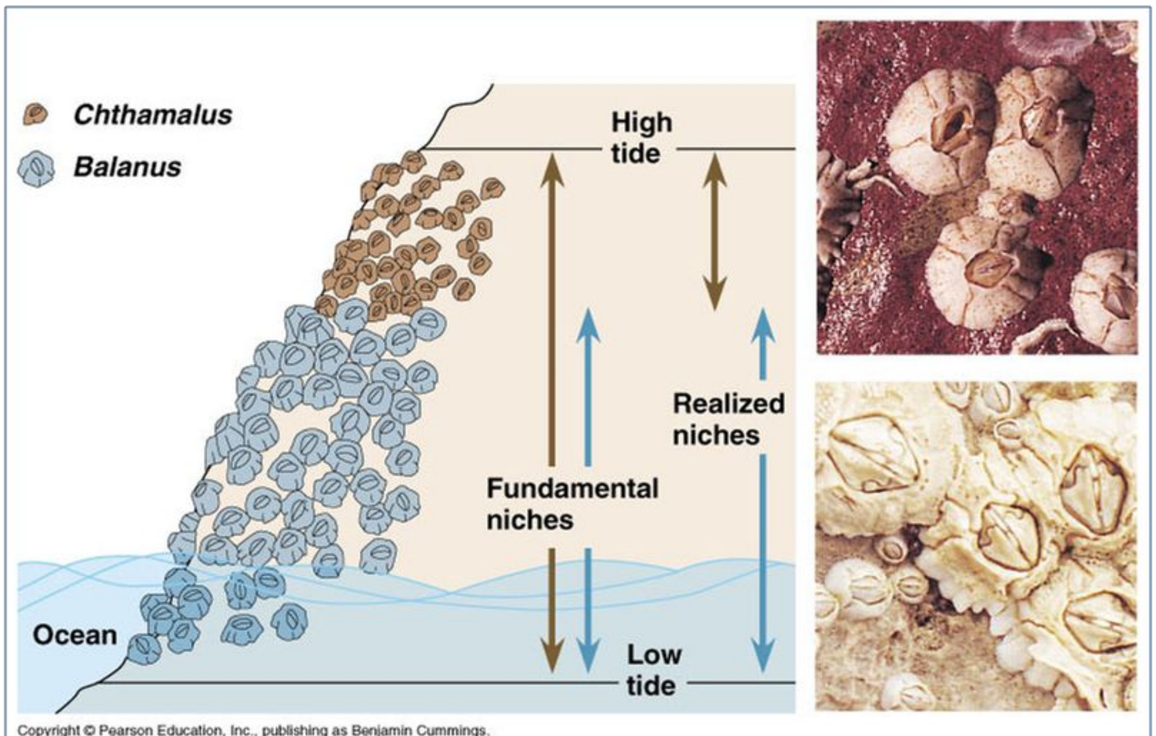
Ecosystem Engineering

Some questions

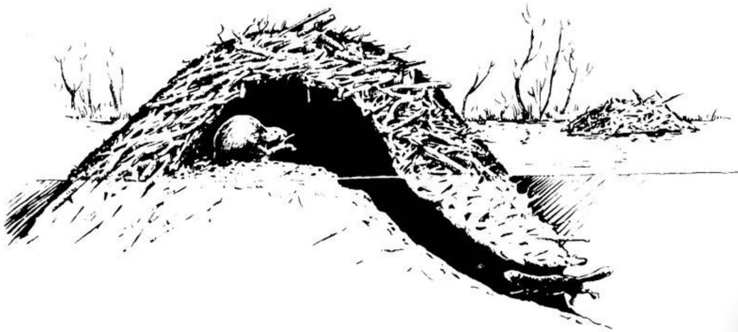
- Why do populations cycle?
- Why are habitat patches unoccupied?

Effects of ecosystems on organisms

- Demography (growth, survival, reproduction)
- Density dependence (intraspecific competition)



Effects of organisms on ecosystems



North American beaver *Castor canadensis*

What population consequences come from the feedback of organisms on ecosystems?

Stages of beaver-modified environment

Beaver active for (~4 years , range: 1-20)
Disintegration and drainage -> Beaver meadow (~70 year)
Conversion to forested riparian zone (~100s years)

Ecosystem Engineering

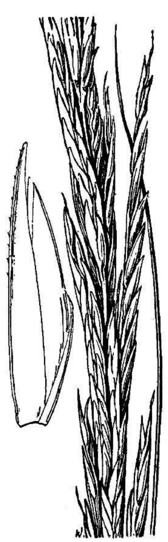
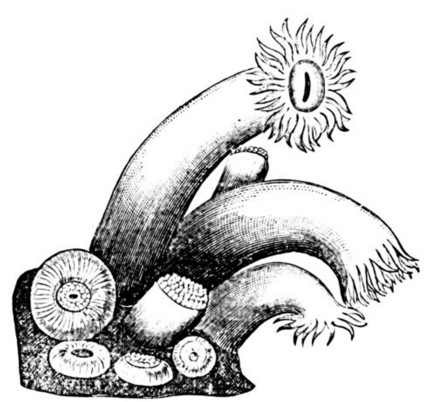
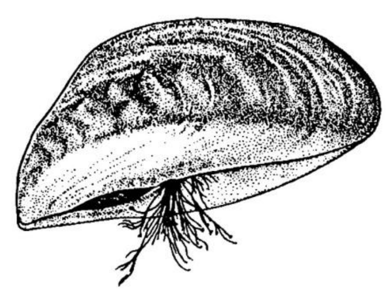
Ecosystem engineering – the physical or chemical modification of habitats by organisms

Universality of ecosystem engineering

Kingdom	Engineering process
Eubacteria & Archaebacteria	•Decomposition •Production of products of metabolism (oxygen, ammonia) •Nitrogen fixation •Bacterial allelopathy
Protista	•Physical/chemical weathering •Soil production •Photosynthetic and metabolic products •Oxygen production
Fungi	•Decomposition •Physical/chemical weathering •Soil production •Moisture retention •Mineral extraction •Creation of environmental structure
Plantae	•Photosynthetic and metabolic products •Physical/chemical weathering •Alteration of hydrology •Soil stabilization •Microclimate modulation •Nutrient retention and modification of nutrient cycles •Allelopathy •Scattering and absorption of light; creation of shade •Modification of wind speed
Animalae	•Construction of nests, burrows, cases, food caches, dens •Provision and protection of nursery environments •Nutrient retention and modification of nutrient cycles •Soil compaction •Decomposition of coarse organic matter

Kinds of ecosystem engineering

- Habitat creation (North American beaver)
- Habitat stabilization (*Spartina alterniflora*)
- Biomixing/Bioturbation (mussels)
- Habitat complexity (corals, trees)


Population dynamics in organism-modified environments (Gurney model)

Rate of change of ecosystem engineer

$$\frac{dE}{dt} = rE\left(1 - E/H\right)$$

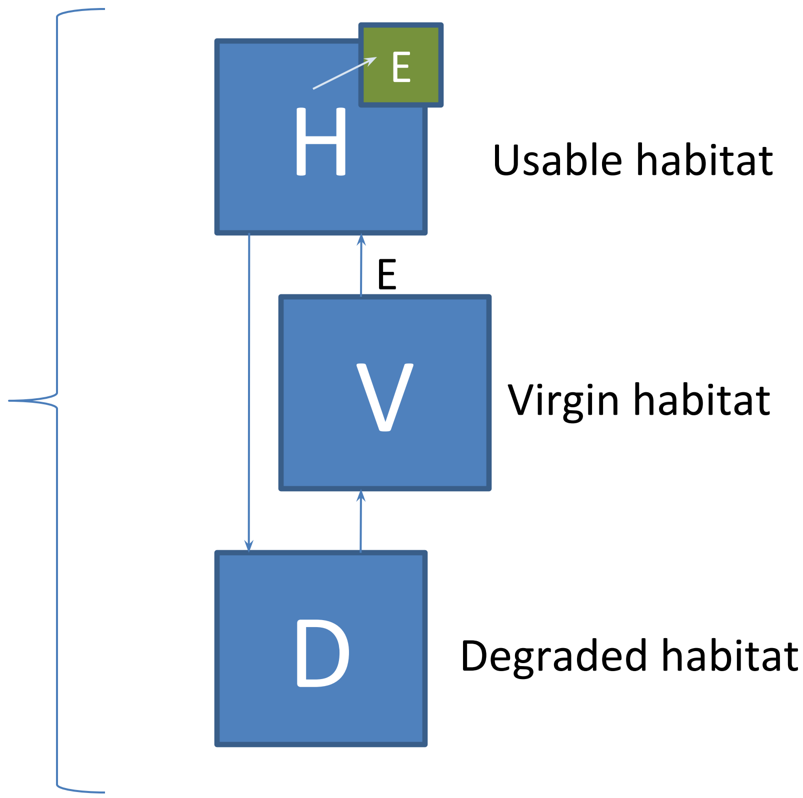
Abundance of limiting resource

Gurney & Lawton (1996)

Population dynamics in organism-modified environments

Total stock (*T*) of habitats is composed of usable habitat (*H*), degraded habitat (*D*), and virgin habitat (*V*)

$T=D+H+V$



Population dynamics in organism-modified environments

Cooperative engineering

$$\frac{dE}{dt} = rE\left(1 - E/H\right)$$

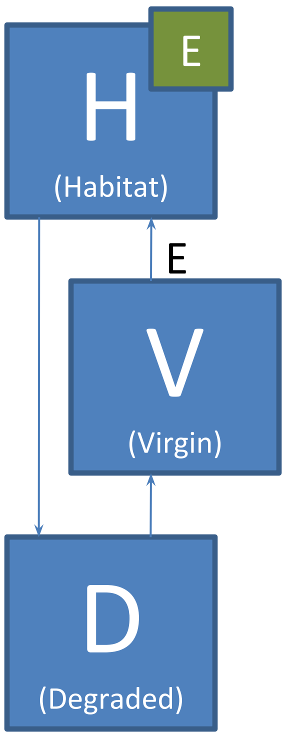
Degradation through use

$$\frac{dH}{dt} = \left(\alpha + \beta E\right)V - \delta H$$

$$\frac{dV}{dt} = \rho\left(T - V - H\right) - \left(\alpha + \beta E\right)V$$

Recovery to virgin state

Conversion through engineering



Equilibria

A single engineer can replenish habitat faster than it degrades

- If $\alpha T > \delta$ then there are two equilibria

Unstable $E^* = 0$ "ZE" state (zero engineer)

Stable or unstable
$$E^* = \frac{T}{2}\left[\frac{1}{1+\delta/p} - \frac{\alpha}{\beta T}\right] + \sqrt{\left(\frac{1}{1+\delta/p} + \frac{\alpha}{\beta t} - \frac{4\delta}{\beta(1+\delta/p)T^2}\right)}$$

Upper "FE" state (finite engineer)

- If $\alpha T < \delta < \frac{\beta T^2(1+\delta/\rho)}{4}\left(\frac{1}{1+\delta/\rho} + \frac{\alpha}{\beta T}\right)^2$ then three equilibria

Stable $E^* = 0$

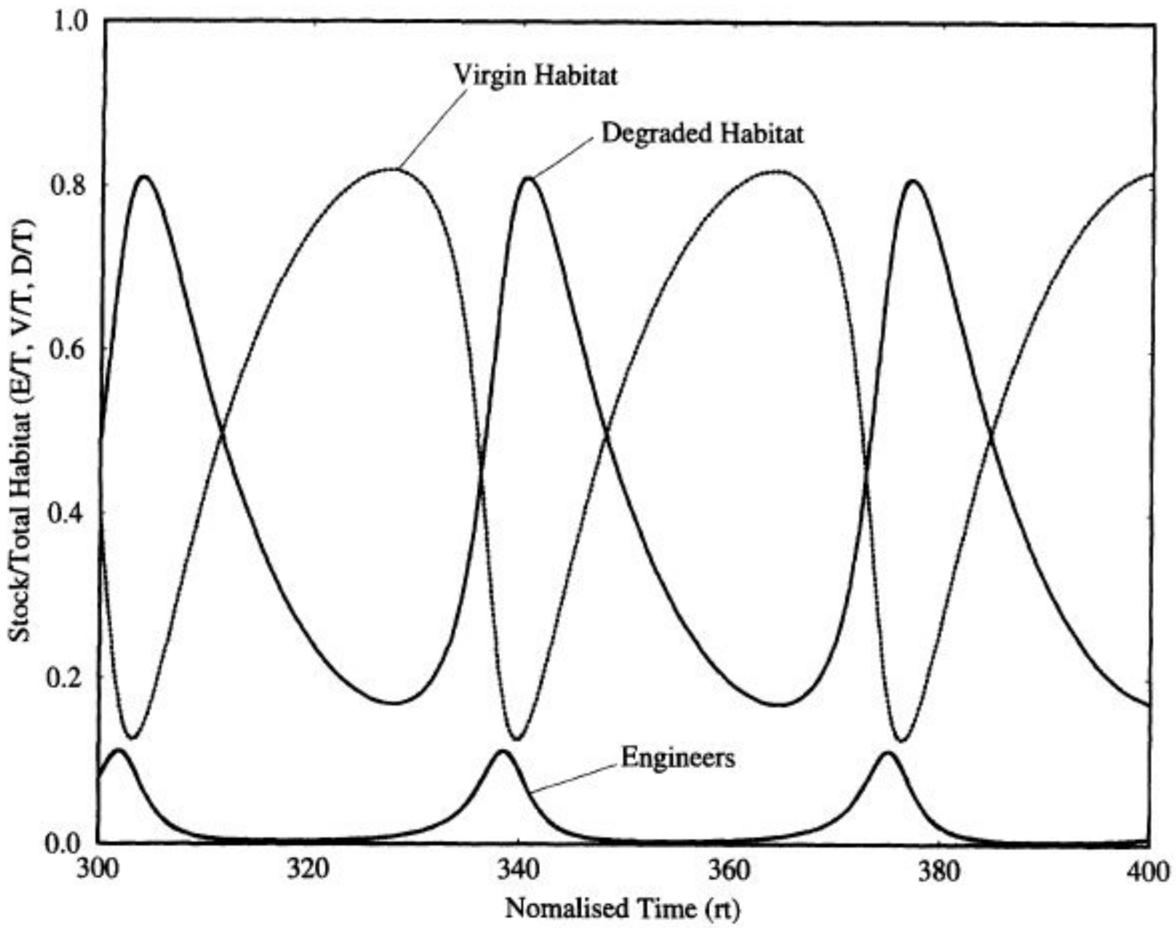
Unstable
$$E^* = \frac{T}{2}\left[\frac{1}{1+\delta/p} - \frac{\alpha}{\beta T}\right] - \sqrt{\left(\frac{1}{1+\delta/p} + \frac{\alpha}{\beta t} - \frac{4\delta}{\beta(1+\delta/p)T^2}\right)}$$

Lower "FE" state

Stable or unstable
$$E^* = \frac{T}{2}\left[\frac{1}{1+\delta/p} - \frac{\alpha}{\beta T}\right] + \sqrt{\left(\frac{1}{1+\delta/p} + \frac{\alpha}{\beta t} - \frac{4\delta}{\beta(1+\delta/p)T^2}\right)}$$

An Allee effect

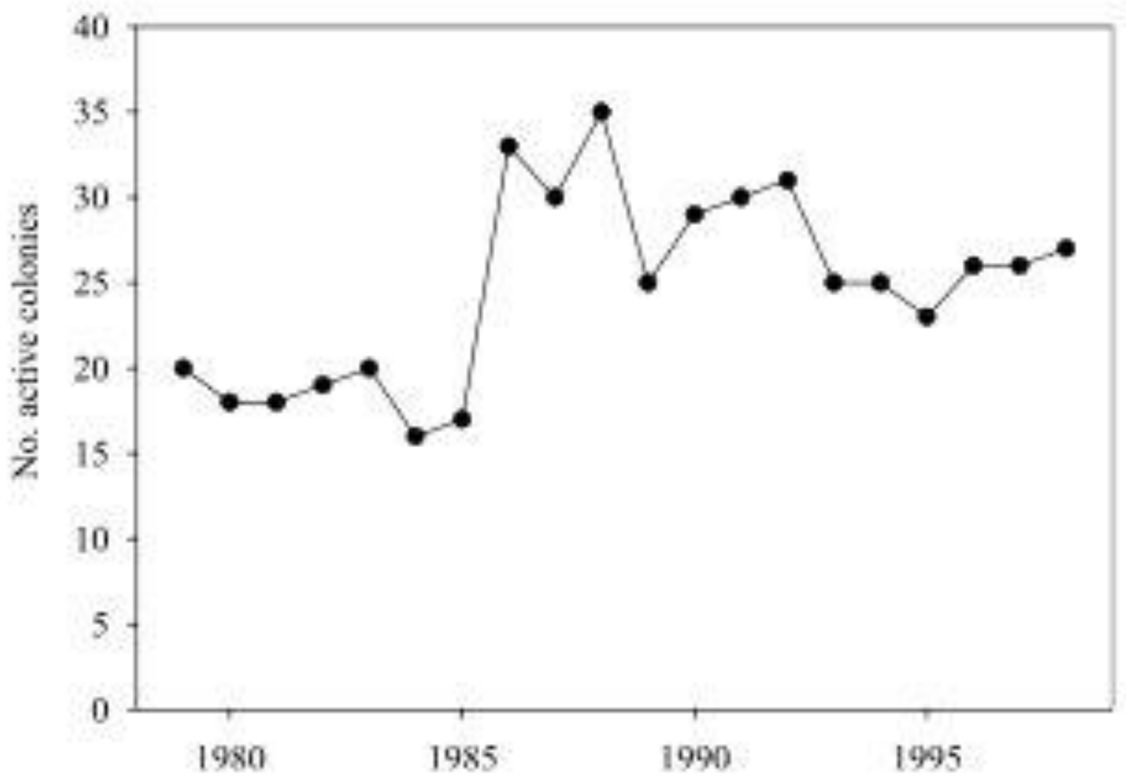
Unstable upper FE state



Unstable if: (1) β too small (little cooperation), (2) δ large (degradation too fast), or (3) ρ to small (environmental recovery slow)

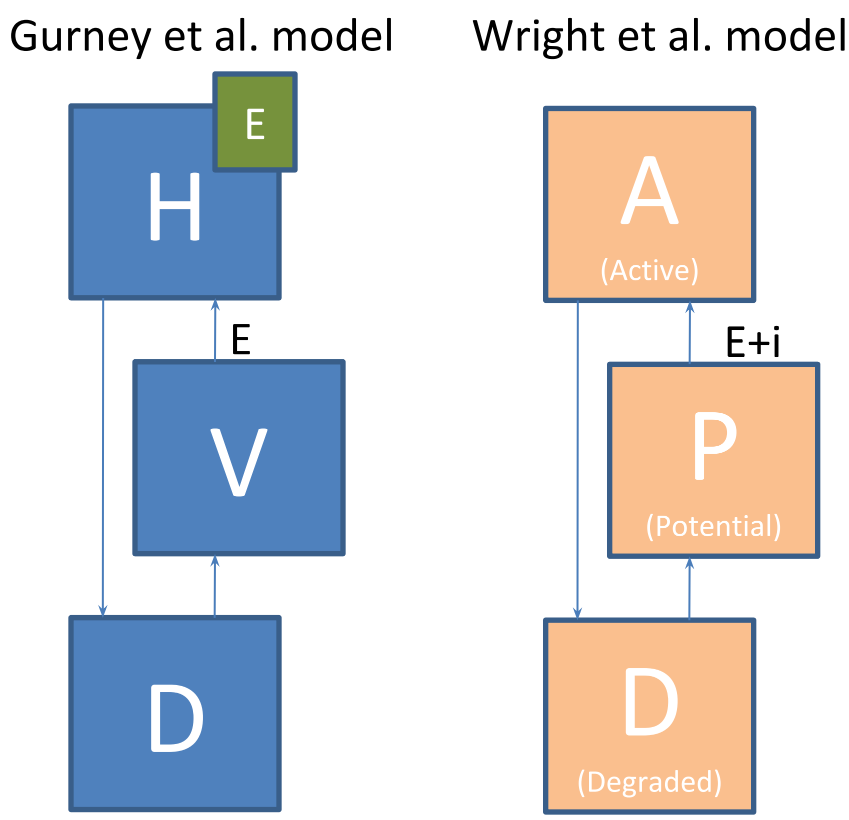
Population dynamics

Active beaver colonies in Huntington Wildlife Forest



"The only mammal known not to have a cycle is the beaver" (Christian 1950)

Population dynamics in organism-modified environments (Wright model)



<u>Two key differences</u>

(1) Organism abundance doesn't just depend on habitats, but is equivalent to it

(2) Habitat construction can be by "local colonists" from within the system and immigrants who arrive from outside (a landscape effect)

Wright et al. (2004)

Steady state solution

$$\left(n\left[1+\delta/\rho\right]\right)A^{*2}+\left(i\left[1+\delta/\rho\right]+\delta-n\right)A^{*}=0$$

n – per patch production rate of colonists
δ – decay rate of patches from active to degraded (A→D); inverse of occupancy duration
ρ – recovery rate from degraded to potential (D→P); inverse of duration degraded
i – immigration rate

Steady state fraction of sites occupied (A*)

- Decreases with δ (the faster a site degrades the fewer active sites there will be at equilibrium)
- Increases with ρ (the faster a site becomes habitable again the more active sites there will be at equilibrium)
- Increases with *n* (the more productive the existing sites are at producing new colonists the more active sites there will be at eq'm)

Steady state fraction of sites occupied (A*) typically less than 50%

Change of model results in a single finite steady state, at which a large fraction of sites may be unoccupied (like metapopulation dynamics)

Effects of ecosystem engineering on populations: Conclusions

- Can give rise to intrinsic cycling without interacting with another species
- Can give rise to a lower unstable equilibrium (an Allee effect)
- Can give rise to a substantial fraction of available habitat occupied at any one time

Summary

- *Ecosystem engineering* is the physical or chemical modification of habitats by organisms
- Ecosystem engineering can result in
  - Population cycles
  - Allee effects
  - Vacant habitats