Human Population 2018

Lecture 8

Ecological footprint.

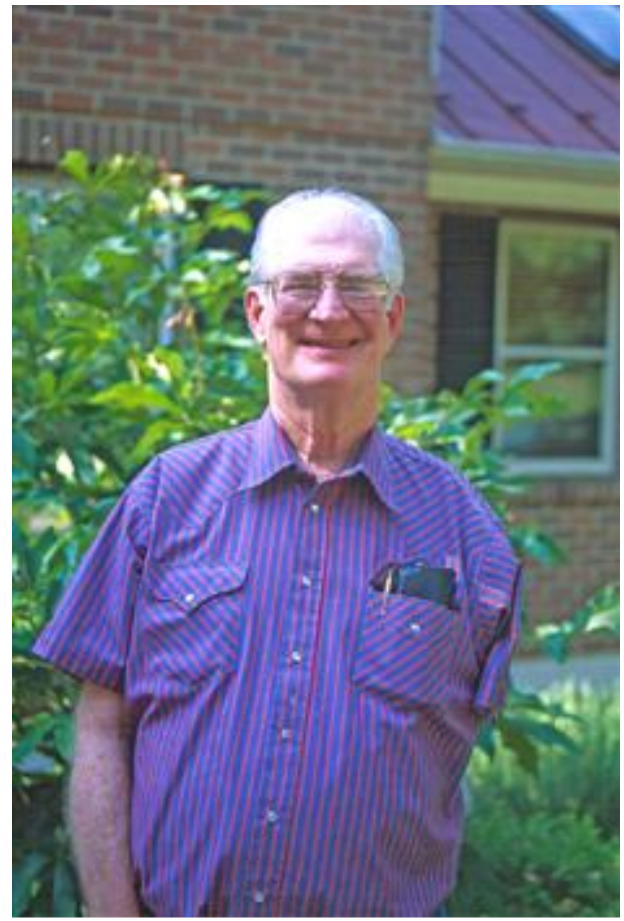
The Daly criterea.

Questions from the reading.

pp. 87-107

Herman Daly

“All my economists say, ‘on the one hand…on the other'. Give me a one-handed economist,” demanded a frustrated Harry S Truman.



BOOKS

Daly, Herman E. (1991) [1977]. **Steady-State Economics** (2nd. ed.). Washington, DC: Island Press.

Daly, Herman E.; Cobb, John B., Jr (1994) [1989]. **For the Common Good: Redirecting the Economy toward Community, the Environment, and a Sustainable Future** (2nd. updated and expanded ed.). Boston: Beacon Press.. Received the Grawemeyer Award for ideas for improving World Order.

Daly, Herman E. (1996). **Beyond Growth: The Economics of Sustainable Development**. Boston: Beacon Press. ISBN 9780807047095.

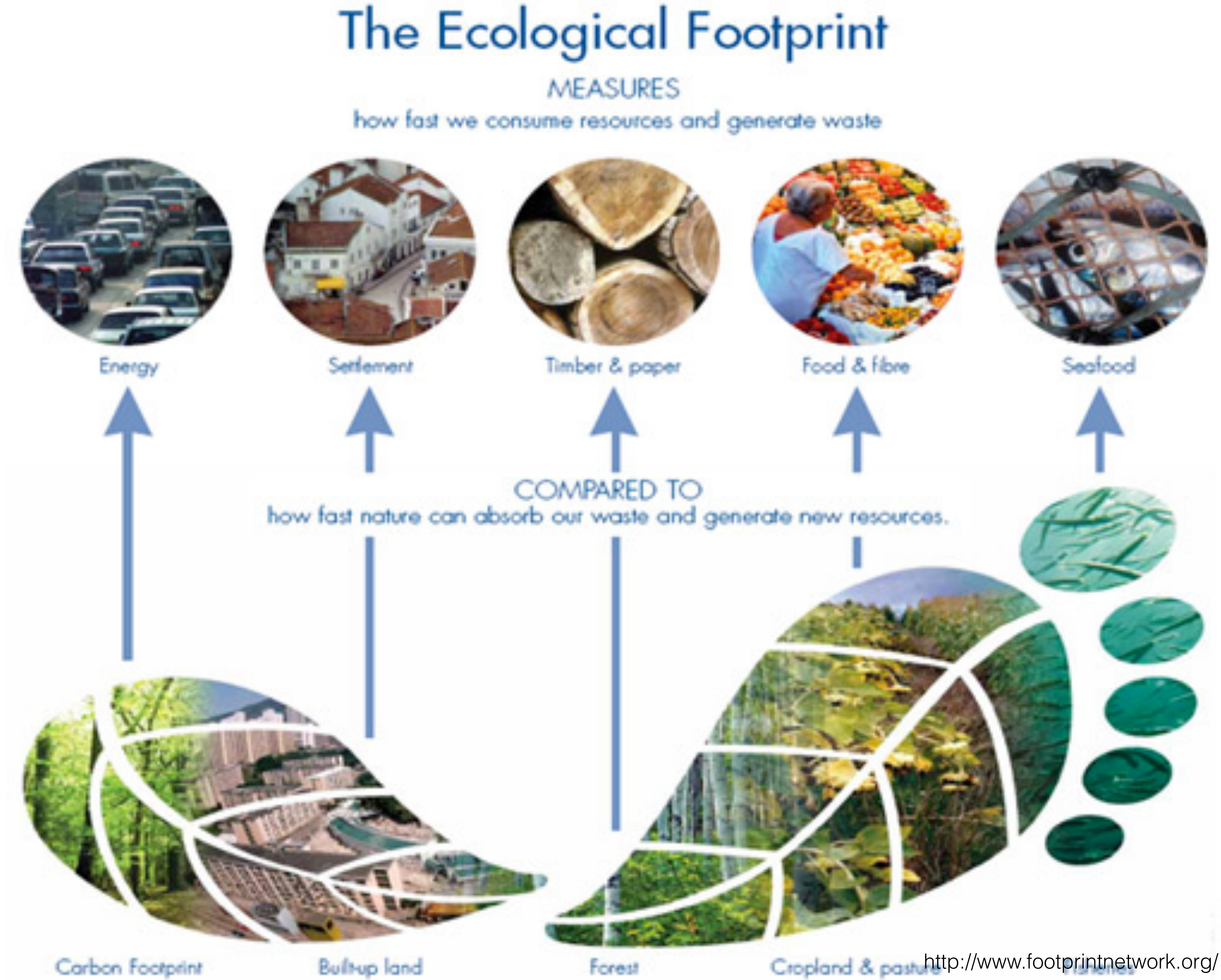
Prugh, Thomas; Costanza, Robert; Daly, Herman E. (2000). **The Local Politics of Global Sustainability**. Washington, DC: Island Press. IS

The Daly Criterea for sustainability

- For a **renewable resource**, the sustainable rate to use can be no more than the rate of regeneration of its source.

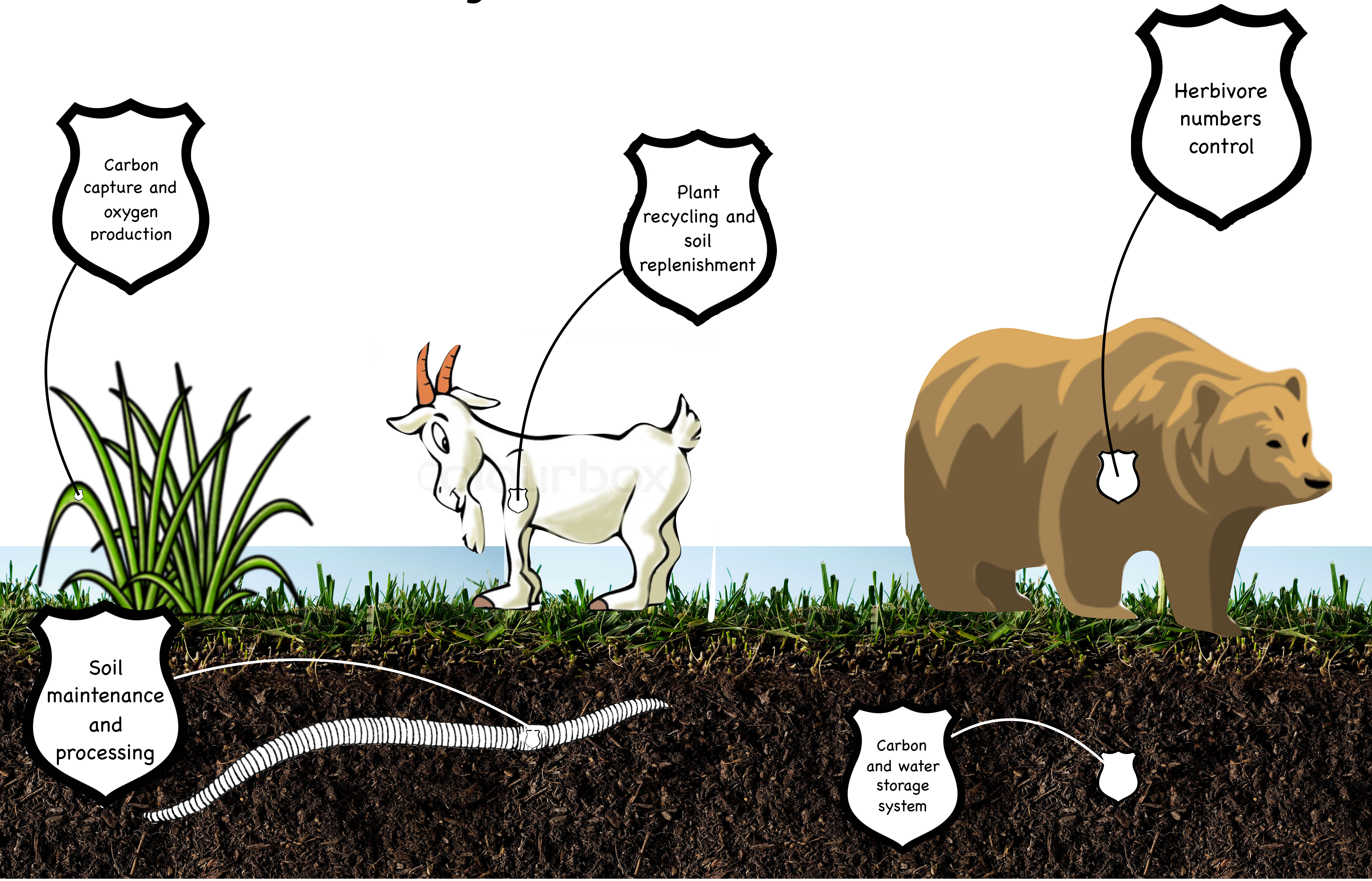
- For a **non-renewable resource**, the sustainable rate of use can be no greater than the rate at which a renewable resource, used sustainably, can be substituted for it.

- For a **pollutant**, the sustainable rate of emmission can be no greater that the rate it can be recycled, absorbed or rendered harmless in its sink.



http://www.footprintnetwork.org/

Ecosystem services



Do we need wild species? (negative)

- We depend mostly on domesticated species for food (chickens...).
- Food for domesticated species is itself from domesticated species (grains..)
- Domesticated plants only need water, nutrients and light. Can't we handle all that?
- We can do the jobs of *pollinators, decomposers, predators*.

Do we need wild species? (affirmative)

- The fact is, we use ecosystem services.
- We harvest woods from wild forests.
- We harvest wild fish.
- We depend on wild pollinators.
- We breathe oxygen.
- We dump waste into the wild.
- To regenerate the quality of farm land, we let it go "wild" (fallow).
- We don't fully understand wild processes -- we might break something.

The **Ecological Footprint** represents the <u>productive area</u> required to provide the <u>resources and services</u> required by humanity.

Do we need land?

Negative:

No, because we can build skyscrapers!

Affirmative:

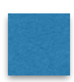
Yes, because only plants reduce carbon.
Plants need sunlight.

hec·tare

/ˈhekˌter/

noun

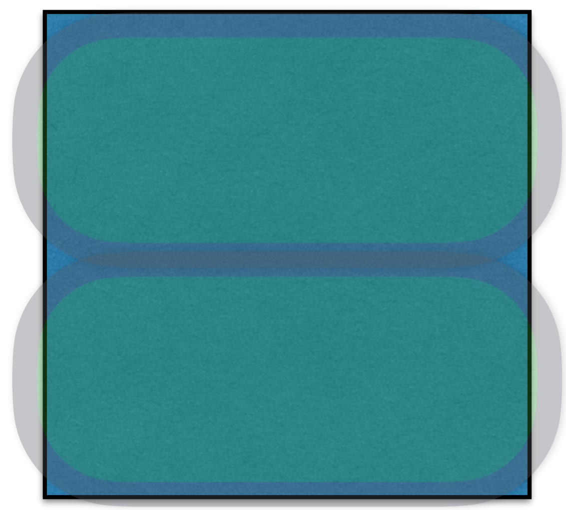
a metric unit of area, equal to 100 *ares* (2.471 acres or 10,000 square meters).



1 *are* $=10x10m^2$

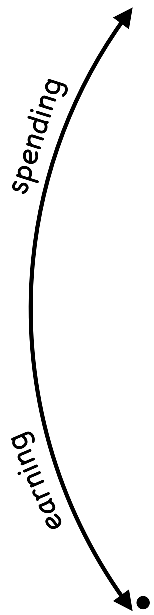
x 100 =

1 *hectare*$=100x100m^2$



1 hectare ≈ 2 football fields

Ecological Footprint/ Biocapacity



- **Ecological Footprint**: a measure of the *demand* populations and activities place on the biosphere in a given year.
  - The amount of land that would be required to provide the natural resources and absorb the waste of a population (i.e. **ecosystem services**).
  - A measure of Human appropriation of Earth's surface (incl. occupied and domesticated).
  - Measured in global hectares (gha).
- **Biocapacity (carrying capacity)**: a measure of the amount of biologically productive land and sea area available to provide the ecosystem services that humanity **consumes** – our "*ecological budget* "or Nature's "*regenerative capacity*."
  - The Earth has a total of biocapacity of **12 billion gha**

Wackernagel, M., 1994. Ecological Footprint and Appropriated Carrying Capacity: A Tool for Planning Toward Sustainability. Ph.D. Thesis. School of Community and Regional Planning. The University of British Columbia

Calculating the Ecological Footprint of **production**

Production (in tons) of commodity (*i*) / year, including CO_2

conversion to **gha** (depends on whether commodity is land, sea, or CO_2)

$$EF_P = \sum_i \frac{P_i}{Y_{N,i}} \cdot YF_{N,i} \cdot EQF_i$$

yield factor, relative to world average yields.

National (*N*) average **yield** for the production of commodity (*i*) (or its carbon uptake capacity in cases where P is CO2), in hectares/ton/year.

ecological footprint of production, in **gha** (global hectares).
May be national, sub-national, or individual.

Earth has a total of 12 billion gha

Dynamic Ecological Footprint of **production**

Intertemporal Yield Factor (depends on the current year *j*)

Production (in tons) of commodity (*i*) / year, including CO_2

conversion to gha (depends on whether commodity is land, sea, or CO_2)

$$EF = \sum_i \frac{P_{N,i,j}}{Y_{N,i,j}} \cdot YF_{N,i,j} \cdot IYF_{W,i,j} \cdot EQF_{i,j}$$

yield factor, relative to world average yields.

National (*N*) average yield for the production of commodity (*i*) (or its carbon uptake capacity in cases where P is CO2), in hectares/ton/year.

ecological footprint of production, in gha (global hectares).
May be national, sub-national, or individual.

Earth has a total of 12 billion gha

Fig. 1. National Footprint Accounts (NFA)' accounting framework.

$P_i, Y_{N,i}$

Crop yields easily obtained from USDA.

All Other Hay Area Harvested, Yield, and Production – States and United States: 2014 and Forecasted August 1, 2015

State	Area harvested		Yield per acre		Production	
	2014	2015	2014	2015	2014	2015
	(1,000 acres)	(1,000 acres)	(tons)	(tons)	(1,000 tons)	(1,000 tons)
Alabama [2]	750	720	2.80	2.50	2,100	1,800
Arkansas	1,220	1,050	2.00	2.30	2,440	2,415
California	500	455	3.40	3.00	1,700	1,365
Colorado	600	700	1.75	1.90	1,050	1,330
Georgia [2]	580	540	2.60	2.80	1,508	1,512
Idaho	300	330	2.10	2.20	630	726
Illinois	250	275	2.70	2.50	675	688
Indiana	360	330	2.75	2.30	990	759
Iowa	345	345	2.20	2.50	759	863
Kansas	1,700	1,800	1.60	2.00	2,720	3,600
Kentucky	2,100	2,100	2.00	2.20	4,200	4,620
Louisiana [2]	470	460	2.70	2.40	1,269	1,104

http://www.usda.gov/nass/PUBS/TODAYRPT/crop0815.pdf

EQF: equivalence factors are based on historical records

- EQF converts areas of different land (use) types to a **common unit** (**gha**), which are hectares of global average bioproductivity.
- EQF for **crops** depend on the "suitability index" of the land.
- EQF for **livestock** (pasture) land based on hectares required to grow *feed* required to produce meat.
- EQF for **CO_2** (yes, it's treated as a commodity!) are based on average CO_2 absorption per hectare of forest.
- EQF for **seafood** is based calorie equivalents of beef.

Ecological footprint of **one country** factors in import/export

Ecological Footprint of Production for commodities *Imported to* nation *n.*

Ecological Footprint of Production for commodities *Exported from* nation *n.*

$$EF_C = EF_P + EF_I - EF_E$$

Ecological Footprint of Consumption for nation *n.*

Ecological Footprint of Production for nation *n.*

Note: *total* global Footprint of Production equals *total* global Footprint of Consumption. (Waste is considered "consumption"), because total exports equals total imports.

Ecological footprint of **one person**

http://www.footprintnetwork.org/resources/footprint-calculator/

Calculate your ecological footprint.
Share with the class.

Calculation of Biocapacity

=<u>Sustainable Carrying Capacity</u> =Total available renewable resources.

"[based on] what each hectare would be able to inherently deliver."

$$BC = \sum_i A_{N,i,j} \cdot YF_{N,i,j} \cdot IYF_{W,i,j} \cdot EQF_{i,j}$$

$A_{N,i,j}$ represents the bioproductive area available at the country (*N*) level, for all commodities (*i*) in a given year (*j*).

Other variables, as before.
Typically expressed as *per capita*.

Question.

$$BC = \sum_i A_{N,i,j} \cdot YF_{N,i,j} \cdot IYF_{W,i,j} \cdot EQF_{i,j}$$

Biocapacity (BC) depends on bioproductive area (A).

Everything else is a conversion factor

What happens to bioproductive area over time with (1) deforestation, (2) erosion?

What causes decrease in biocapacity?

24 m wheat harvester (also threshes)

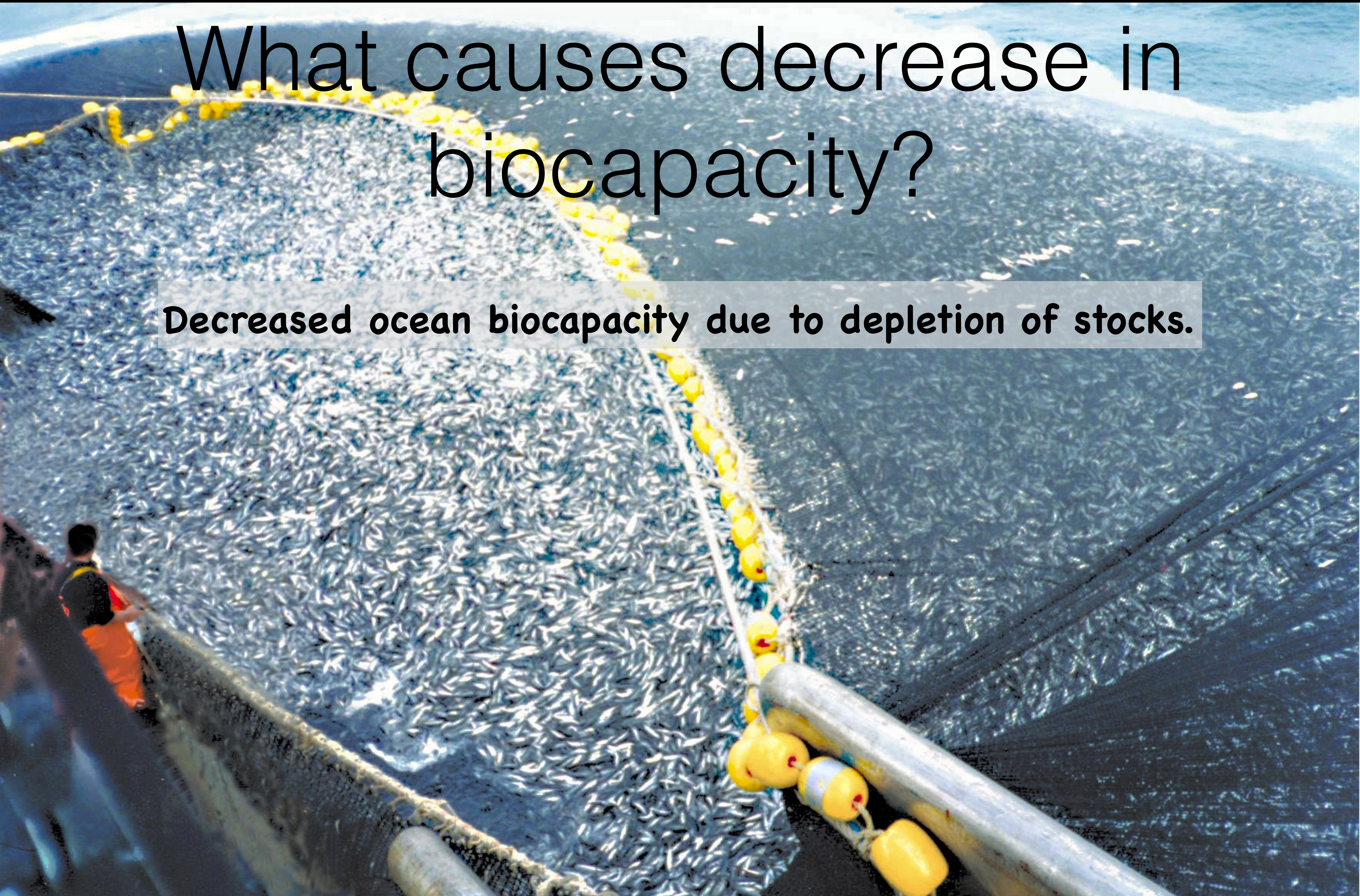
https://youtu.be/FGokREwBu00

What causes decrease in biocapacity?

Decreased carbon sequestration due to deforestation.

- https://youtu.be/WQIbFx4xc-M

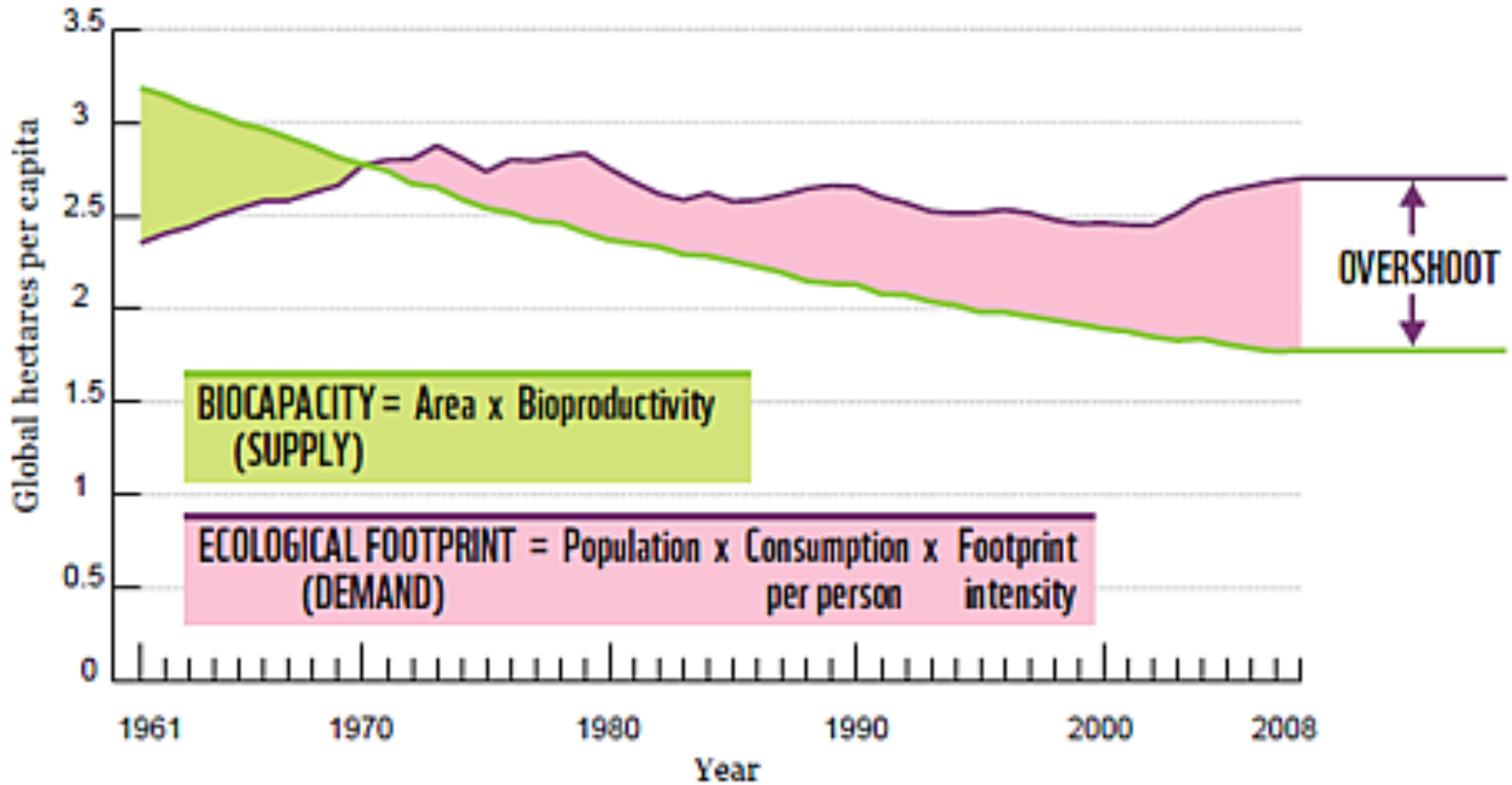
What causes decrease in biocapacity?



Decreased ocean biocapacity due to depletion of stocks.

purse-seine ocean fishing

Footprint increasing
Biocapacity decreasing. 1960-2008



IPAT : a formula for ecological footprint

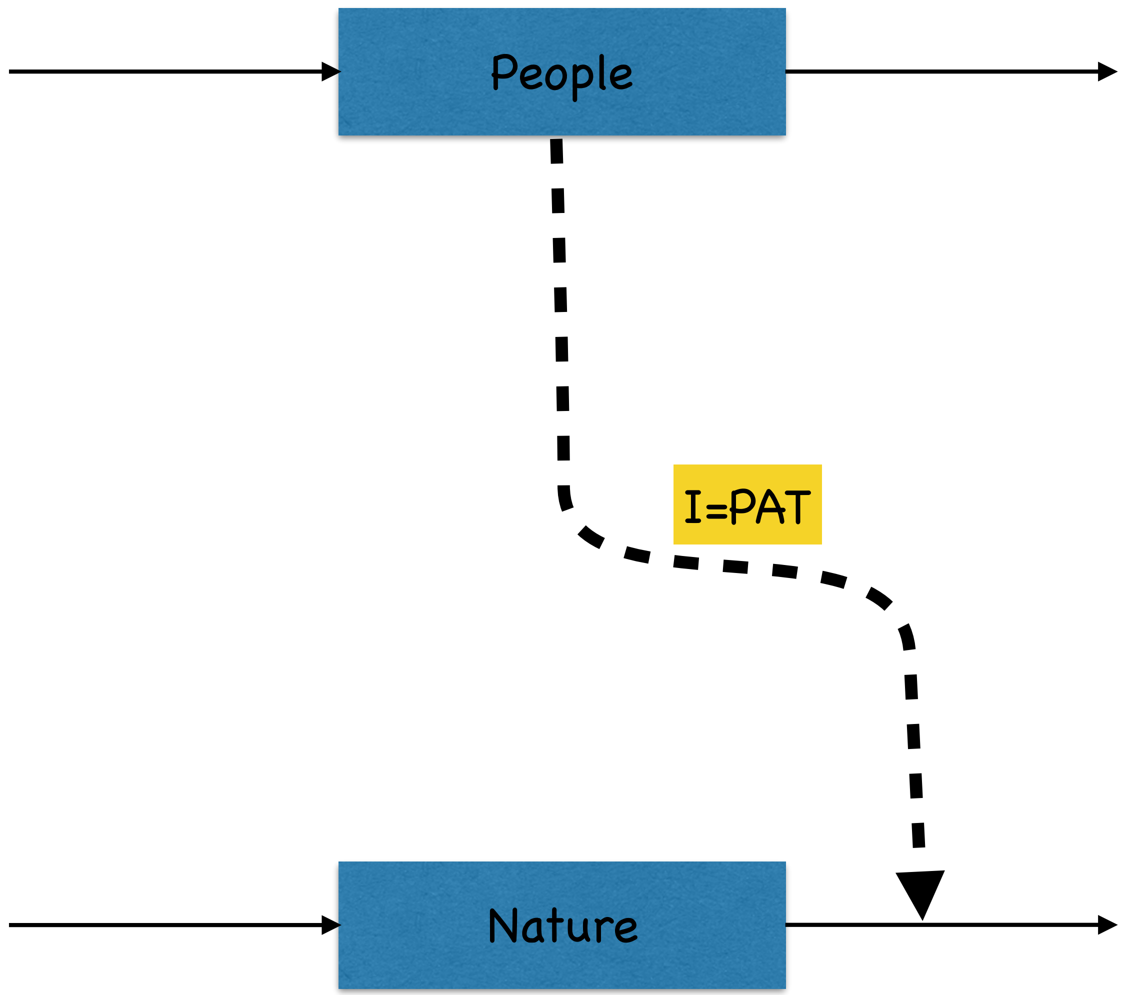
I = P*A*T

Impact = Population * Affluence * Technology

I = **Impact**. Measured in *gha*. Land area required for the whole population.
P = **People**.
A = **Affluence**. Consumption. Measured in goods/person.
T = **Technology**, measured in gha/goods

Technology can amplify/diminish the impact of **Affluence**.
For example, a new tree whacker can increase Impact. (T > 1).
But, solar panels can decrease Impact. (T < 1).

Ehrlich, Paul R.; Holdren, John P. (1971). "Impact of Population Growth". Science (American Association for the Advancement of Science) 171 (3977): 1212–1217.


People
I=PAT
Nature

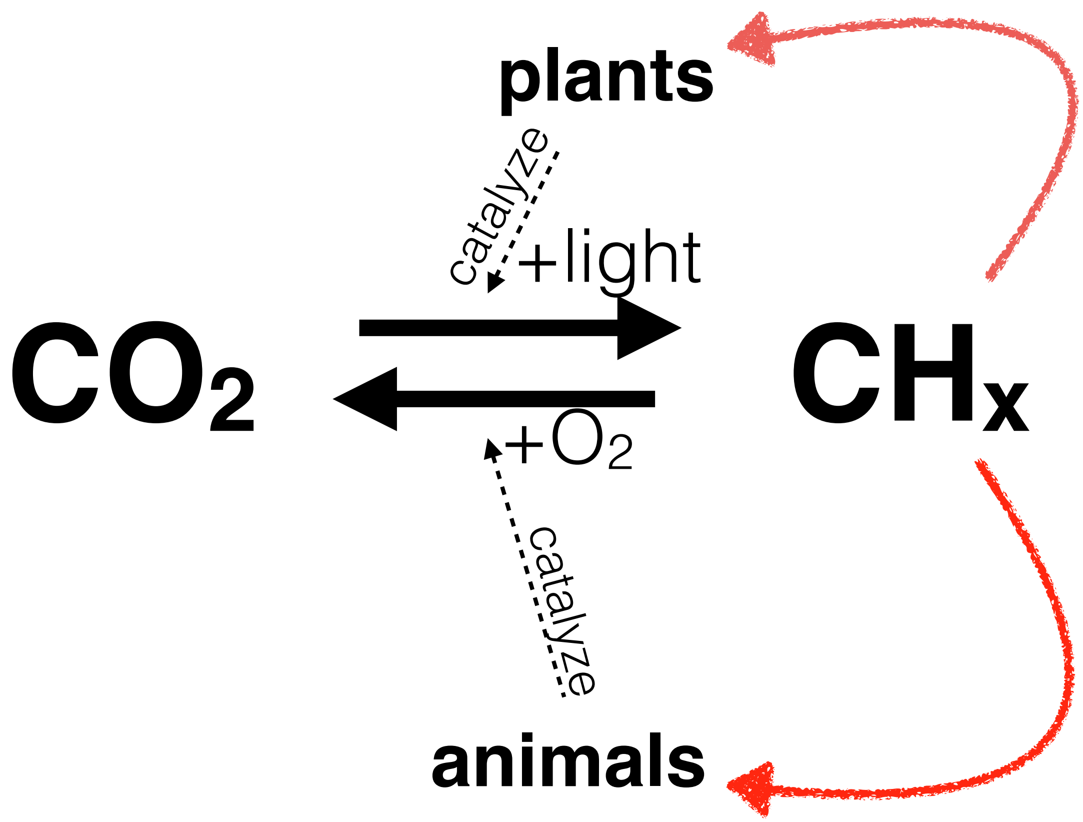
What is an ecosystem?

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.

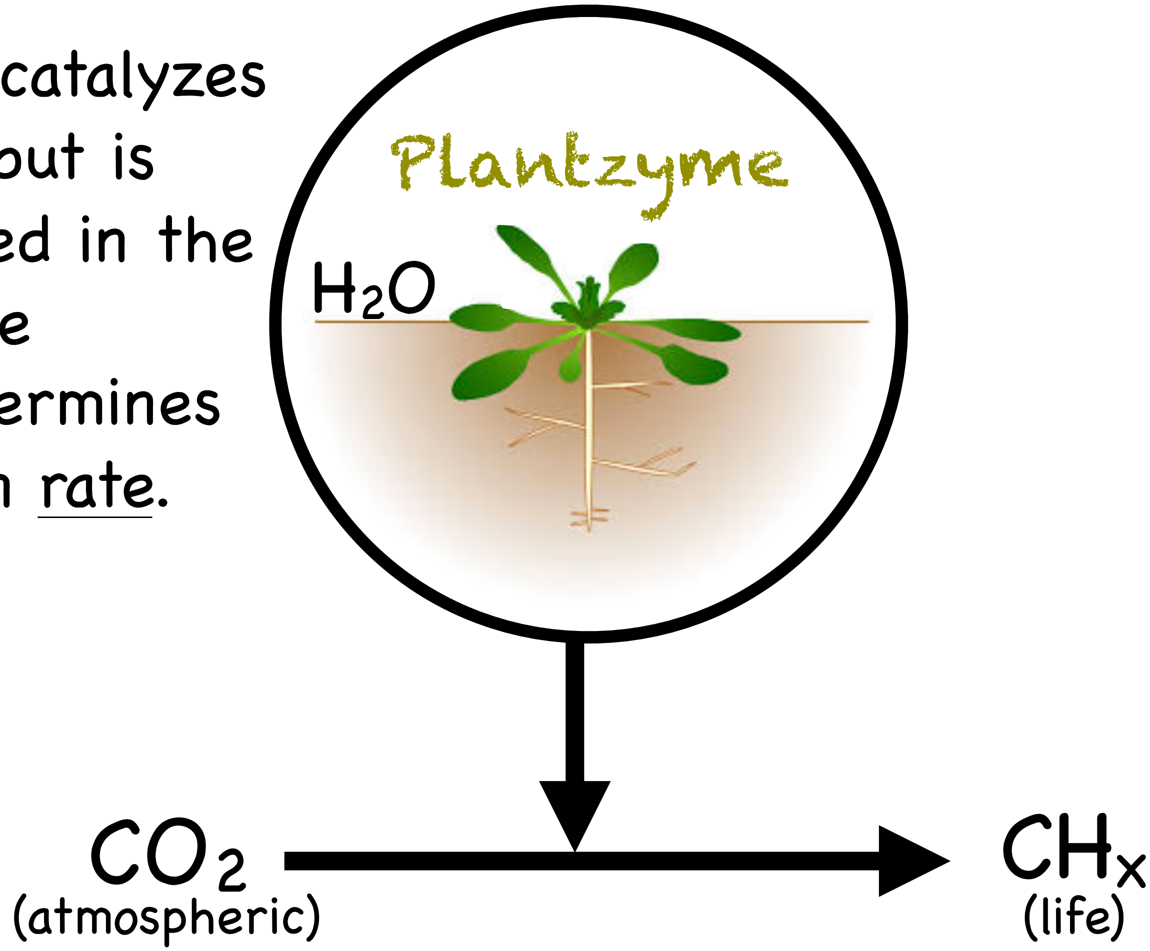
Oxygen and nitrogen have similar cycles.

Plant is to **carbon fixation**

as

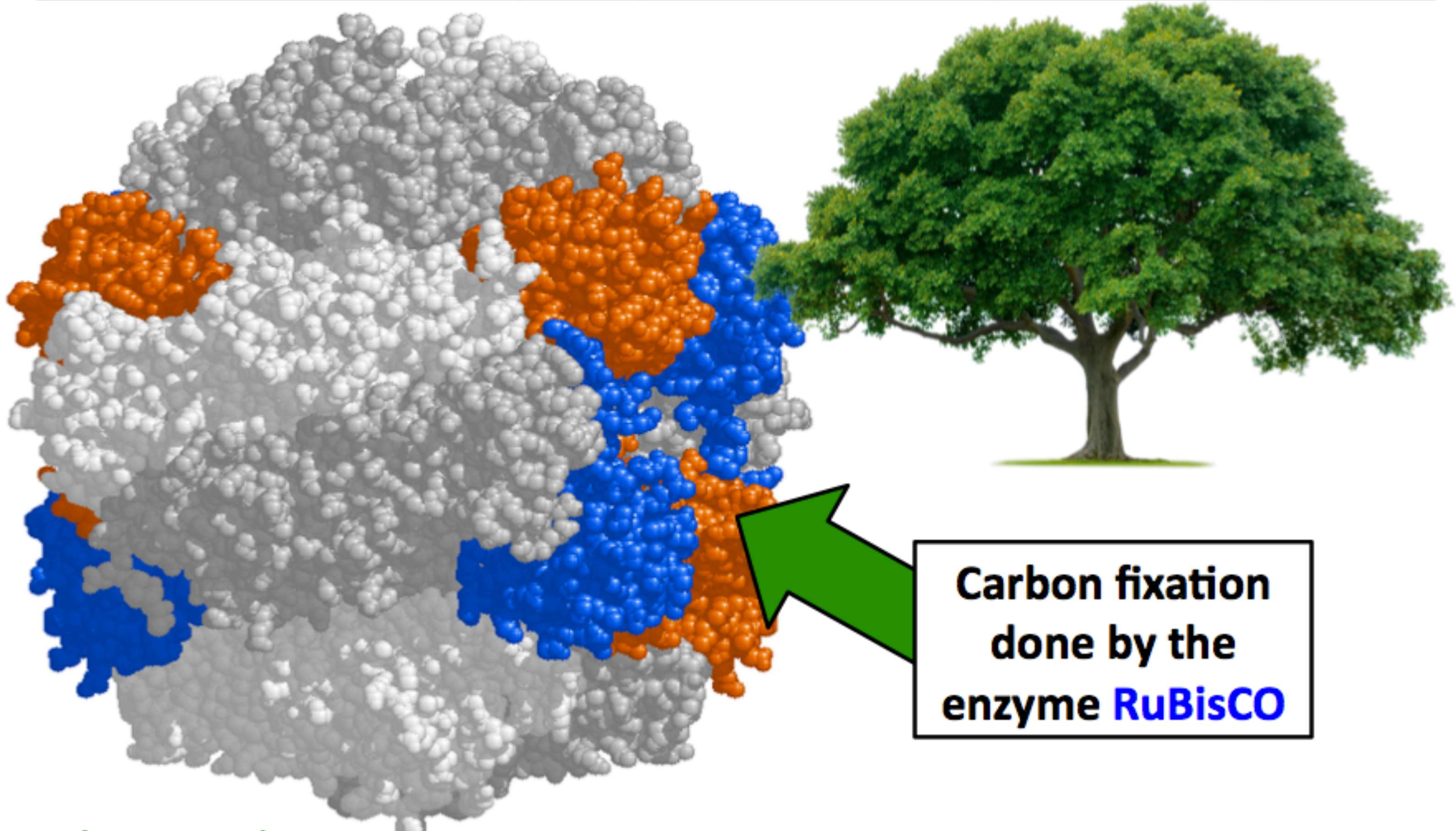
Enzyme is to **chemical reaction.**

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:

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

<u>Only plants</u> catalyze: (oxidized carbon) ---> (reduced carbon)

Why the high cost of nitrogen fixation?

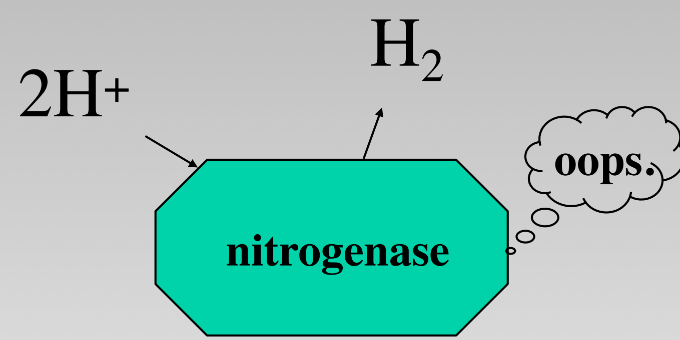
N_2 is the most stable form of nitrogen. All other nitrogenous compounds are "energetically uphill" from N_2.

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

$$N_2 + (6+2n)H^+ + (6+2n)e^- + \mathbf{p(6+2n)ATP} \longrightarrow 2NH_3 + nH_2 + p(6+2n)ADP + p(6+2n)P_i$$

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!!!

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.

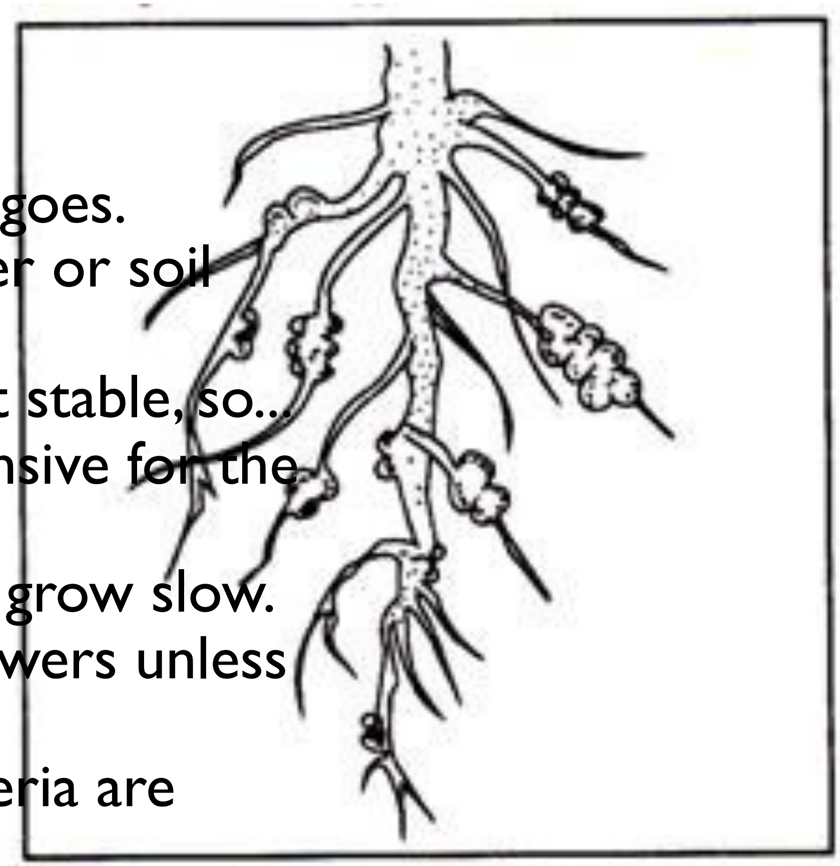


Fig. 2.3. Root nodules of a leguminous plant containing nitrogen-fixing bacteri

Soil symbiotes fix N_2

- Nitrogen fixing bacteria: nitrobacter, rhizobia.

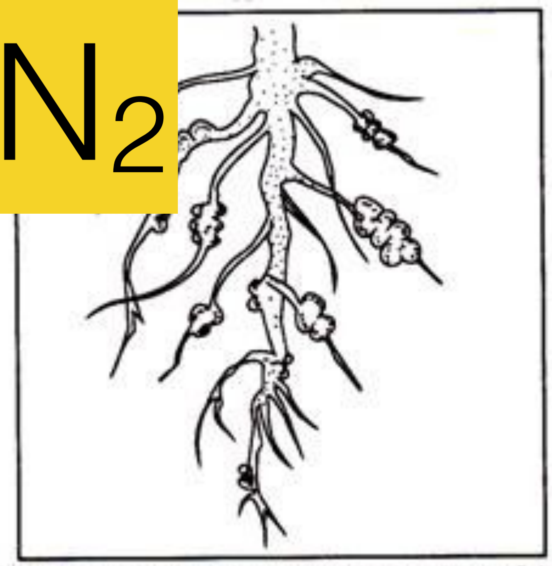
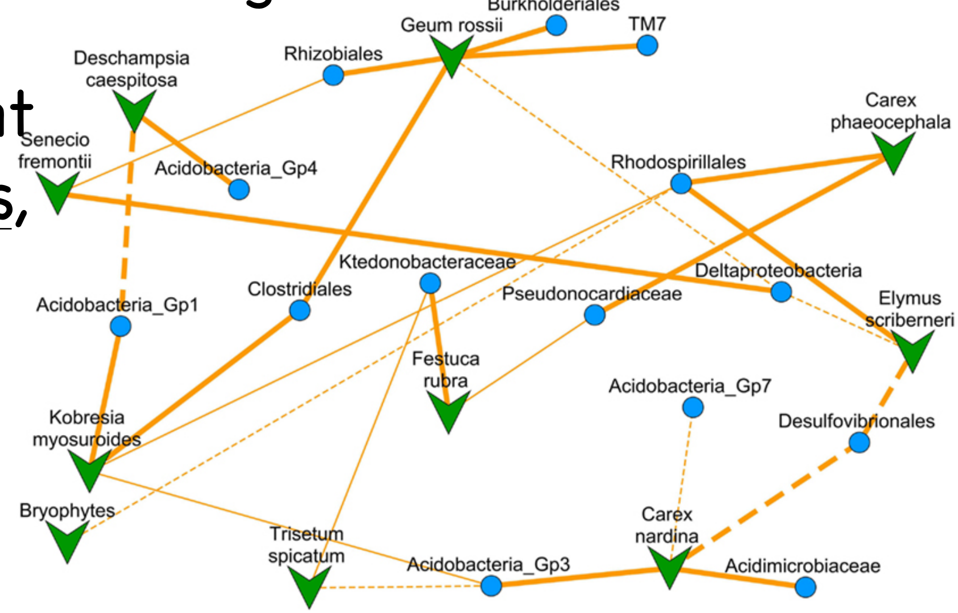


Fig. 2.* Root nodules of a leguminous plant containing nitrogen-fixing bacteria

- 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,



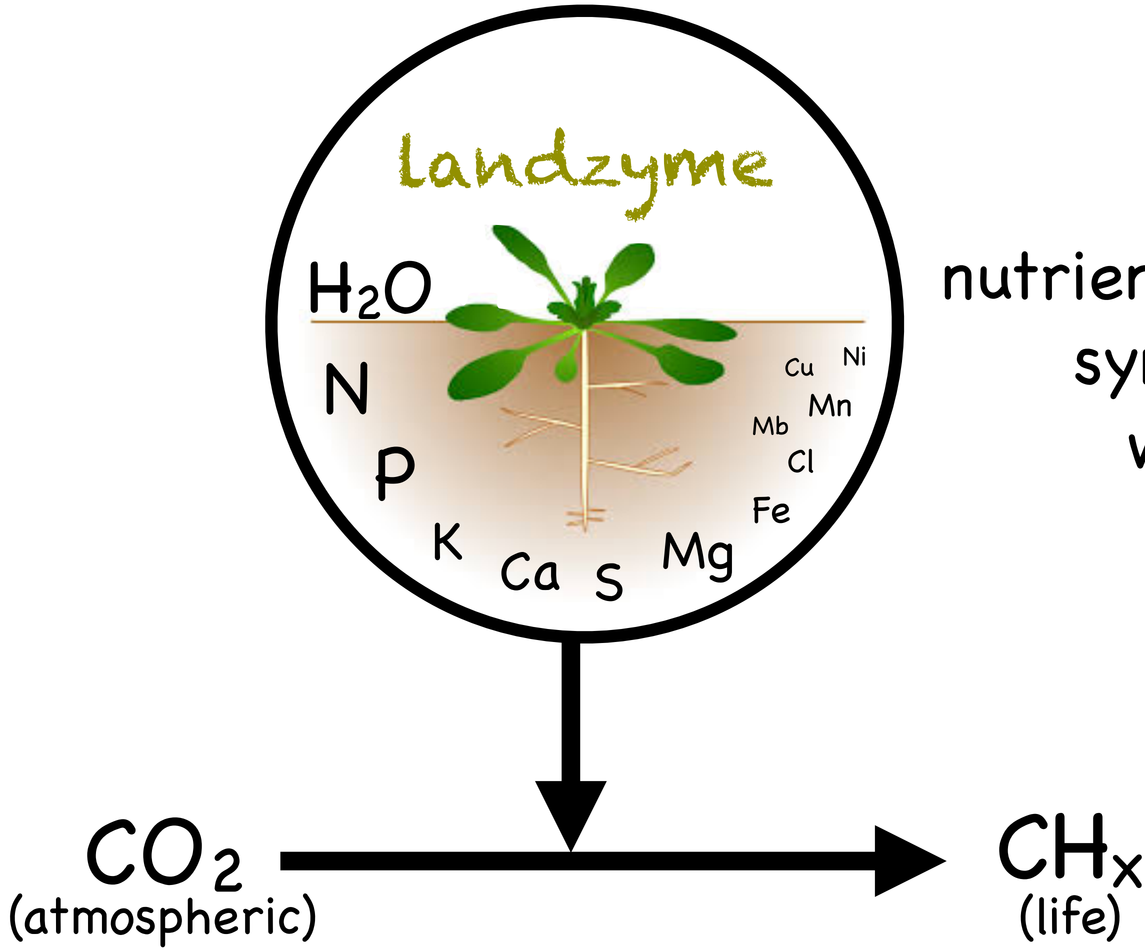
*Vrieze, Jop de (2015-08-14). "The littlest farmhands". Science 349 (6249): 680–683.

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

Plant is to **Land**

as

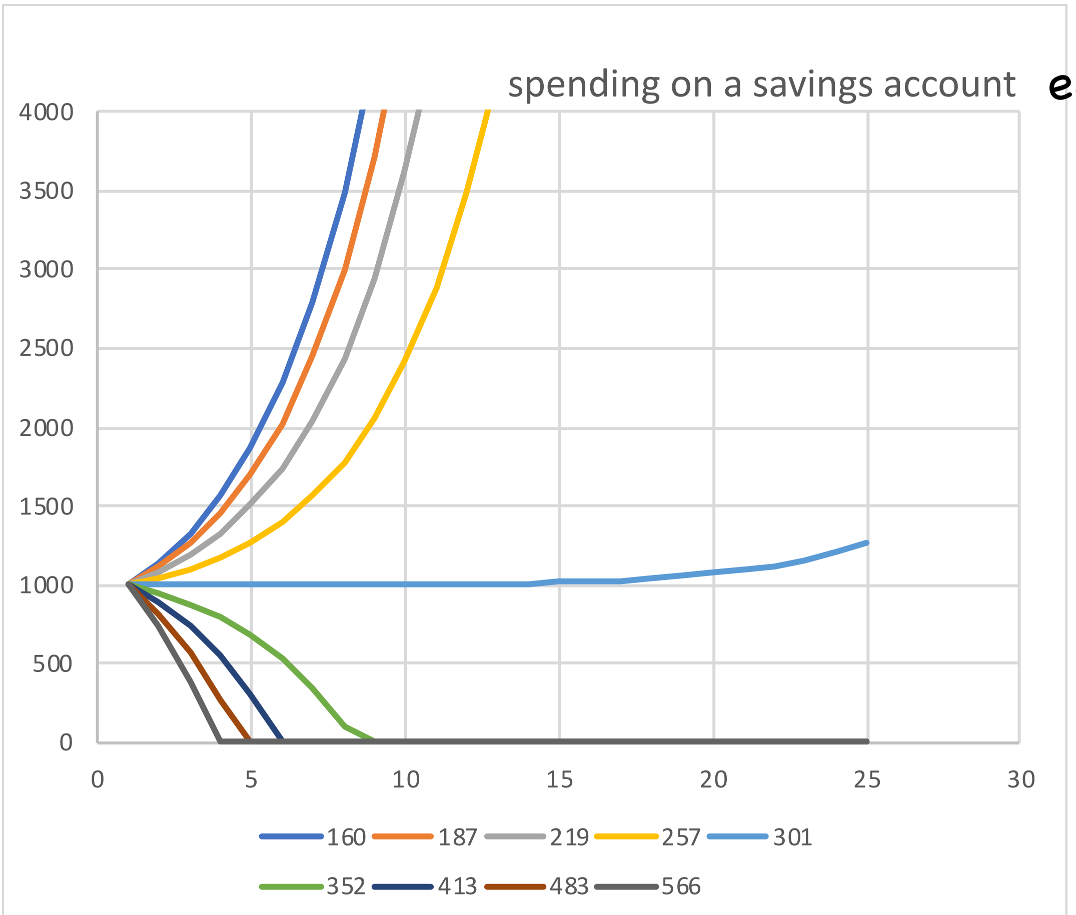
Enzyme is to **co-factors**.



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

Living off the interest.

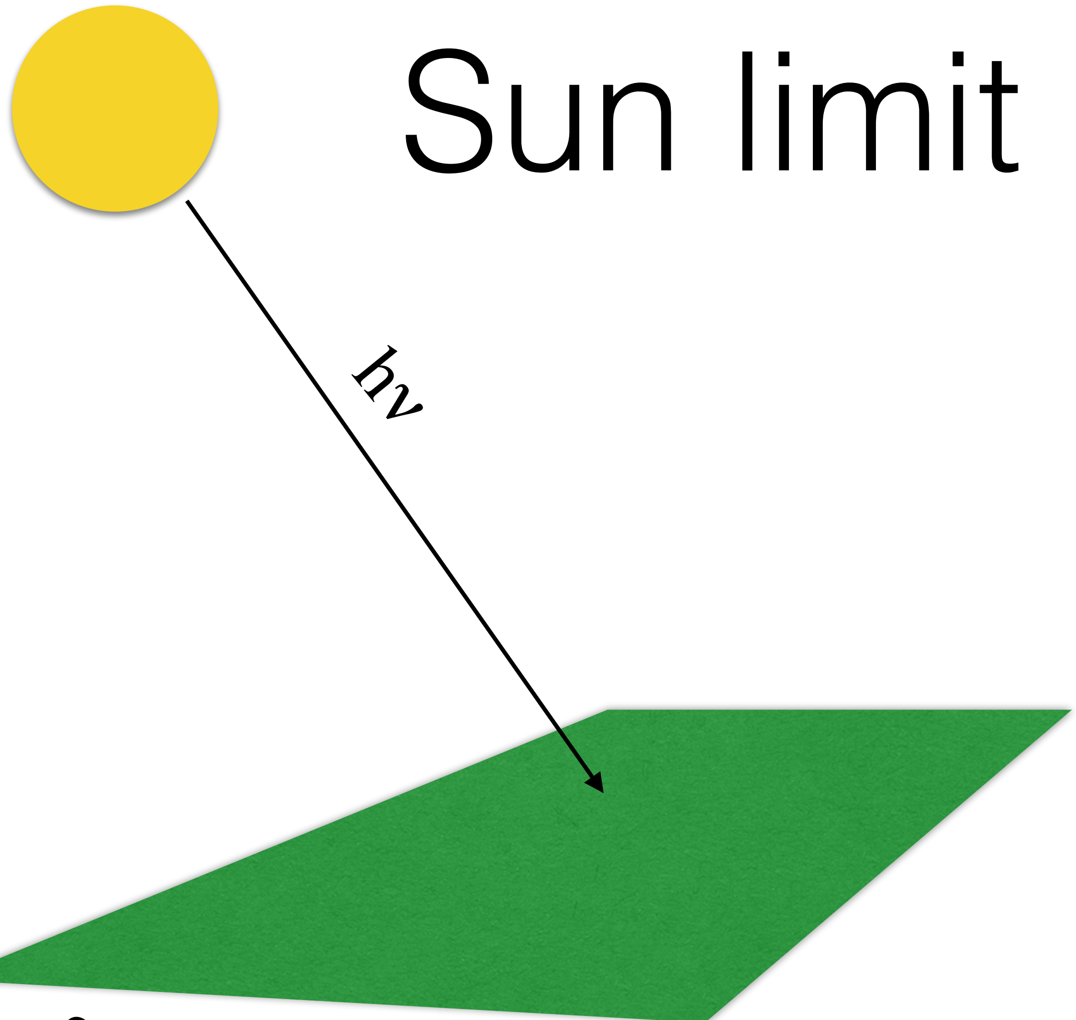
savings account



earning 30%/y

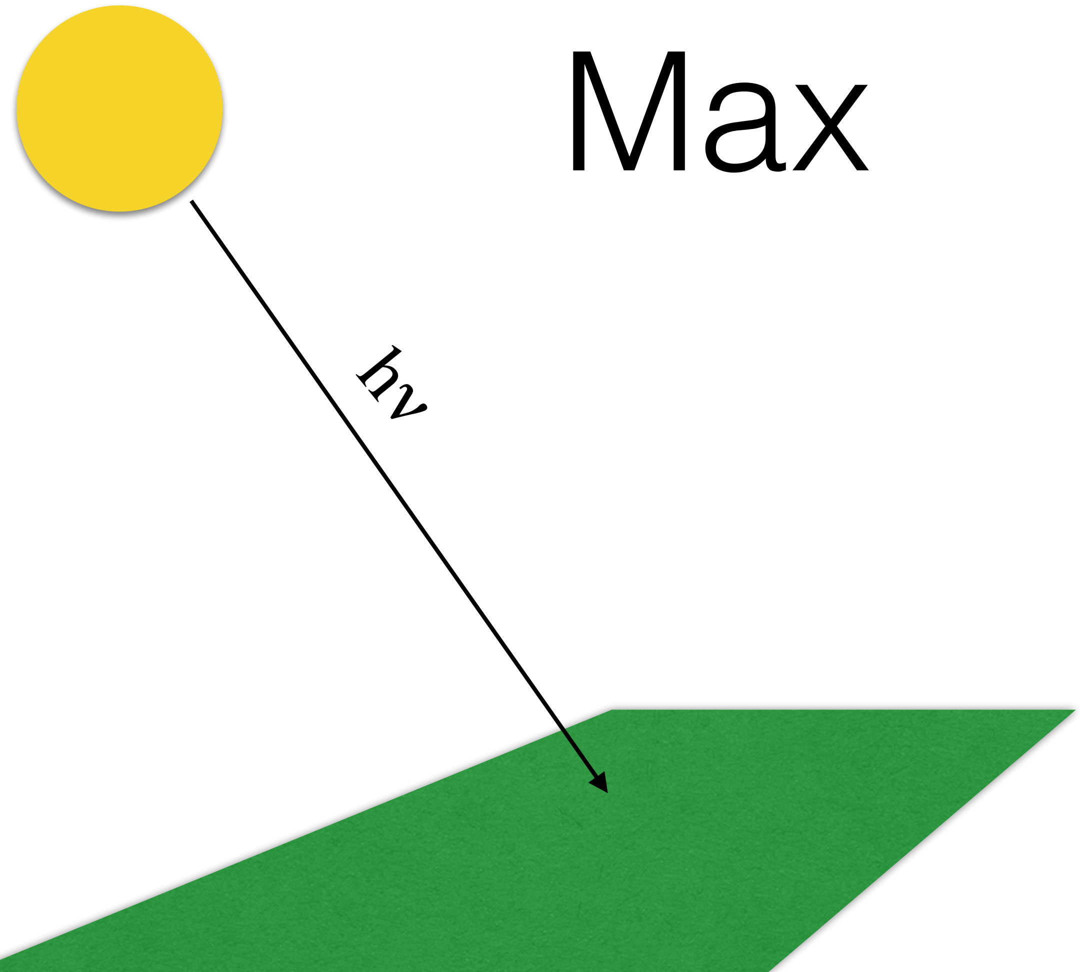
spending rate

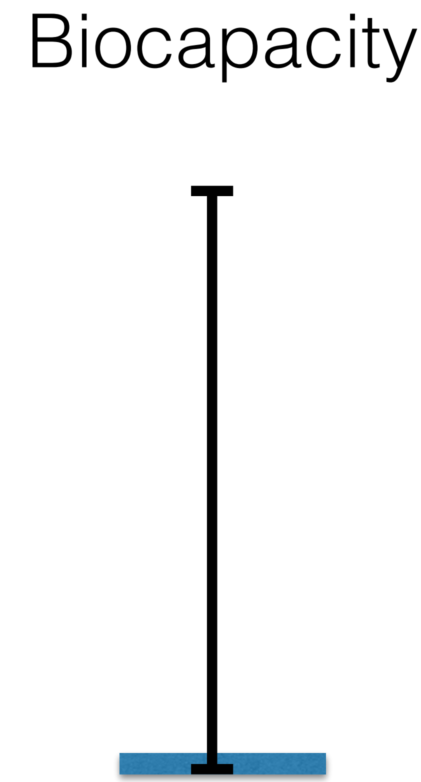
Sun limit



- 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.

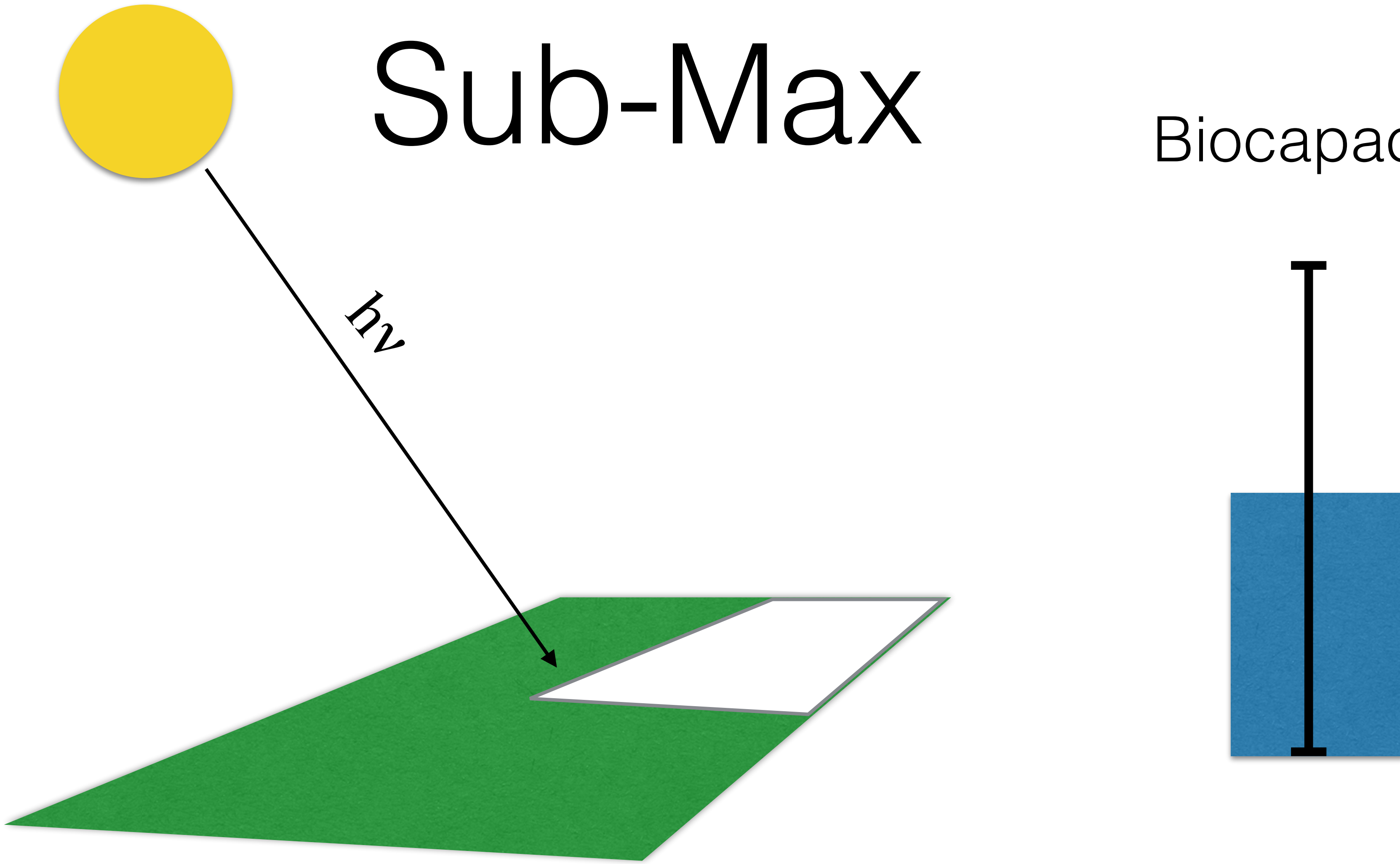
Max





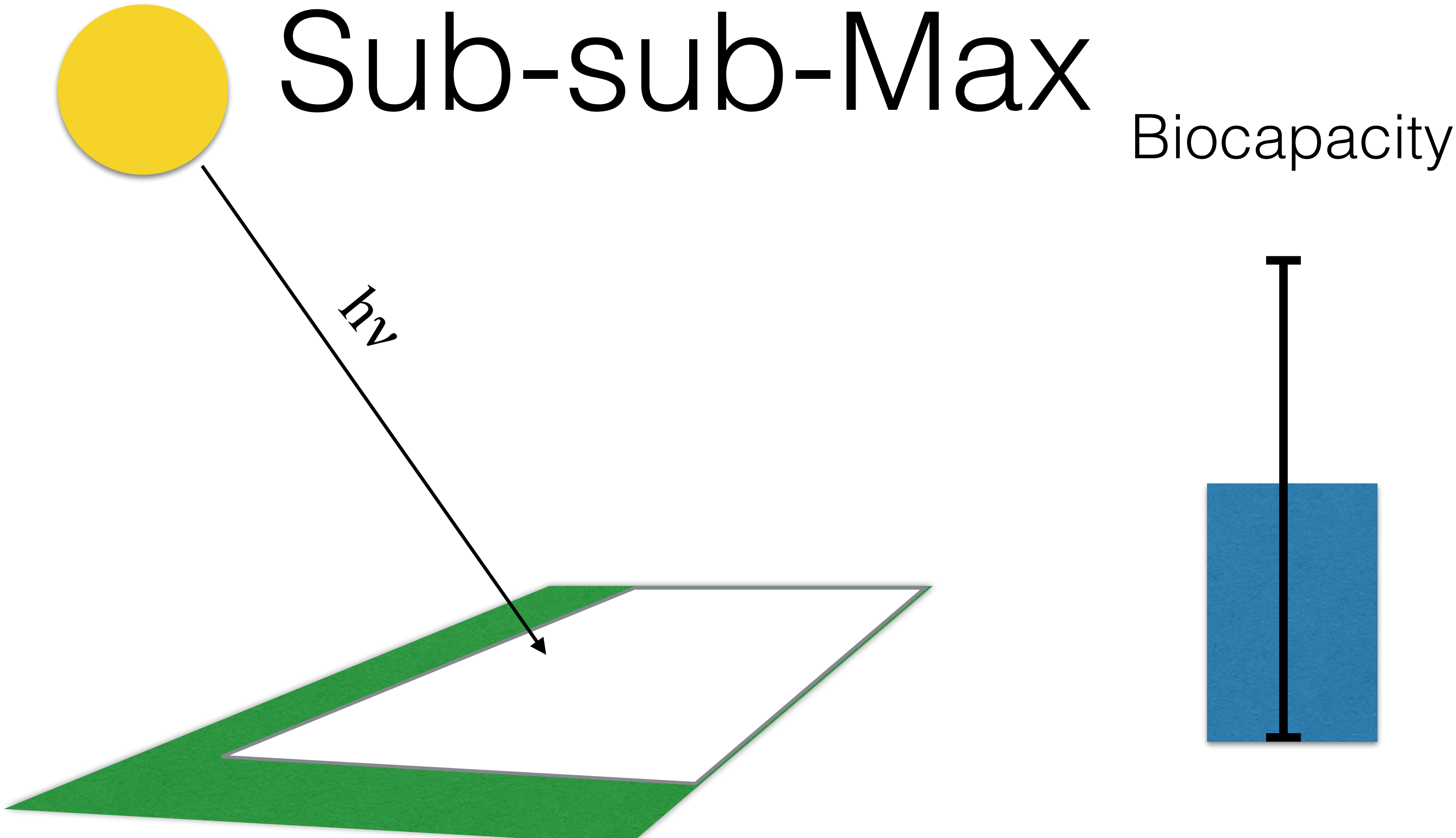
- At Earth Maximum, all light is used by plants.
- Water and minerals may also be limiting.
- No net growth is possible, since the limit has been reached.
- This is a mythical, unobtainable maximum, since animals have always been consuming plants since the beginning of plants.

Sub-Max



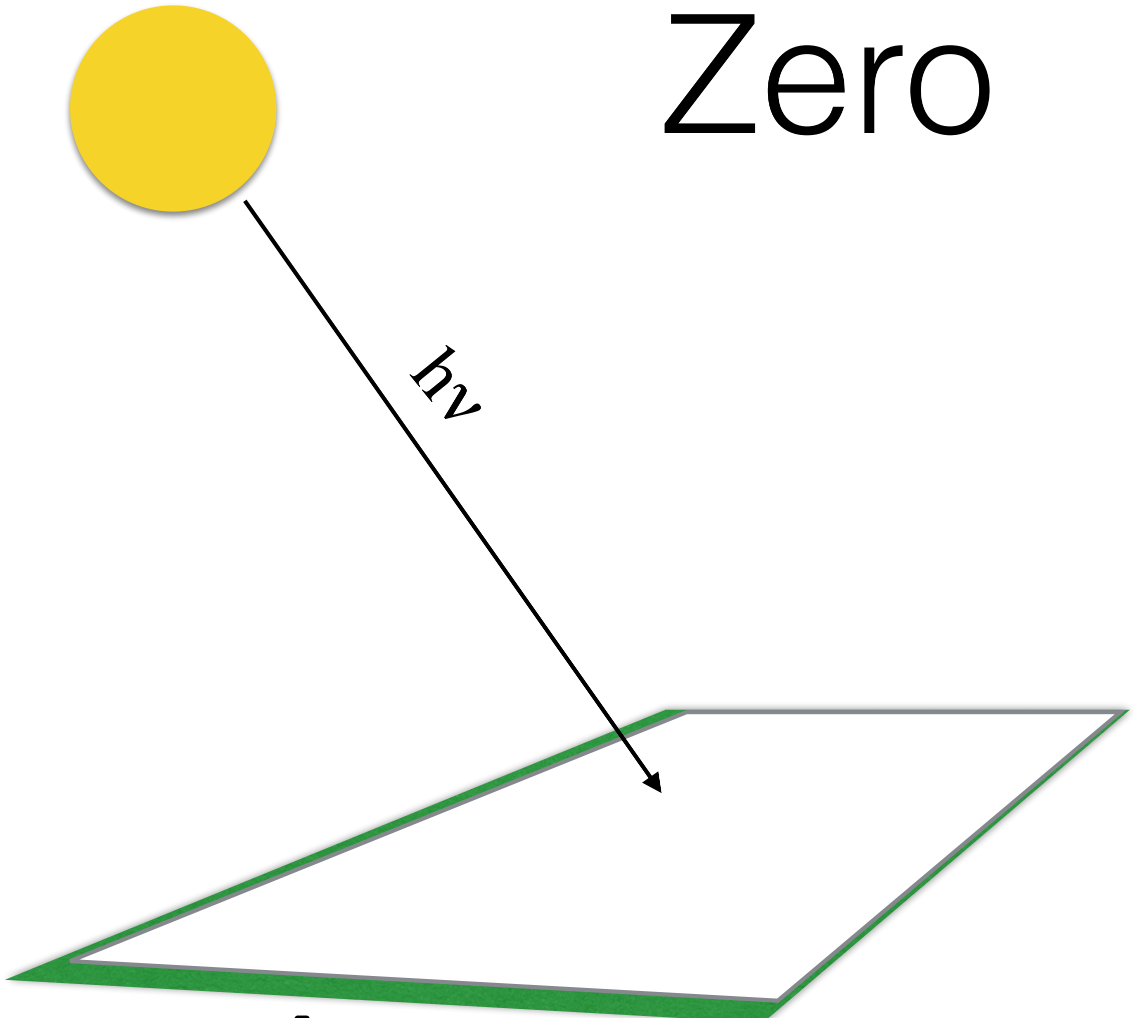
- At 3/4 Max, the amount of available light is rate-limiting.
- When [eco capital] is close to the limit, regeneration is proportional to the unused space.

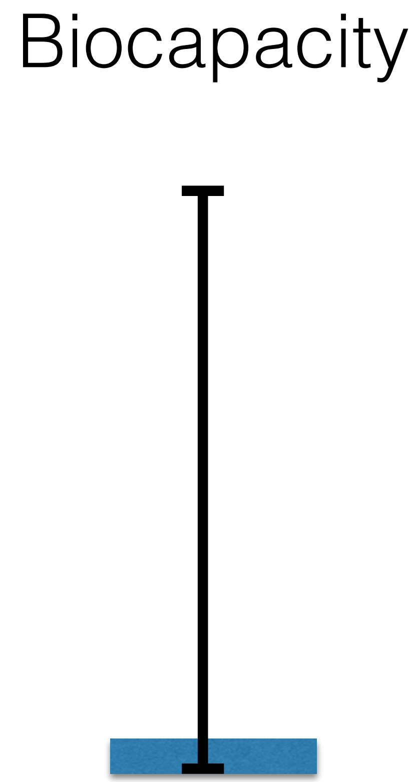
Sub-sub-Max



- 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.

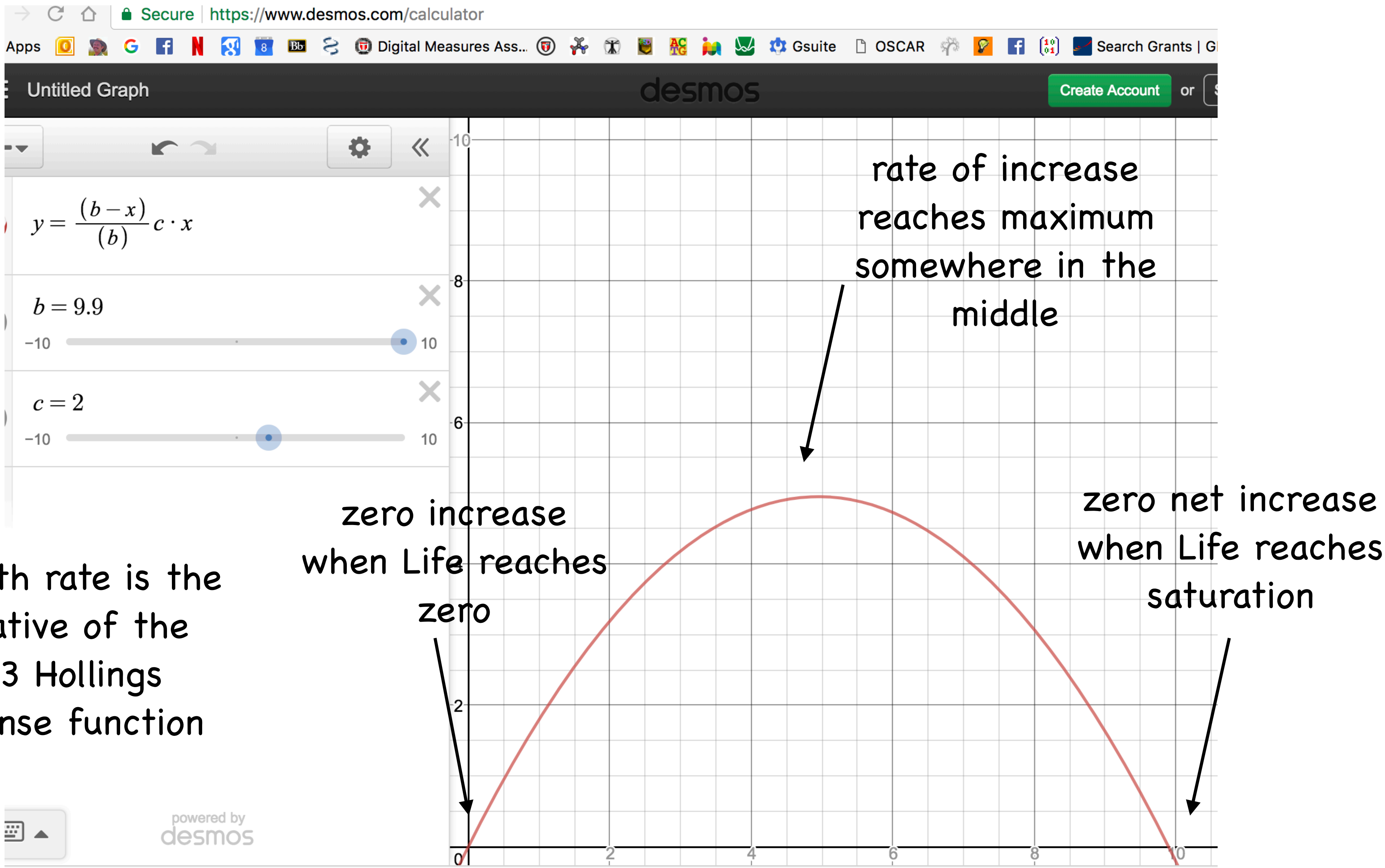
Zero





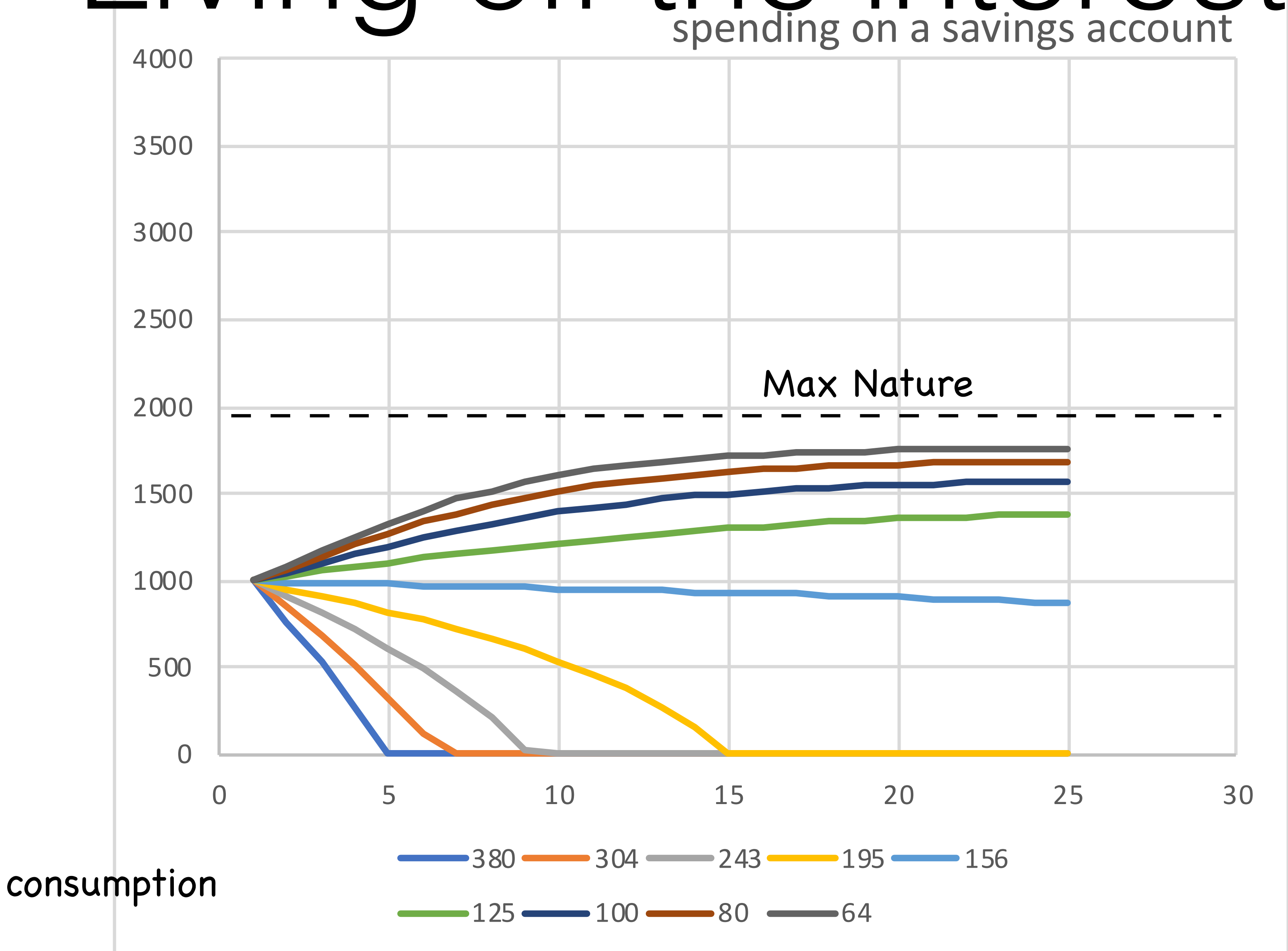
- At [eco capital] = zero, Biocapacity = zero, because there is nothing to grow from.
- In a reasonable scenario, [eco capital] cannot reach zero. Or can it?

Assume **biocapacity** goes to zero at zero Nature and zero at Max Nature, with smooth transition throughout.



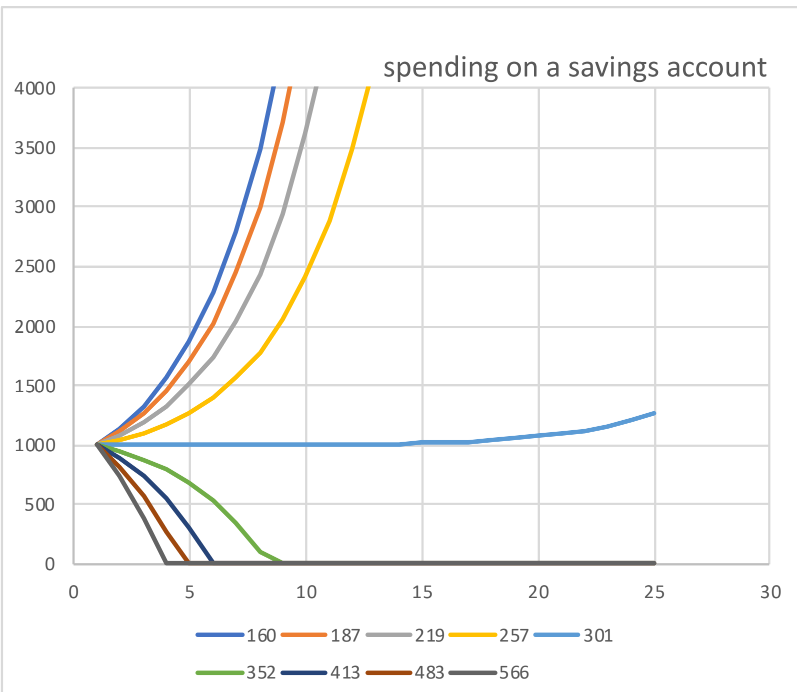
Growth rate is the derivative of the Type 3 Hollings response function

Living off the interest.

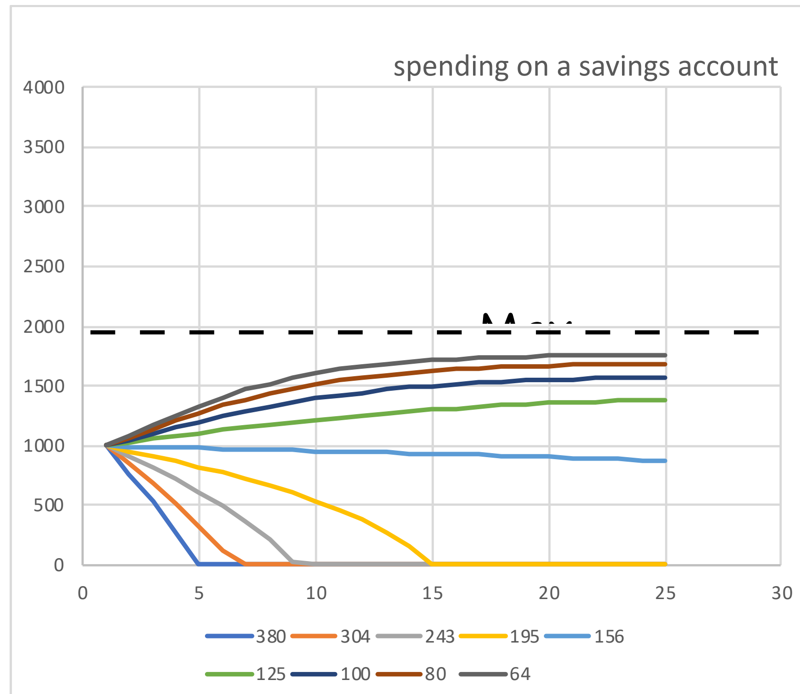


Living off the interest.

Compare



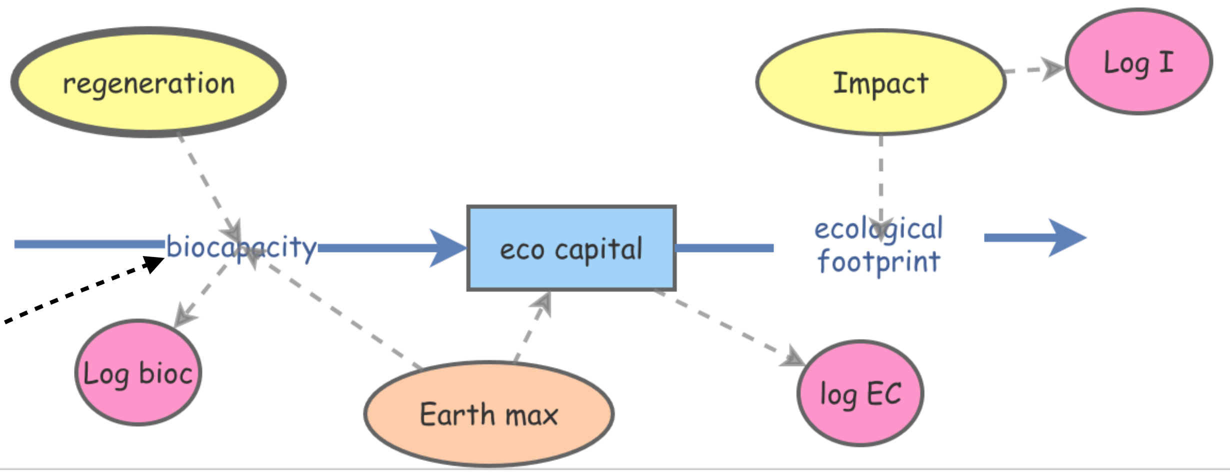
No limit to savings



Savings ceiling

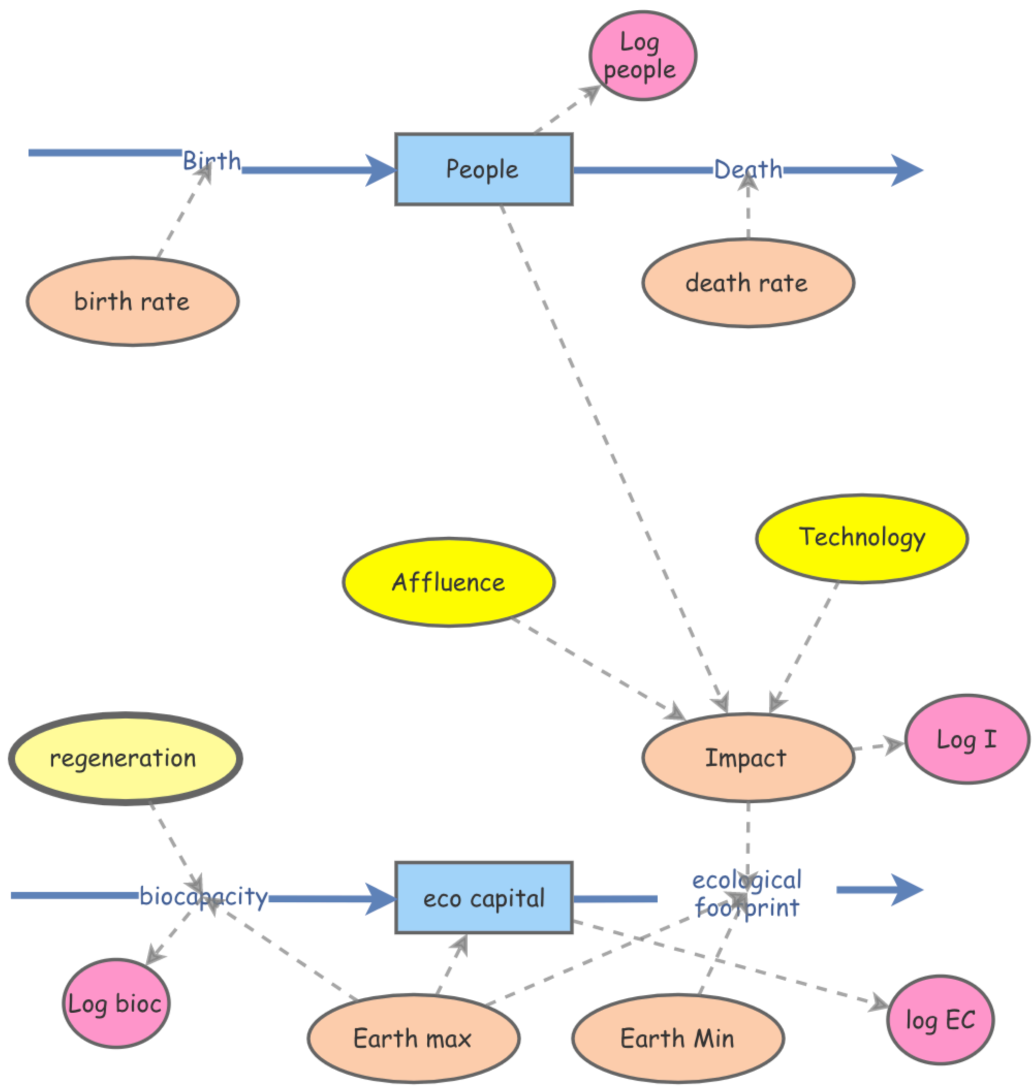
InsightMaker: Impact on Nature

How does this model behave?




```
## deriv of Type 3 Hollings ##
x <- [Earth max]-[eco capital]
x <- x/[Earth max]
x <- x*[regeneration]*[eco capital]
return x
##
```

People + Nature + I=PAT



BIOL 4961 Human Population
Homework 3

I=PAT

Set up a model that looks like this. (The coloring is optional)

```
[birth rate] = slider ( 0. 0.05 )
[death rate] = slider (0., 0.05)
[Birth] = [birth rate]*[People]
[death] = [death rate]*[People]
[People] = 1.5e9  (the human
population in 1900, approximately)
[Affluence] = slider (0, 1.0)
[Technology] = slider (0., 1.0)
[Impact] = [People]*[Affluence]*[Technology]
[ecological footprint] =
```

```
x <- [Impact]
If ([eco capital] < [Earth Min])
Then
  x <- 0
Else
  x<- [Impact]
End If
return x
```

```
[Earth Max]=1.5e10
[Earth Min]=0 (for now)
[eco capital] = [Earth Max]
[Regeneration] = slider(0., 1.0)
[biocapacity] =
```

```
## deriv of Type 3 Hollings ##
x <- [Earth max]-[eco capital]
x <- x/[Earth max]
x <- x*[regeneration]*[eco
capital]
return x
##
```

to be continued....

Debate 2 topic