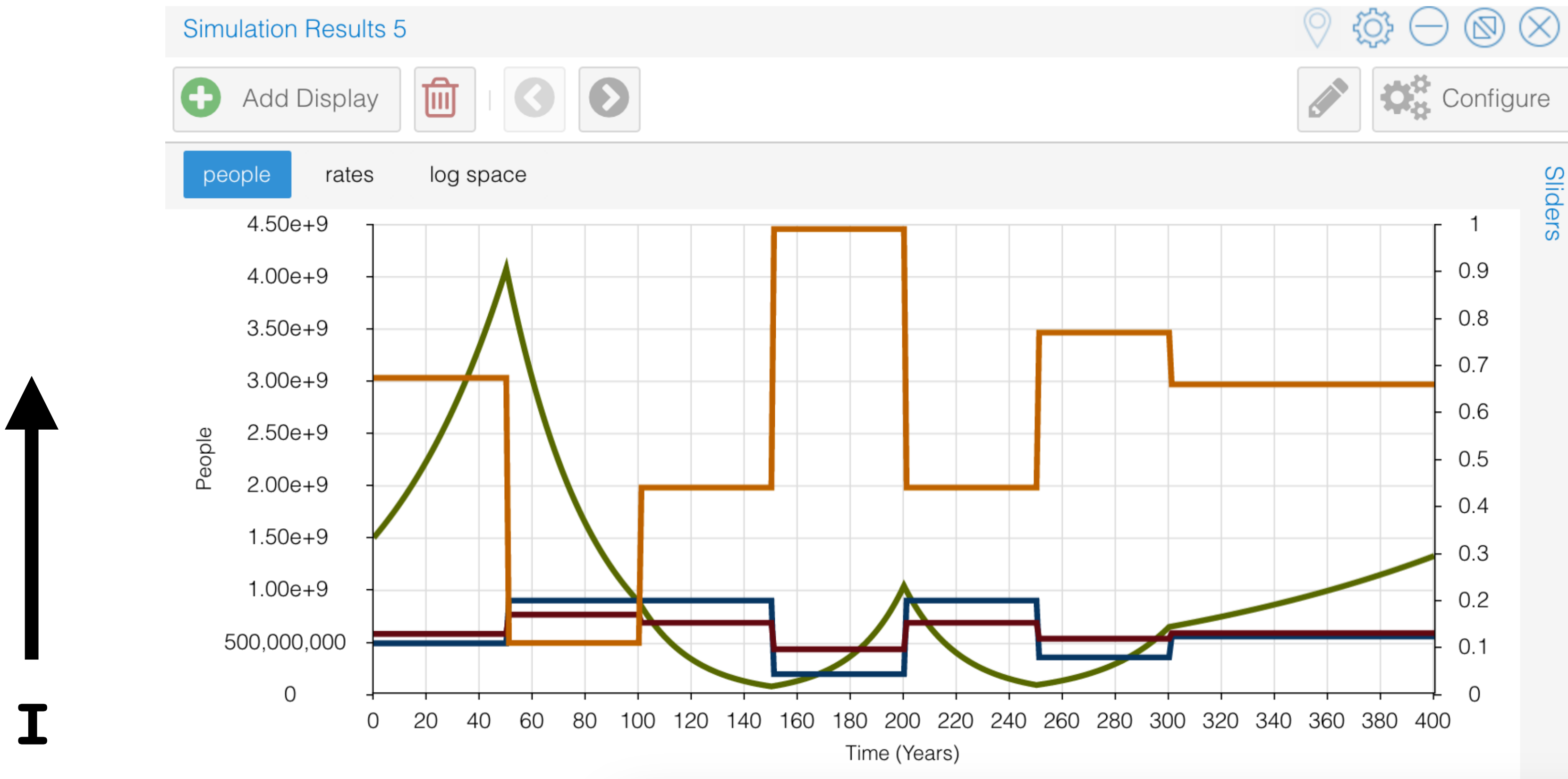
With increasing Delay, increasing overshoot, increasing severity of collapse.

"Endowment trust" + exponential instability = ?





The spiky nature of the exponential function



Slope (positive or negative) is proportional to people.

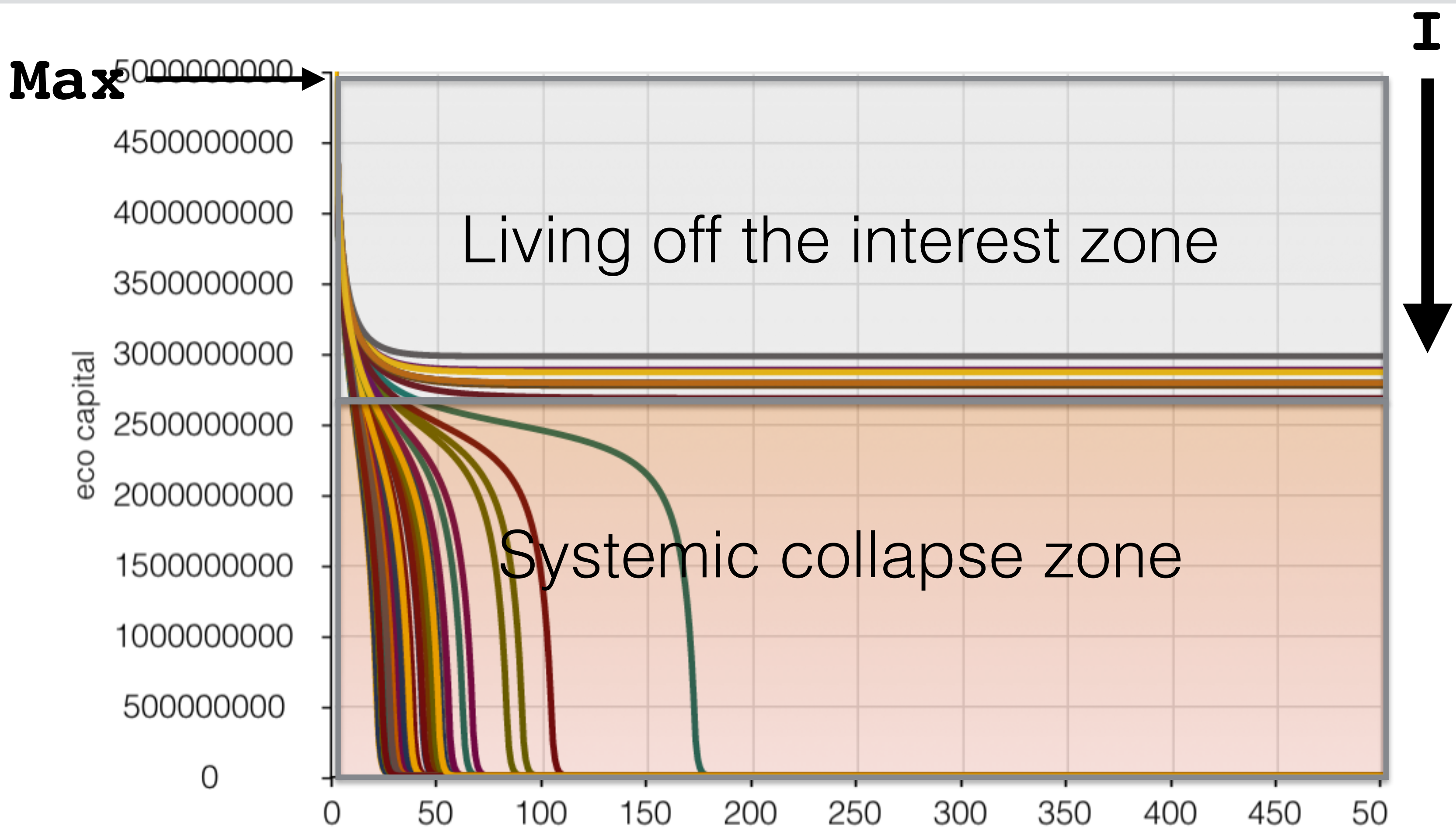
Spikes are caused by instant shift from growth to decline. Not realistic, but mathematically simple.

Endowment trust syndrome

stability vs systemic collapse

```
As long as impact (I) remains low, [eco capital]
constantly regenerates itself up to a sustainable level.
```

```
This level is below Max, the limiting amount of capital.
```



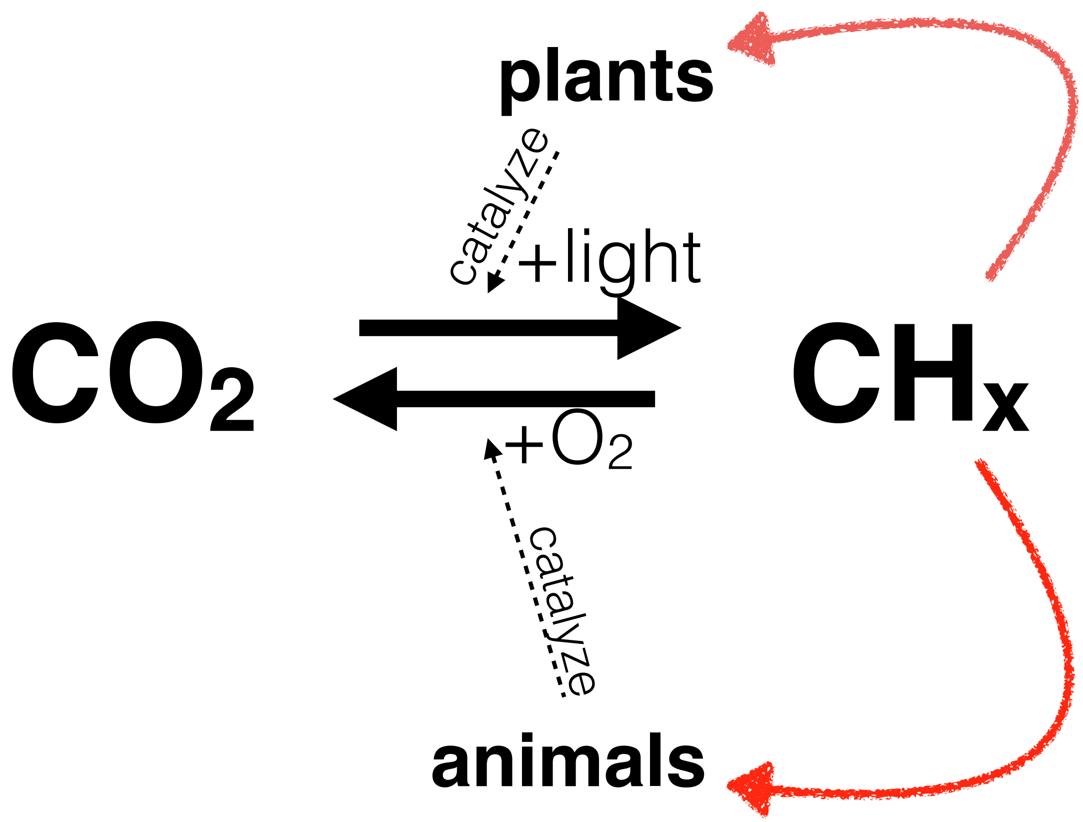
What is an ecosystem?

And what does it mean to regenerate it?

- All plant and animal life
- Animal life depends on plant life (trophic cascade)
- Plant life depends on sunlight, water, temperature, nutrients and soil microbes.

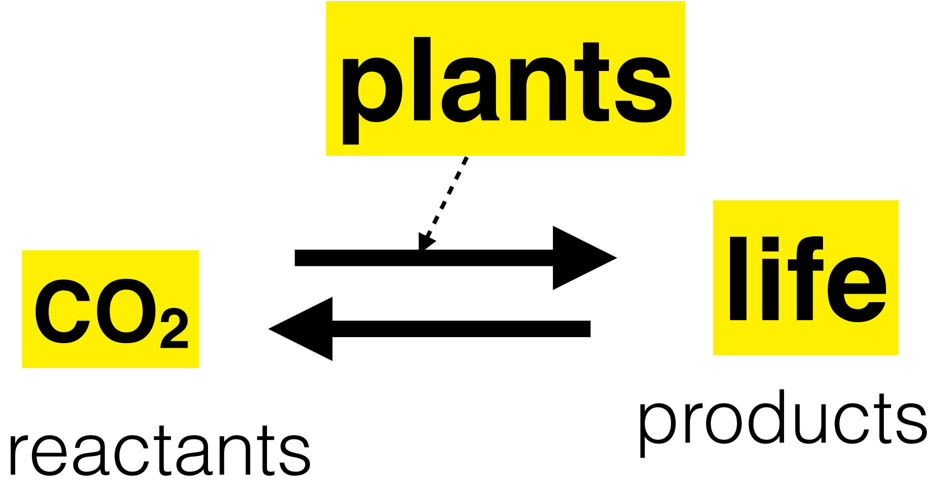
g l o b a l   b i o c h e m i s t r y

Life is an enzyme that converts atmosphere to soil, and soil to atmosphere.



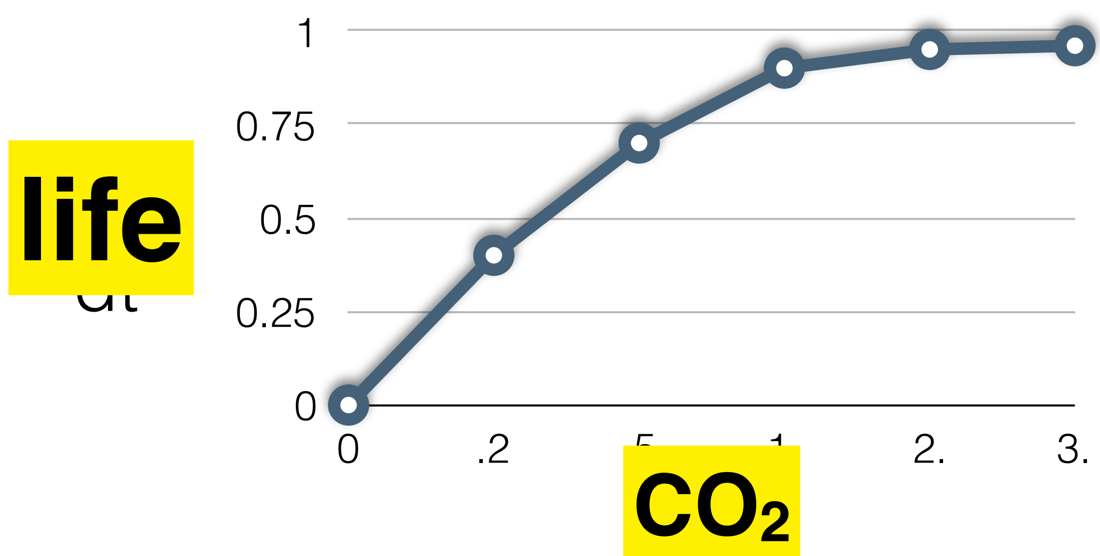
A balance of plants and animals assures that CO2 does not build up in the atmosphere, nor is it depleted.

Oxygen and nitrogen have similar cycles.



$$\frac{dB}{dt} = \frac{k_{cat}[\text{enzyme}]\,[A]}{K_m + [A]}$$

Michaelis-Menton equation



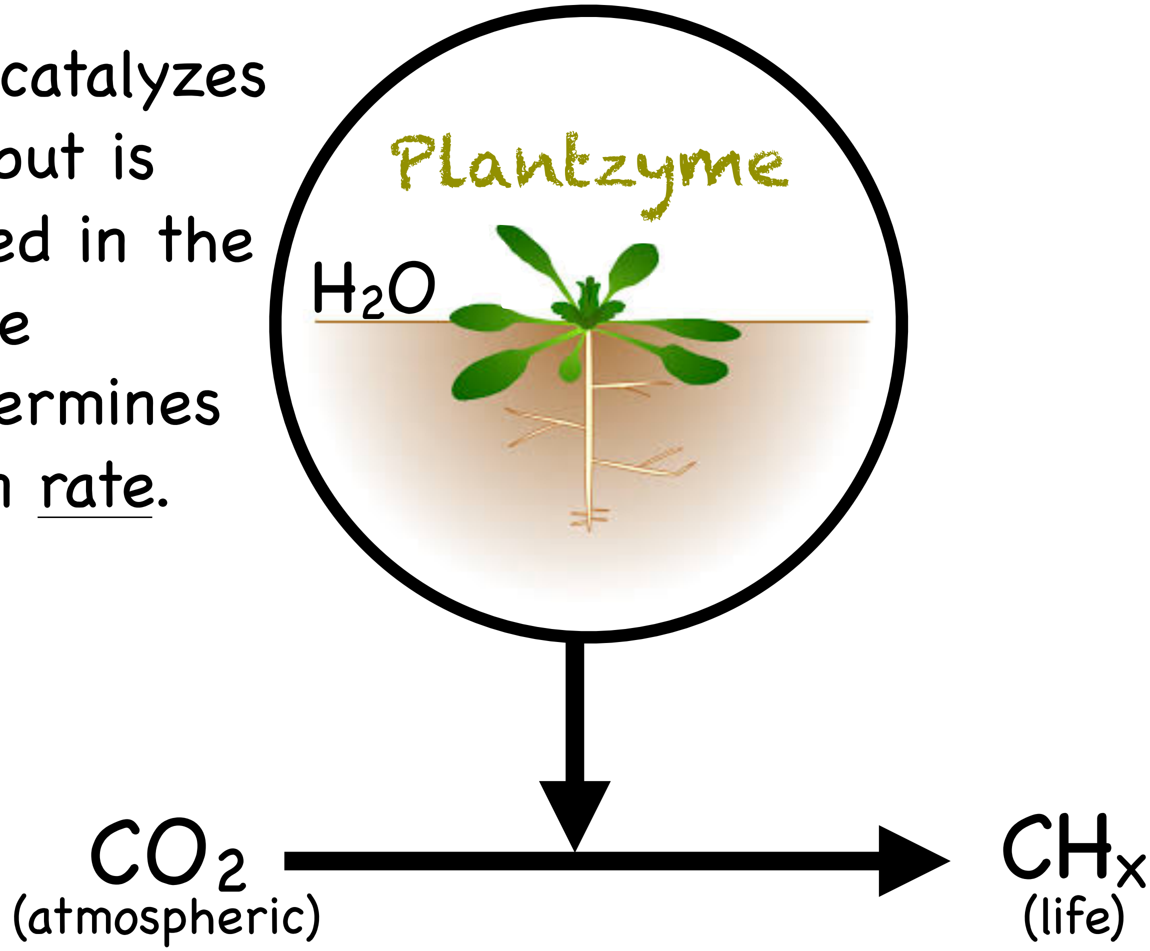
Enzyme kinetics for plants and atmosphere.

Plant is to **carbon fixation**

as

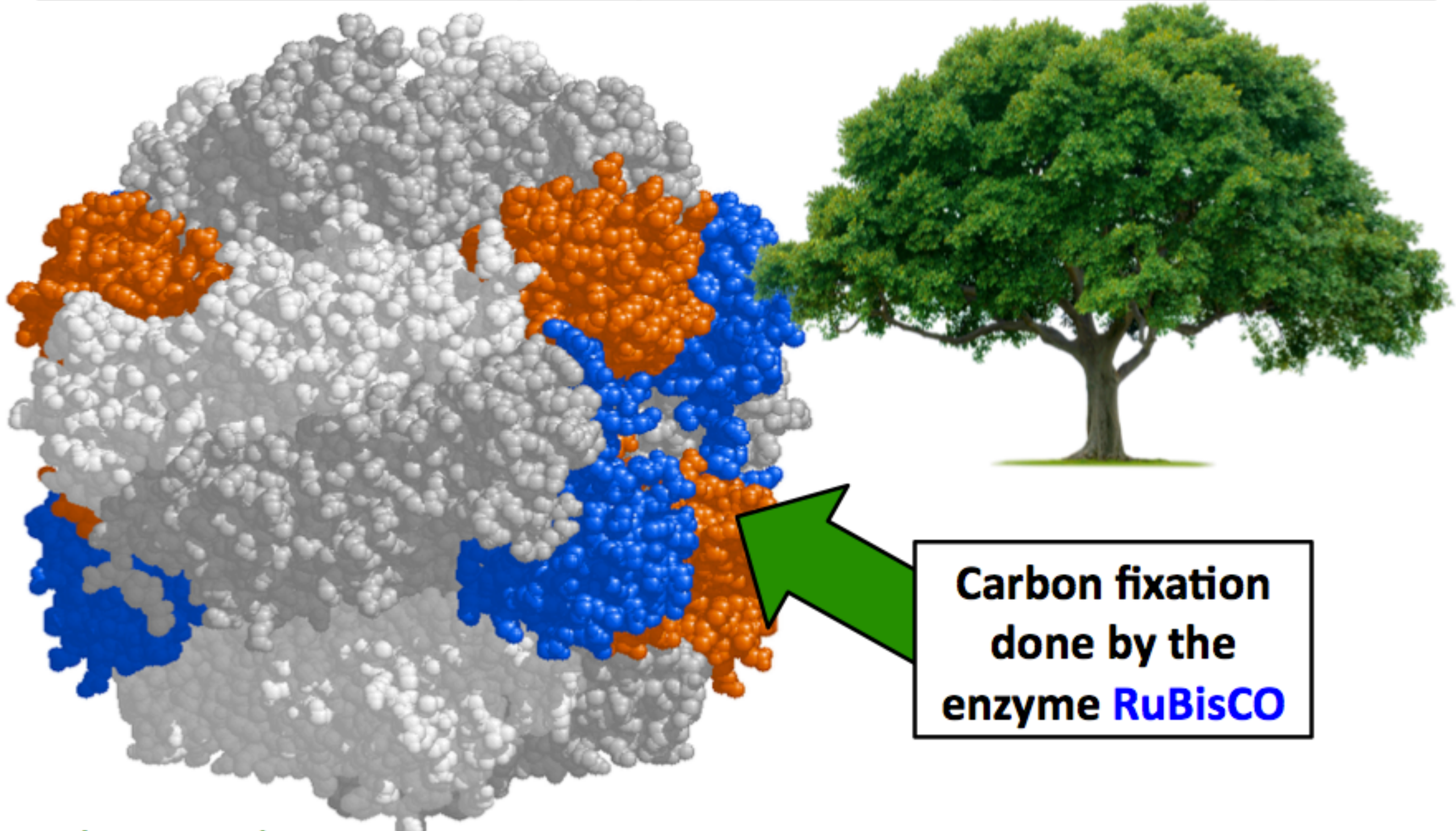
Enzyme is to **chemical reaction.**

An enzyme catalyzes a reaction, but is not consumed in the reaction. The enzyme determines the reaction rate.



carbon fixation function of plants

Ribulose-1,5-bisphosphate carboxylase oxygenase



photosynthesis:

$$2n\ CO_2 + 4n\ H_2O \xrightarrow{\text{light}} 2(CH_2O)_n + 2n\ O_2 + 2n\ H_2O$$

Only plants catalyze: (oxidized carbon) ---> (reduced carbon)

nitrogen fixation function of soil

- Plants can't fix (oxidize or reduce) nitrogen (N_2).
- Only soil bacteria can fix nitrogen.
- Problem with fixed nitrogen:
  - It is very soluble in water.
  - Therefore, it goes wherever water goes.
  - Therefore, land plants need fertilizer or soil symbiotes.
- Atmospheric nitrogen is abundant, but stable, so...
  - Biological N-fixation is energy intensive for the soil bacteria.
  - Bacteria that use too much energy grow slow.
  - Other bacteria kill off the slow growers unless they are protected.
  - Therefore, nitrogen fixing soil bacteria are symbiotic
    - Plants protect them
    - Fungi protect them.
    - They use niches.

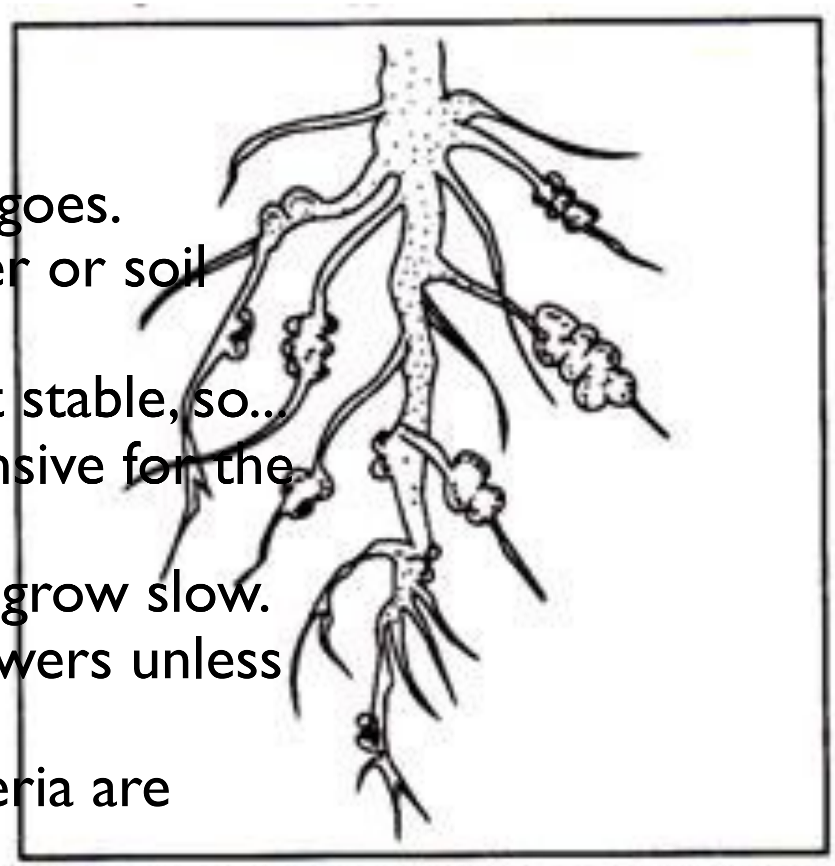


Fig. 2.3. Root nodules of a leguminous plant containing nitrogen-fixing bacteri

Why the high cost of nitrogen fixation?

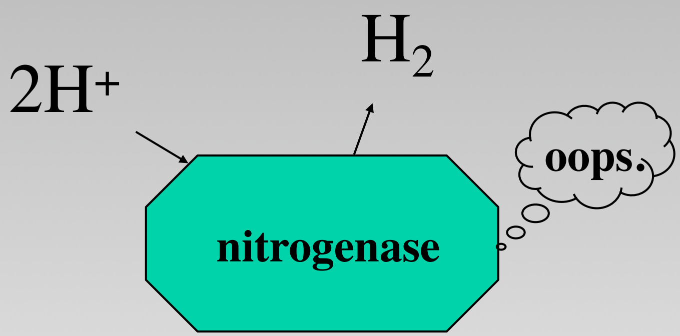
N_2 is the most stable form of nitrogen. All other nitrogenous compounds are "energetically uphill" from N_2.

True stoichiometry of nitrogenase is still not completely known. Approx the following

N_2 + (6+2n)H^++ (6+2n)e^- + **p(6+2n)ATP -->**2NH_3 + nH_2 + p(6+2n)ADP + p(6+2n)P_i

n=number of H_2 molecules formed (1 or 2, unknown)

p=number of ATP required per electron (probably 2)



Note the large number of ATP per N_2
Most likely 20!!!

Soil symbiotes fix N_2

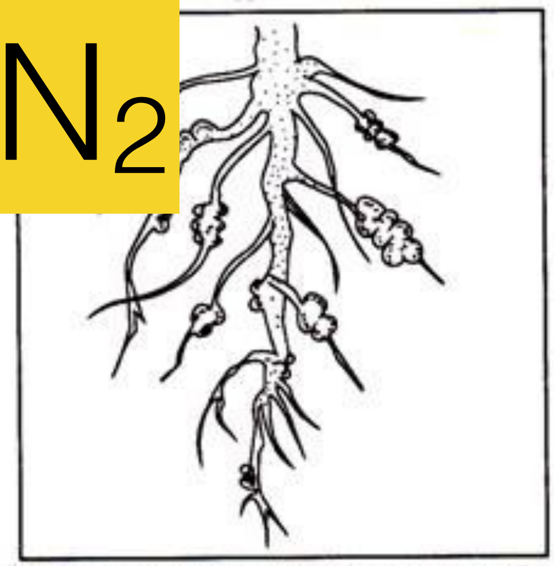
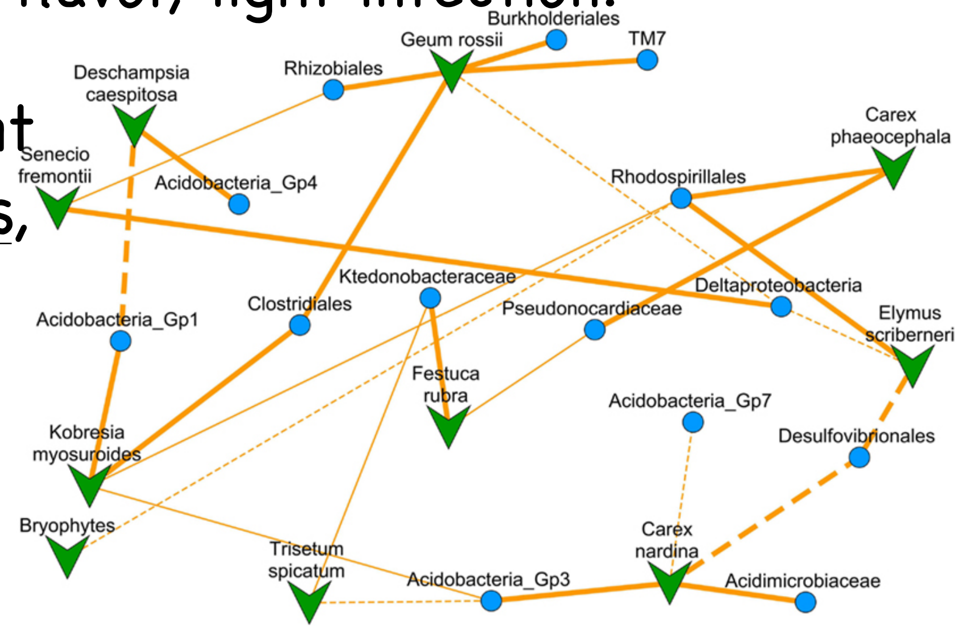


Fig. 2. Root nodules of a leguminous plant containing nitrogen-fixing bacteria

- Nitrogen fixing bacteria: nitrobacter, rhizobia.
- Mycorrhizal fungi: create a larger effective root surface area.*
- Symbiotes provide plant a balanced diet, increase draught tolerance, contribute to flavor, fight infection.
- Symbiotes depend on soil/plant niches, co-symbiotic organisms,



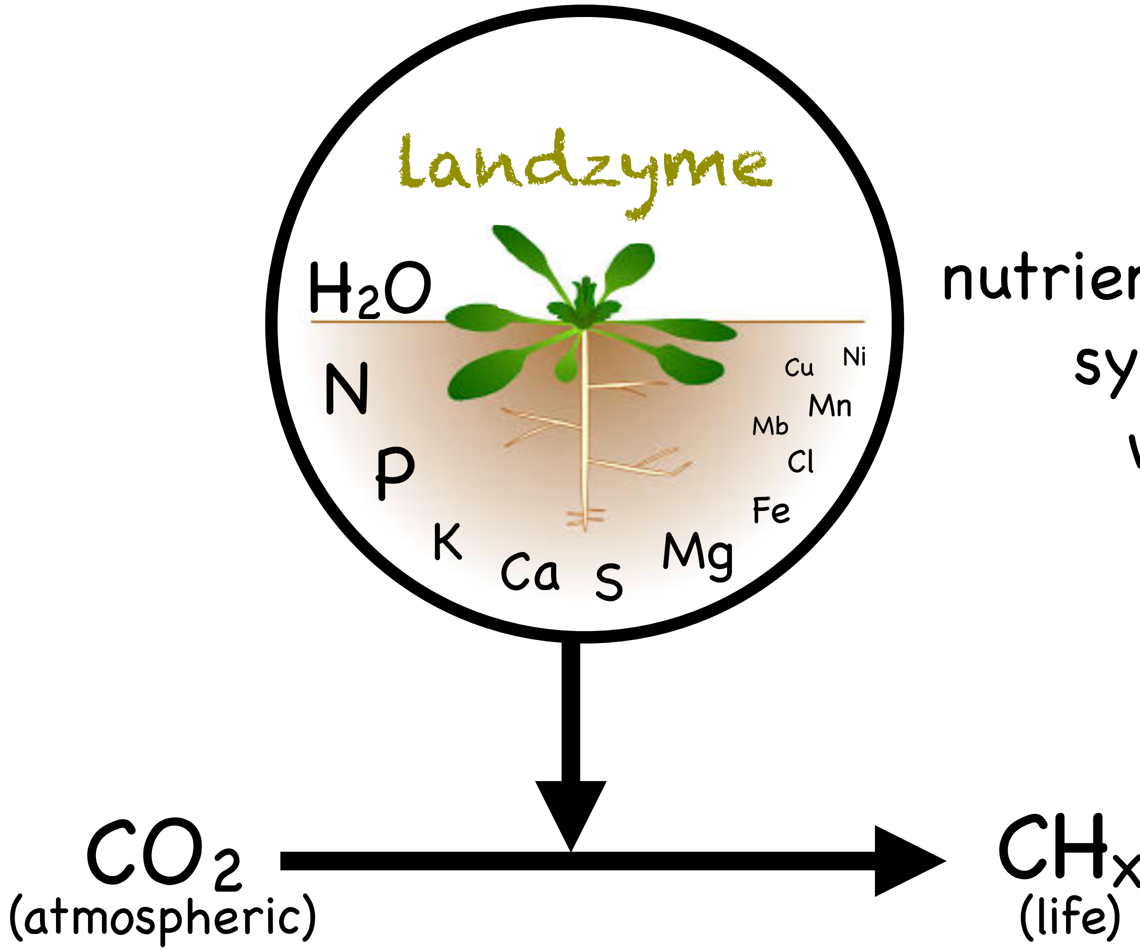
*Vrieze, Jop de (2015-08-14). "The littlest farmhands". Science 349 (6249): 680–683.

** Dommergues YR, editor. Interactions between non-pathogenic soil microorganisms and plants. Elsevier; 2012 Dec 2.

Plant is to **Land**

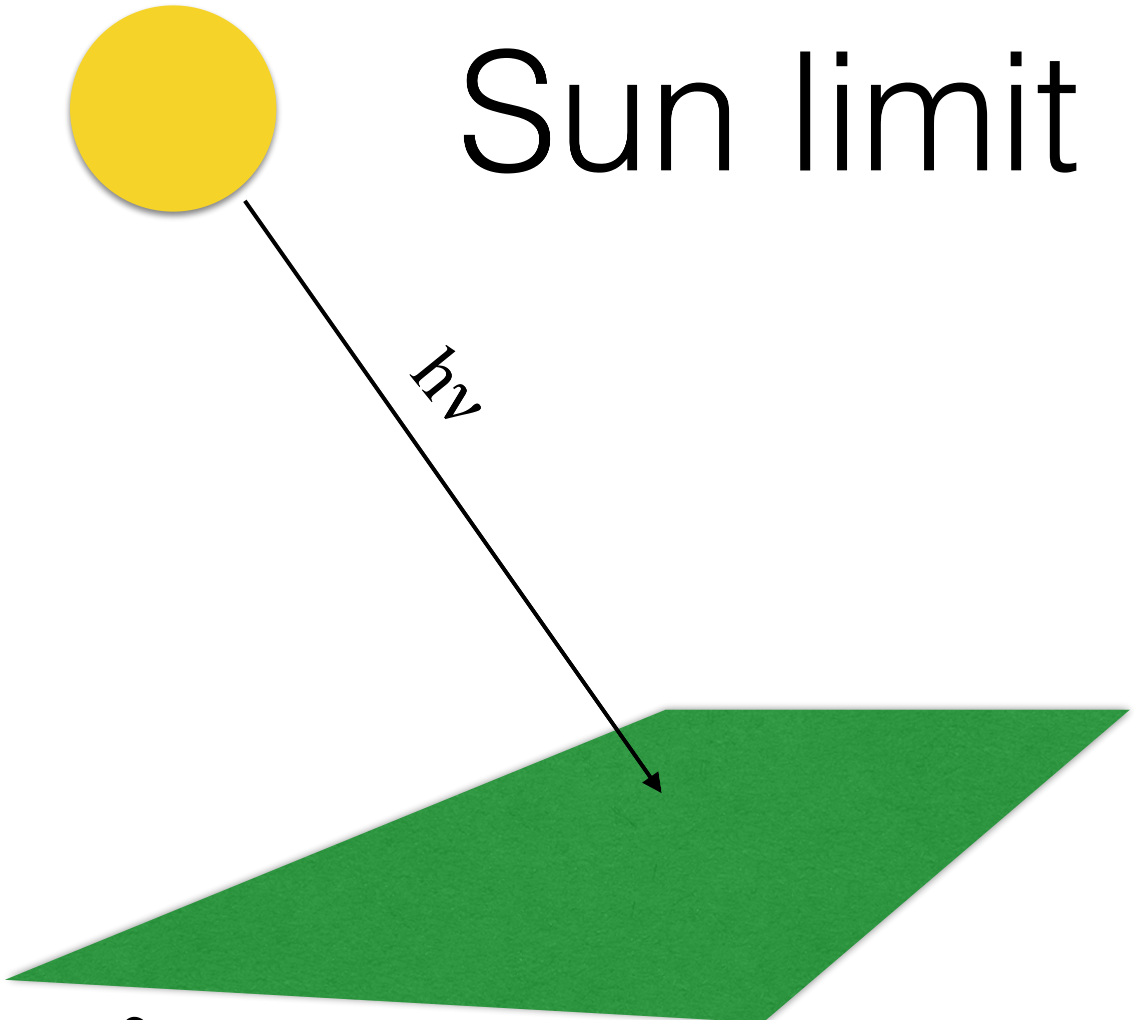
as

Enzyme is to **co-factors**.



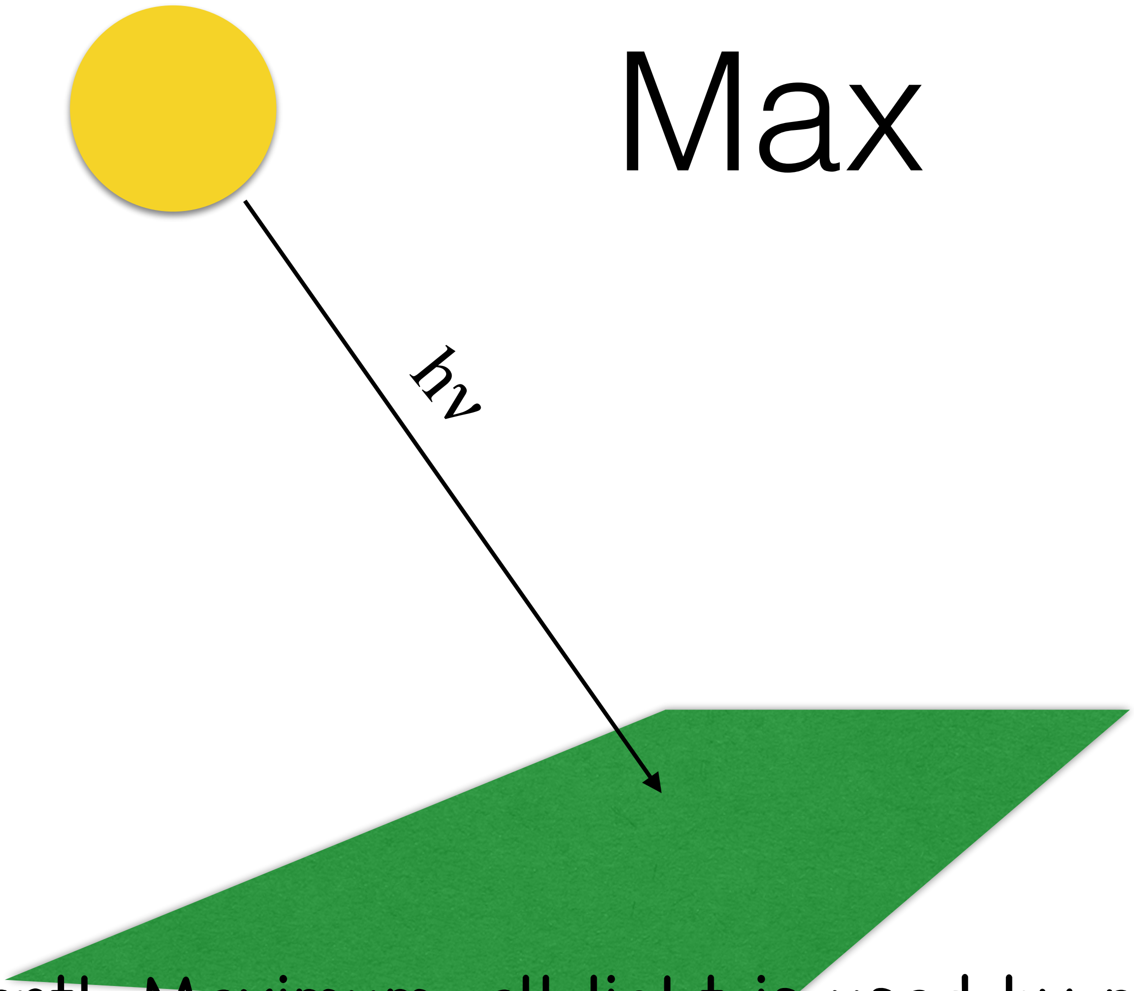
Land provides nutrients, symbiotes, symbiote niches, water storage.

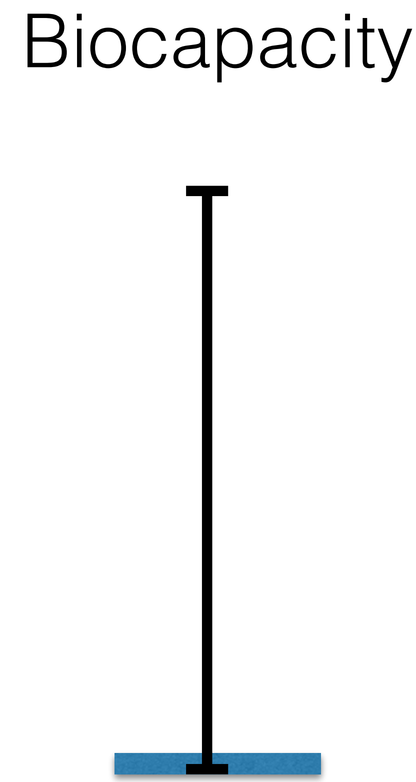
Sun limit



- Earth is finite.
- Therefore, Earth gets a finite amount of light energy per day.
- CO_2 is reduced in proportion to light energy and plant cover.
- New plants (food) are produced at a limited rate.

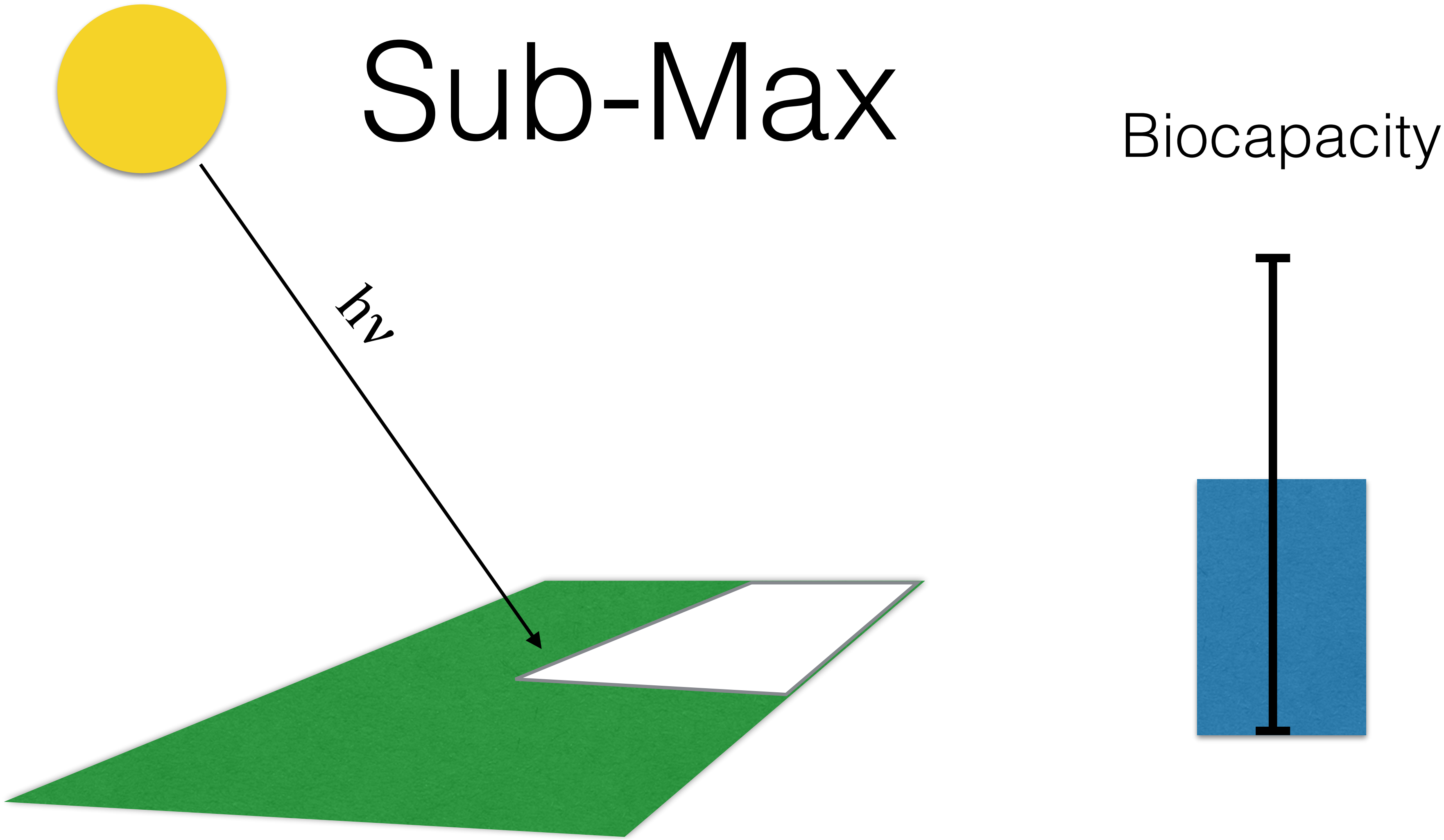
Max





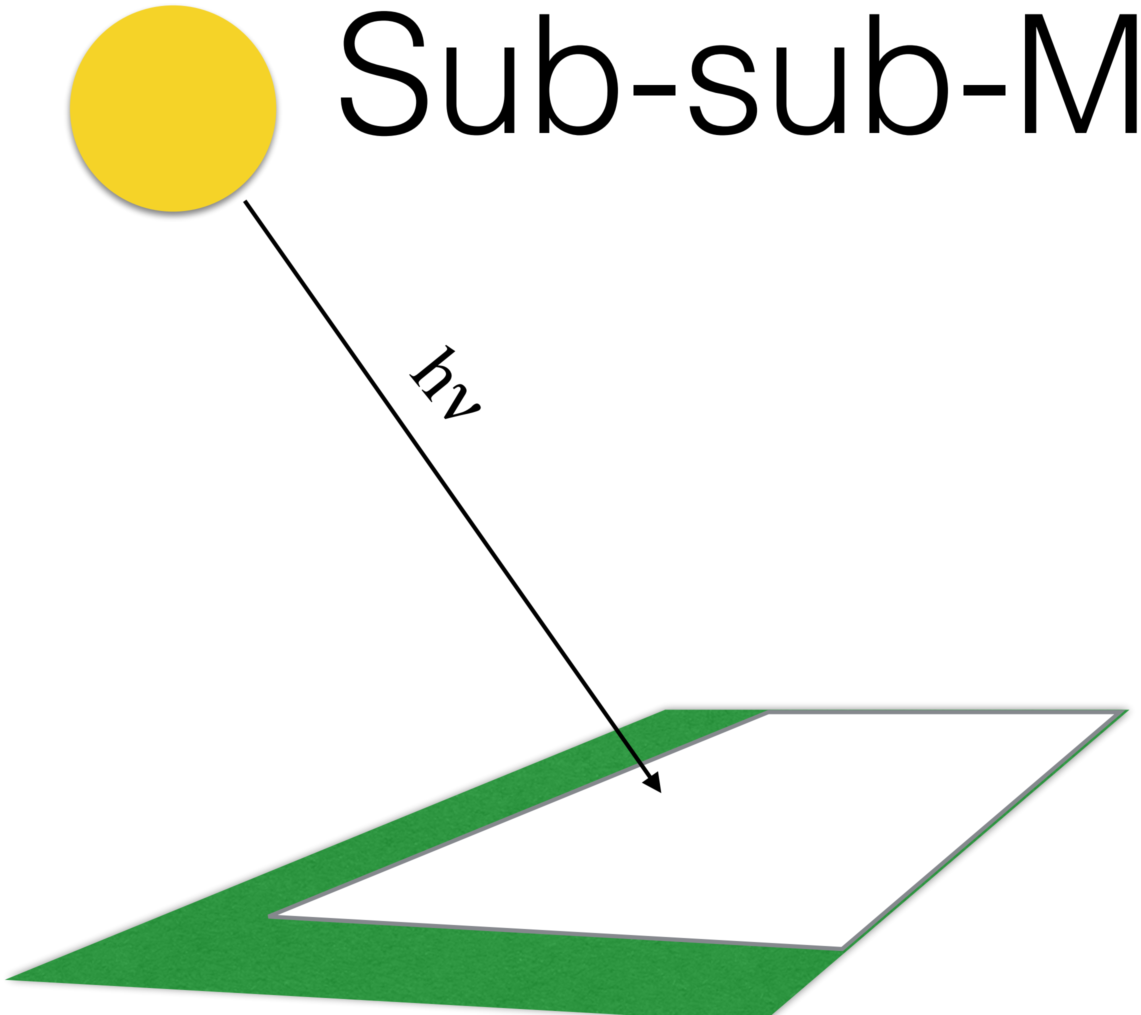
- At Earth Maximum, all light is used by plants.
- Water and minerals may also be limiting.
- No net growth is possible, since the limit has been reached.
- This is a mythical, unobtainable maximum, since animals have always been consuming plants since the beginning of plants.

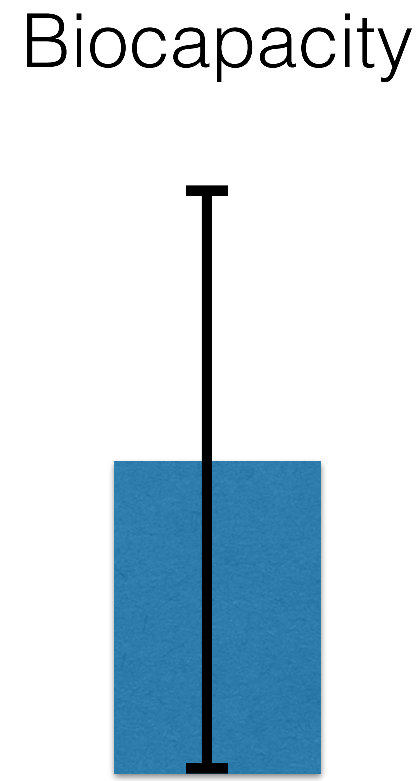
Sub-Max



- At 3/4 Max, the amount of available light is rate-limiting.
- When [eco capital] is close to the limit, regeneration is proportional to the unused space.

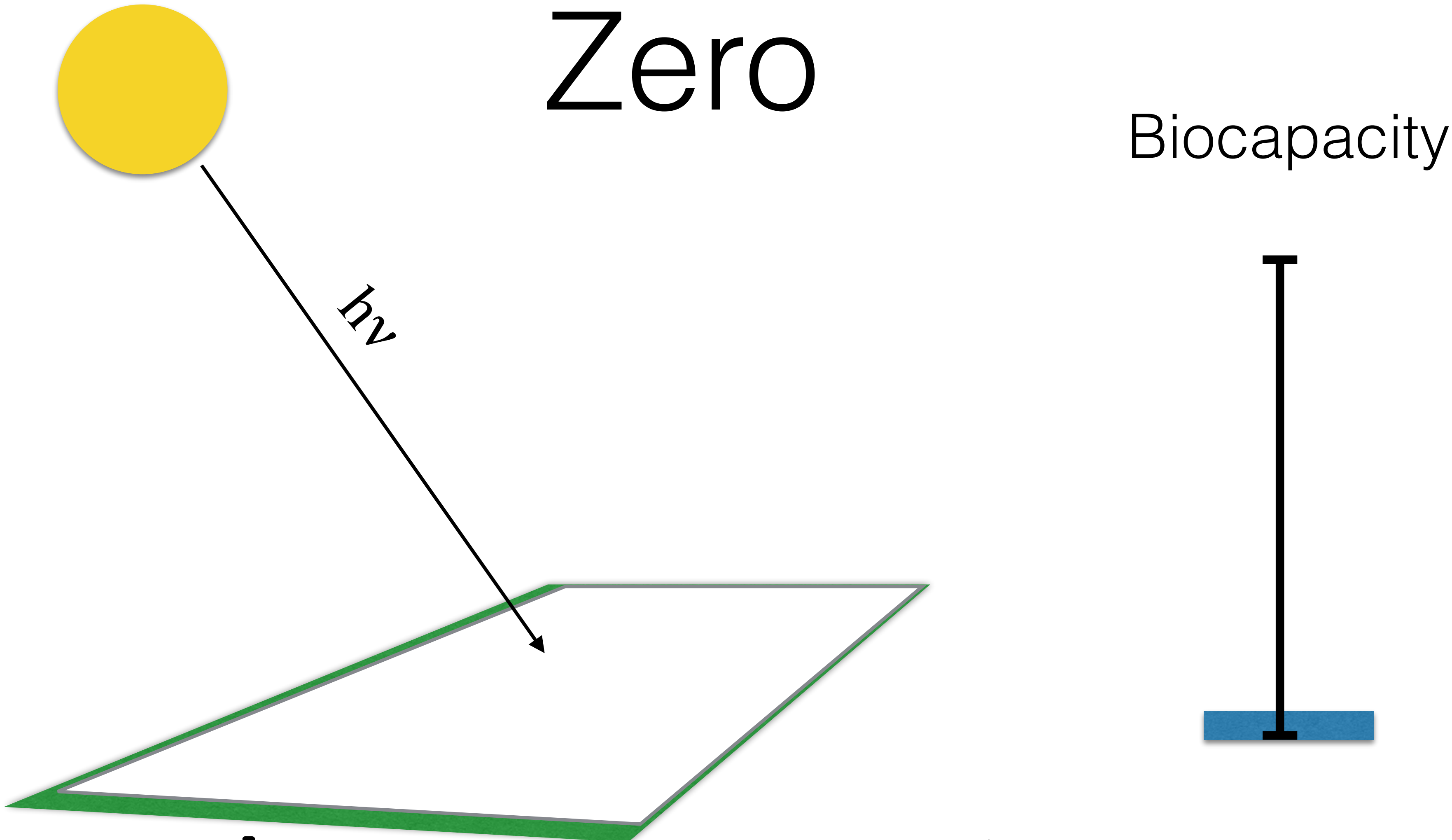
Sub-sub-Max





- At 1/4 Max, the amount of life is rate limiting.
- Regeneration is proportional to current [eco capital], because life expands exponentially when there are no other limits.

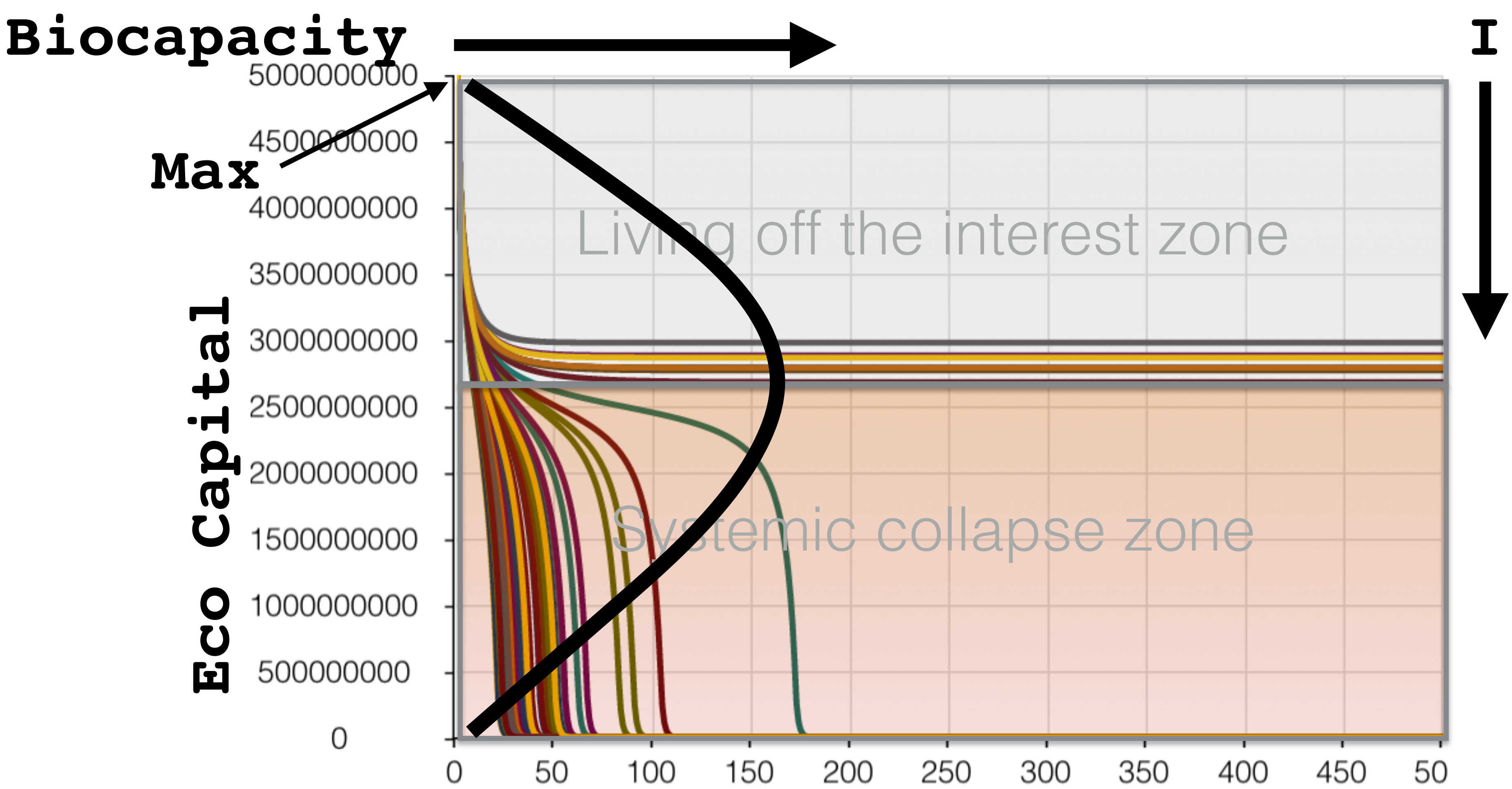
Zero



- At [eco capital] = zero, Biocapacity = zero, because there is nothing to grow from.
- In a reasonable scenario, [eco capital] cannot reach zero. Or can it?

Biocapacity

Biocapacity reaches a maximum as growing room starts to exceed growth rate.

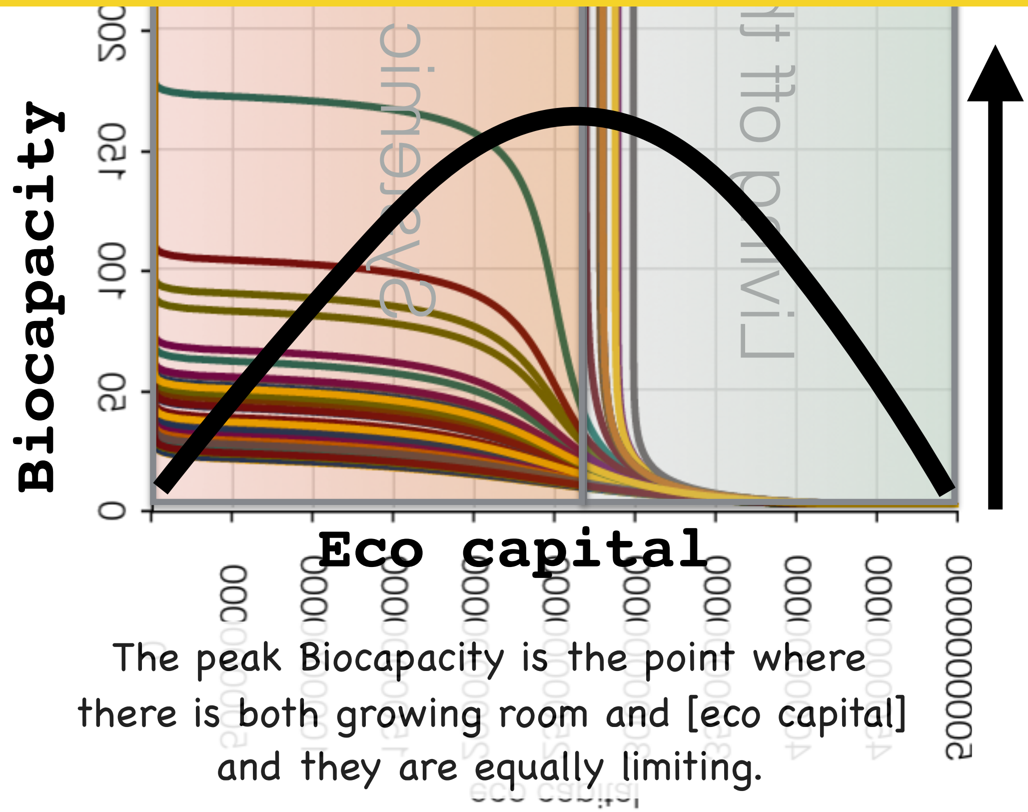


Biocapacity

Material will move out of the source stock and into the sink stock at the rate determined by this equation.

```
x <- [Earth max]-[eco capital]
x <- x/[Earth max]
x <- x*[regeneration]*[eco capital]
return x
## [biocapacity] goes to zero as [eco capital] approaches [Earth
    max] and as [eco capital] approaches zero.
```

Biocapacity =
(Max -[eco capital])*Regeneration*[eco capital]/Max



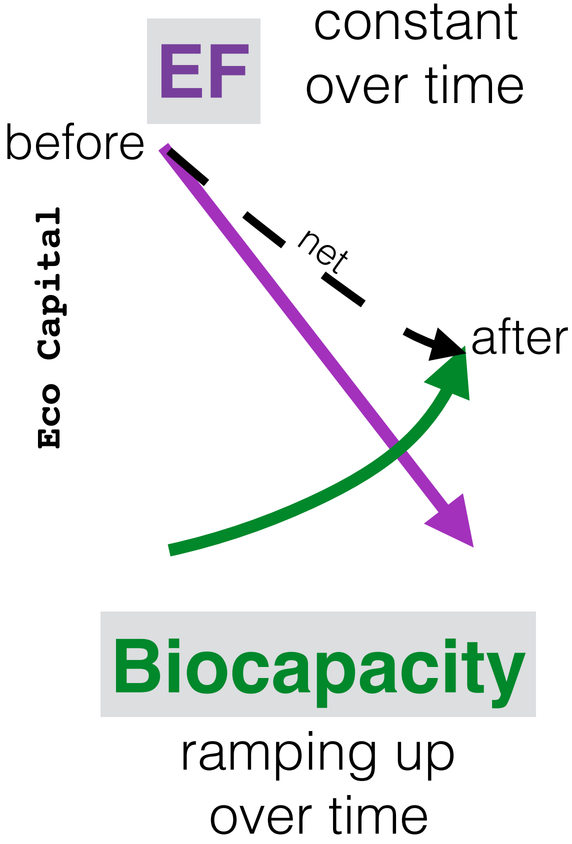
When [eco capital] is low, Biocapacity goes up as [eco capital] goes up.

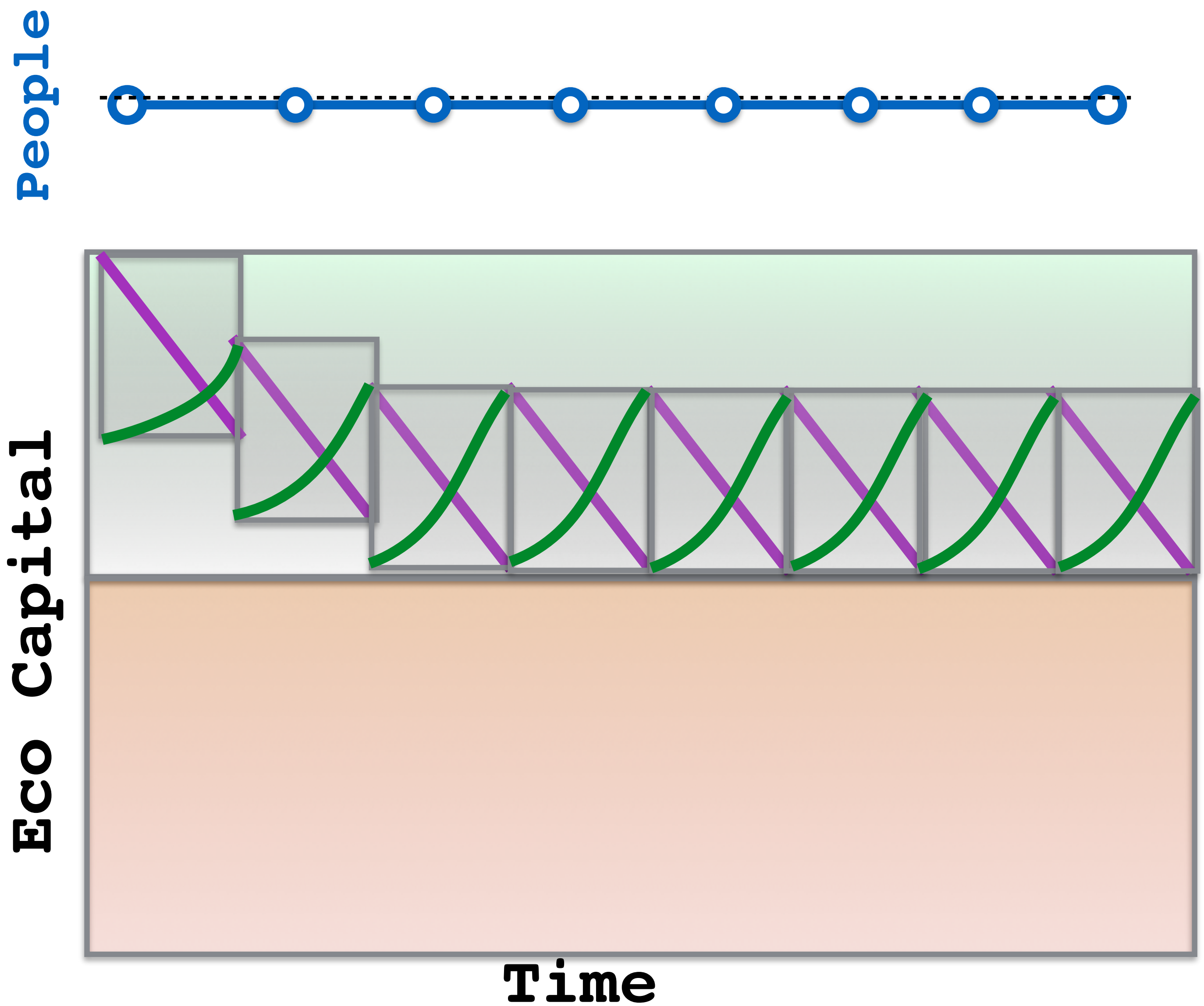
The peak Biocapacity is the point where there is both growing room and [eco capital] and they are equally limiting.

When [eco capital] is high, Biocapacity goes up as growing room goes up.

Living below the carrying capacity is sustainable

Constant impact, ecological footprint (EF)

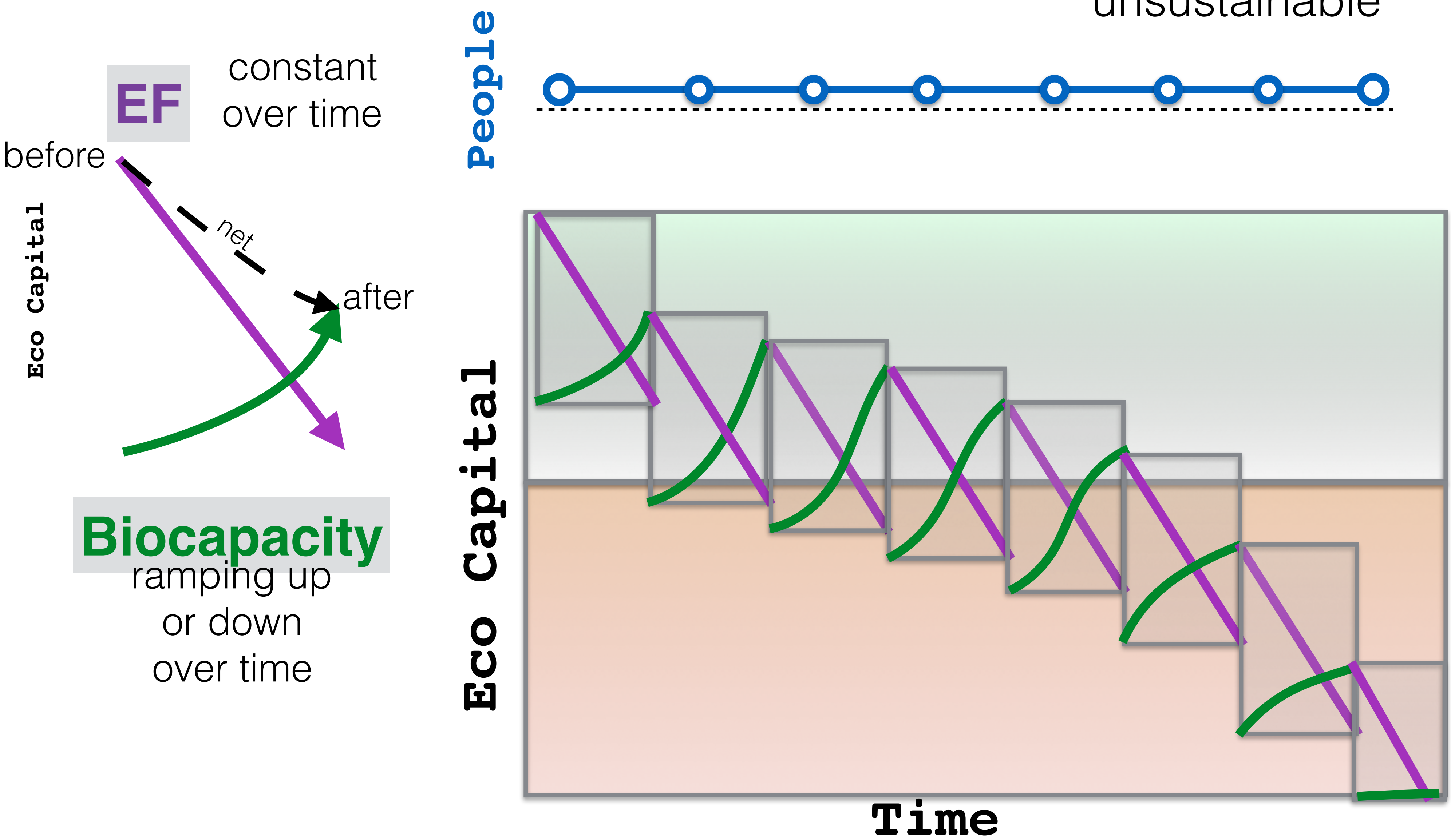




Endowment trust syndrome

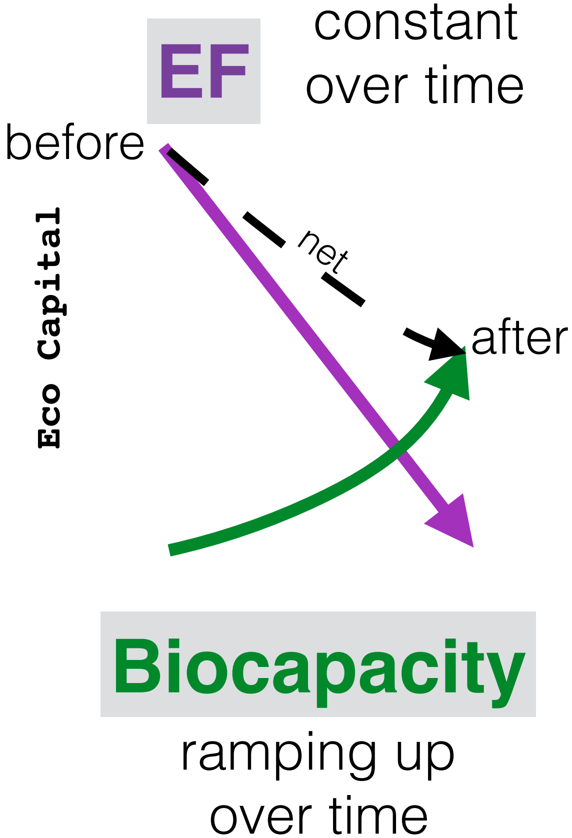
<u>High</u> Constant impact, ecological footprint (EF)

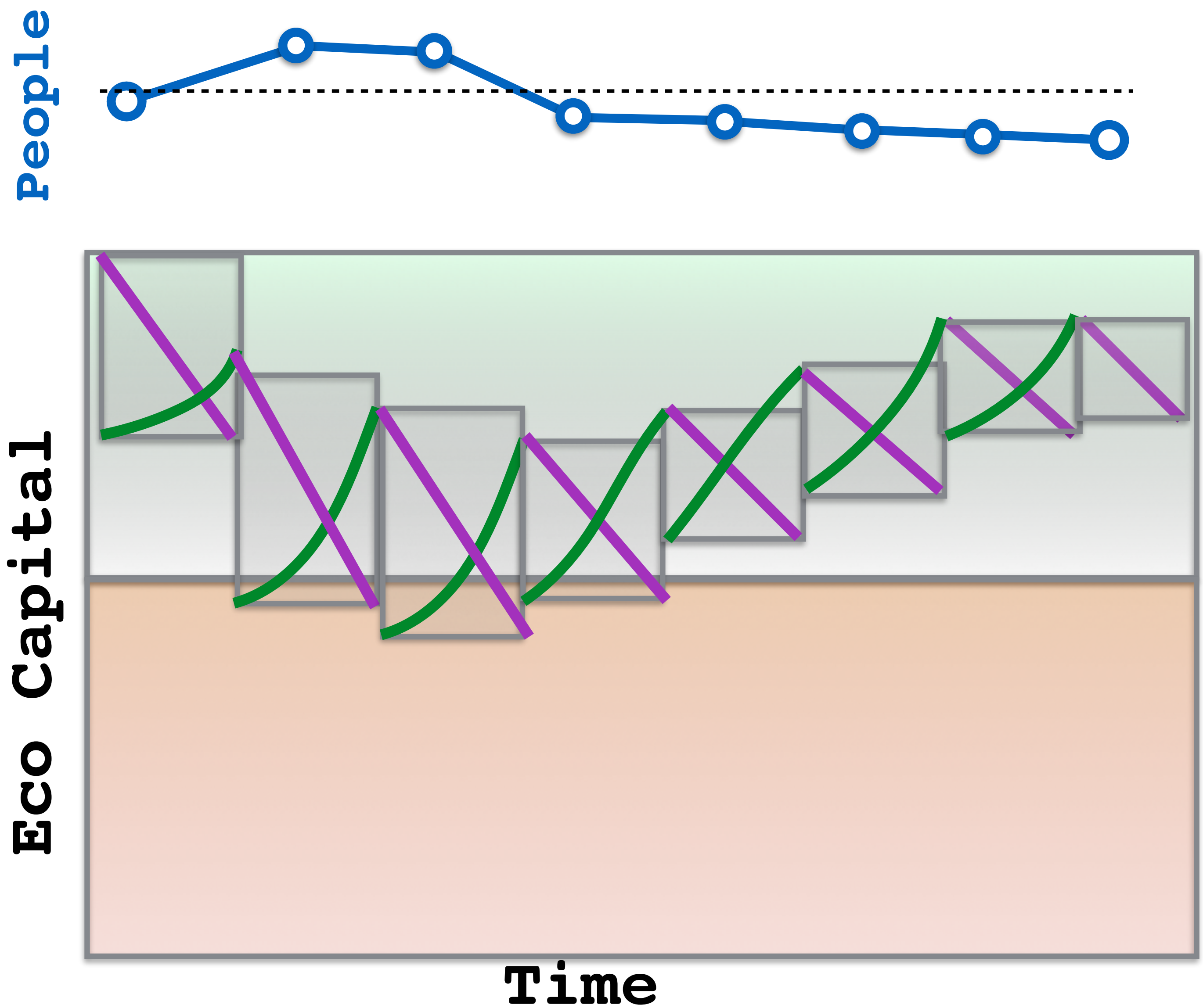
unsustainable



Can we avoid collapse after overshoot?

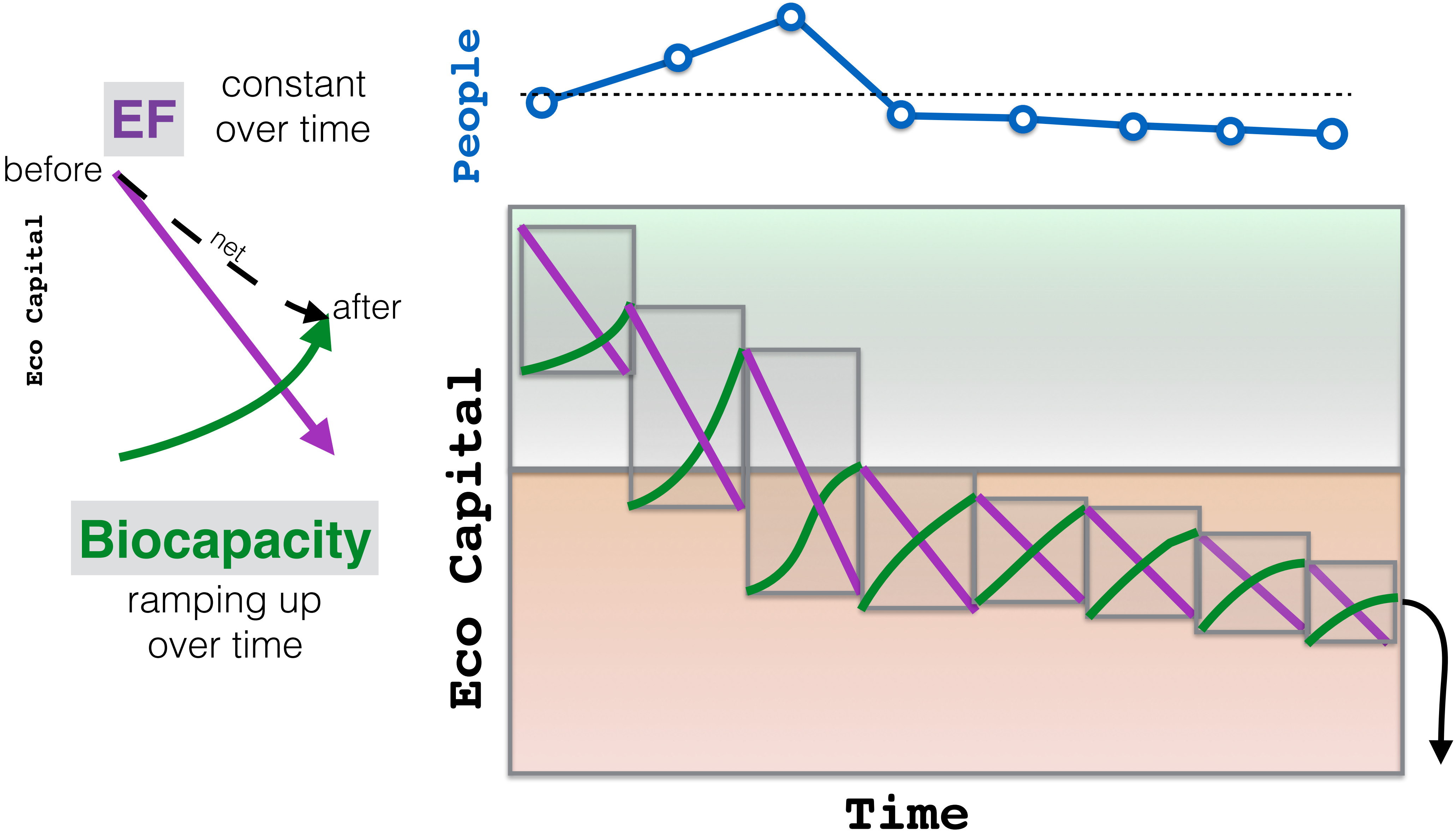
Overshoot, followed by decreased impact. Recovery.



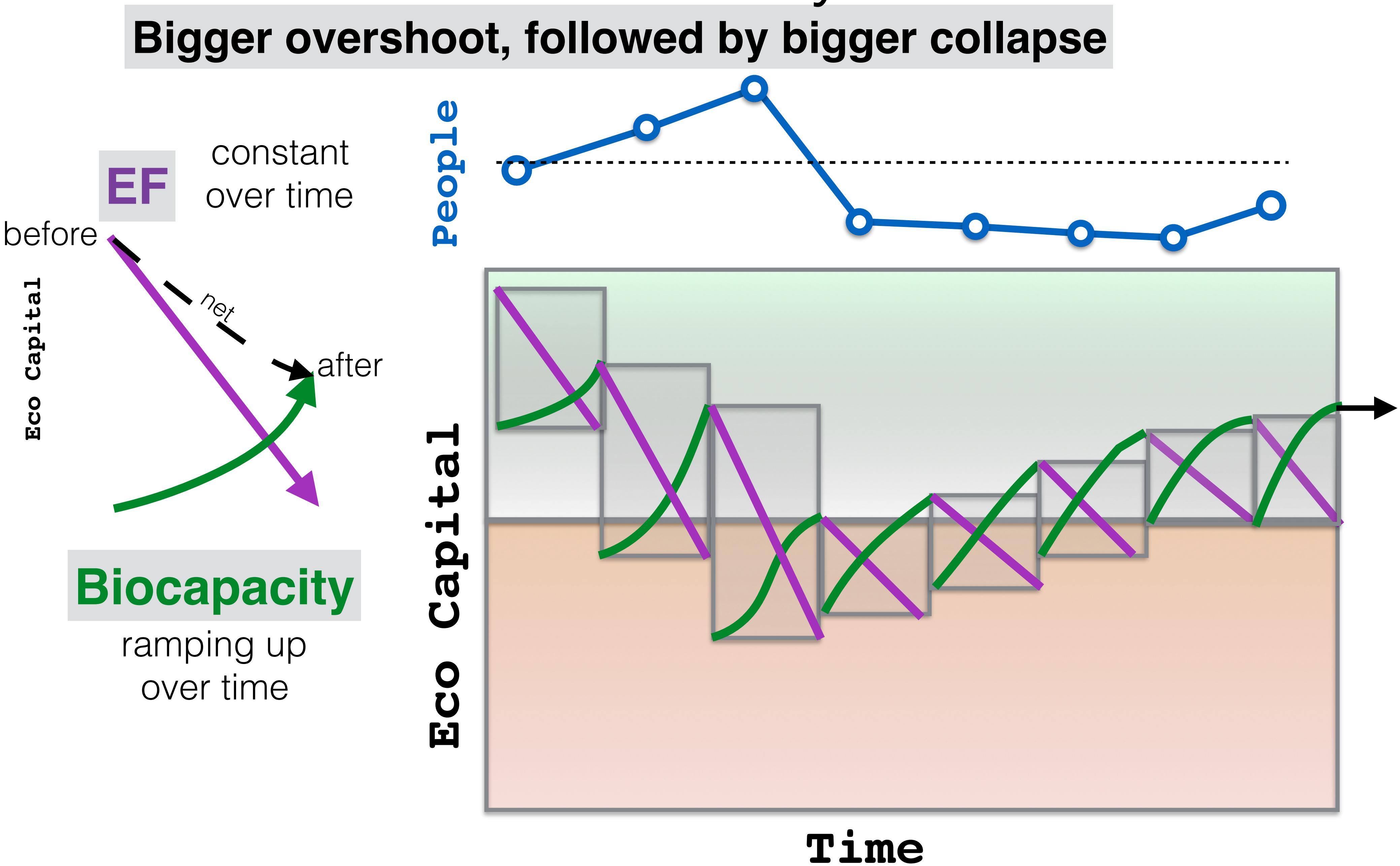


Greater overshoot, same correction, collapse.

Greater overshoot, followed by decreased impact

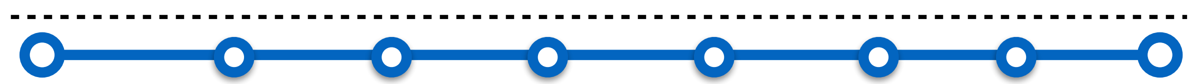


Greater overshoot, greater correction, recovery.

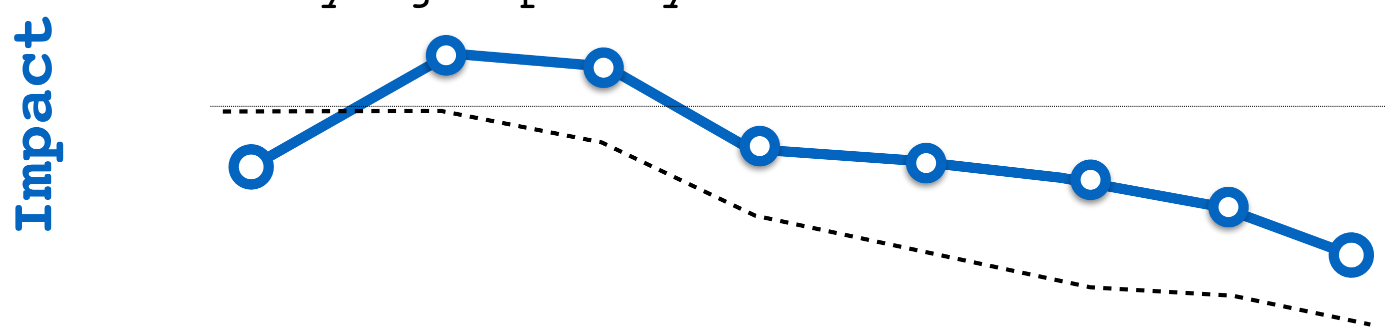


Carrying capacity is the maximum level of Impact that can be balanced by biocapacity

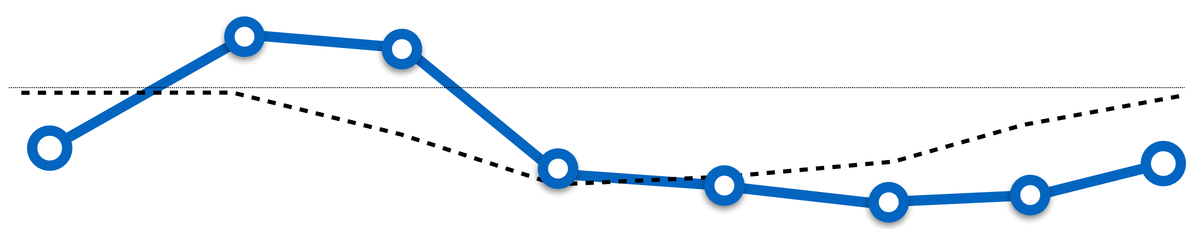
If there is no overshoot of the carrying capacity, it remains constant.



If there is overshoot, then carrying capacity decreases for as long as Impact is above carrying capacity.



A correction requires impact to go below the new carrying capacity.



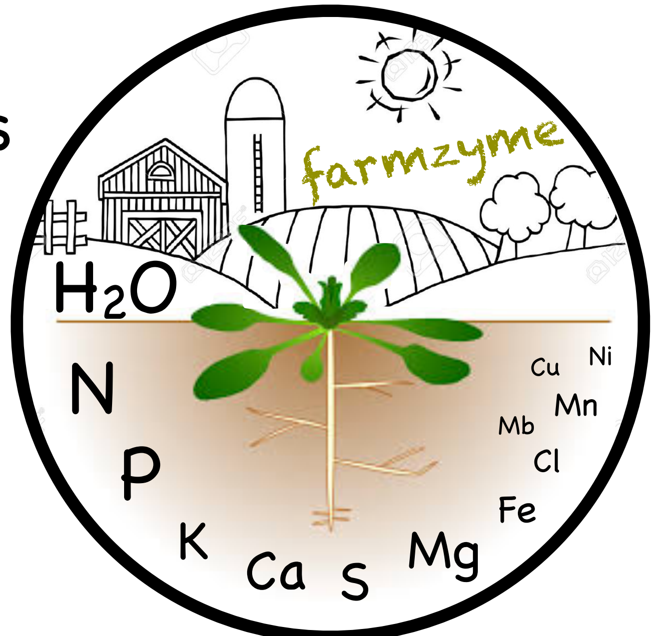
Farm is to **carbon fixation**

as

Chemostat is to **chemical reaction.**

i.e. optimized for biocapacity

Farmers provide water and nutrients and eliminate the competition (bugs, weeds). Farmers optimize the conditions for plant growth.



Farming requires energy. Intensive farming requires more energy.

CO_2 (atmospheric) → CH_x (people)

What happens during famine?

from Hopfenberg & Pimentel

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)

Hopfenberg, Russell, and David Pimentel. "Human population numbers as a function of food supply." Environment, development and sustainability 3.1 (2001): 1-15.

Food limitations to growth

Yeast

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

Growth rate is attentuated 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.

Food limitations to growth

Mouse

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

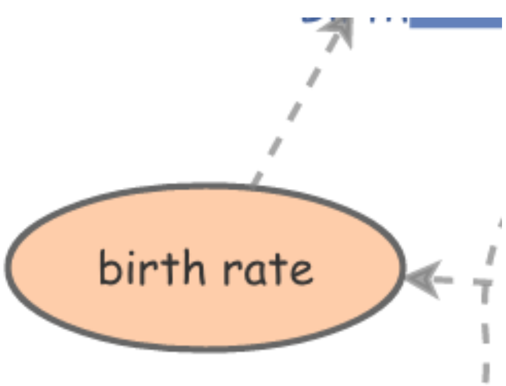
Bendell, J. F. "Food as a control of a population of white-footed mice, Peromyscus leucopus noveboracensis (Fischer)." Canadian Journal of Zoology 37.2 (1959): 173-209.

Do humans behave like mice?

Infant mortality increases replacement value

Human

- As infant mortality increases, the number of children reaching child bearing age goes down as a fraction of births. Increased replacement value.




```
HDI <- [HDI]
TFR <- -8.2918*HDI + 8.9601
## TFR from HDI is modeled as a line
maom <- 25
## median age of mother
m <- 2.0
rv <- 2 + (1-[HDI])*m
## replacement value is modeled as an inverse function of HDI
## to model increased infant mortality in places with low
## development index. Note since HDI is a linear function
## of ecological footprint, rv models increase infant mortality
## with decreased resources (food).
br <- (TFR/rv)/maom
## birth rate from TFR. Total fertility over replacement is the
## growth rate over the median age of the mother. Dividing
## by median age of mother gives the annual birth rate.
return br
```

The Real Club of Rome

These are real

http://www.clubofrome.org/

https://en.wikipedia.org/wiki/Club_of_Rome

These are junk

http://conspiracywiki.com/articles/new-world-order/club-of-rome/

http://www.theforbiddenknowledge.com/hardtruth/clubofrome.htm

http://green-agenda.com/globalrevolution.html

The World 3 model

From the author

- Donella Meadows in "Groping in the Dark: The First Decade of Global Modelling"

"We have great confidence in the basic qualitative assumptions and conclusions about the instability of the current global socioeconomic system and the general kinds of changes that will and will not lead to stability. We have relatively **great confidence in the feedback-loop structure** of the model, with some exceptions which I list below. We have a **mixed degree of confidence in the numerical parameters** of the model; some are well-known physical or biological constants that are unlikely to change, some are statistically derived social indices quite likely to change, and some are pure guesses that are perhaps only of the right order of magnitude. The structural assumptions in World3 that I consider most dubious and also sensitive enough to be of concern are:

- the constant capital-output ratio (which assumes no diminishing returns to capital),
- the residual nature of the investment function,
- the generally ineffective labour contribution to output."