Overview of Lecture: Ecology: Biosphere & Populations

Read: Text ch 52 & 53

Bullet Points:
- population ecology
- limiting factors
- spatial patterns
- dynamic demographics
- geometric pop growth
- looking back
- exponential growth
- logistic growth
- maximum sustainable yield
- deterministic chaos
- the human footprint
**Organisms** live in populations 
{& kin groups & social groups}  

**a Population**

and social (ex: mating) behavior.

Not as tightly integrated as an organism, but more tightly integrated than a community of populations.

Characteristics of a pop's ecology include

1. **range**, 2. **spacing**, & 3. **size**, all may vary over **time** & across age, sex, **demographics**
We begin with the current distribution map for each tree species, to characterize and define the occupied (or occupiable) volume of environmental space by statistically cataloging all combinations of env conditions which are habitable by this species.

To predict a new distribution for the species under altered environmental conditions, we re-cluster using all cells from a map... the altered spatial distribution now habitable by this species under the new env conditions will be shown... 

{assuming what about time, luck & adaptation?}

**II. Time, luck & adaptation:** pop ranges are changing over time, w/ luck & adaptation

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**Most species have relatively limited geographic ranges** - limited by what?

- each species & pop is adapted to a limited range of incl. temp, humidity, mineral nutrients etc **{fundamental niche}**
- incl. prey, competitors, predators, parasites etc **{realized niche}**

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**Oak Ridge National Laboratory (ORNL) Environmental Sciences Division (ESD)**

**... Predicting Changes in a Species Distribution Map**

**Following Changes in Environmental Conditions {ex global warming}**


G.E. Hutchinson (1957,1965) suggested that an organism's **niche** could be visualized as a multidimensional hypervolume comprised of all combinations of the env. conditions which permit an individual of that species to survive and reproduce indefinitely.

... **fundamental niche:**

... **realized niche:**

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... the altered spatial distribution now habitable by this species under the new env conditions will be shown...

{assuming what about time, luck & adaptation?}
Demographic **processes** (ex: **Birth, Immigration, Death, Emigration**) (text Fig 52.2) within Populations create **patterns** of **Distribution** and **Abundance** (text Fig 52.3)

Begin w/ a **null model** - the distribution is ‘random’ (Fig 53.4c)
If we know abundance & area (& a little probability theory)
   we can construct expected random distribution of
   a) nearest neighbor distances, or
   b) number indiv’s in small sample quadrats
   (like expected chocolate chips per cookie if Poisson)
Random distributions rarely persist in nature – ecological interactions.
Nonrandom spatial distribution **patterns** suggest causal **processes**.

If there are too many the variance in # indiv’s per quadrat is too high, then reject the null model that the distribution is random.
The distribution pattern is **Clumped.** (Fig 53.4a)
Potential **processes** include
and/or

If there is too little variation
   or in # indiv’s per quadrat, then reject the null model.
The distribution pattern is **Uniform**
(or hyperdispersed) (Fig 53.4b)
Potential **processes** include

{consider seating pattern in a bar: might be some clumping & some hyperdispersal}
In general, if you look at a big enough scale, species tend to be clumped but if you look at a small enough scale they tend to be hyperdispersed.

At continental scale, breeding birds are clumped in regions, biomes, habitats (grasslands, pastures). Within habitats, aggregate at profitable patches (heavily grazed). Within patches, territories are hyperdispersed over microhabitats. Within territories, behaviors aggregate over microhabitats.

Most organism spatial distribution patterns are ‘scale sensitive’ 
{fractal patterns ("chaos in space" – later) are scale insensitive}
One of the most fundamental patterns in a population is **Abundance through Time**.

Population growth or decline depends on demographic processes of

These demographic processes depend on **ecological interactions**, like *resource competition, predation, disease* etc, and on details of **population structure**, like *proportion of mature females* and **life history characteristics**, like *age at 1st repro, offspring per ‘clutch’* etc., that we will consider later.

We use **population growth models** to:

Begin w/ simple binary fission in bacteria.
Begin with geometric growth:

Suppose we start with 1 bacteria at time $t = 0$: $N_0 = 1$, and at each unit of time the bacteria undergo binary fission and the number of bacteria doubles.

Then

- $N_0 = 1$
- $2N_0 = N_1 = 2$
- $2N_1 = N_2 = 4$
- $2N_2 = N_3 = 8$

... $2N_{t-1} = N_t = \ldots$

The geometric growth rate per unit time is $\lambda = \left( \frac{N_t}{N_{t-1}} \right)$.

For bacteria in lab, $\lambda \sim 2$ per 20 min. = $\lambda_{20\text{min}}$

Can you figure out $\lambda$ per hour? $\lambda_{\text{hr}} = \ldots$

Can you figure out $\lambda$ per day? $\lambda_{\text{day}} = \ldots$

"The mathematics of uncontrolled growth are frightening. ... in a single day, one cell of E. coli could produce a super-colony equal in size and weight to the entire planet Earth."

{obviously something is missing from this simple model of geometric growth}
March 15 - HOW POPULATIONS CAN GROW

Populations can grow very rapidly. … if a simple geometric growth rate is assumed (which was the assumption made by Charles Darwin in relation to his imagined “struggle for existence” in nature), it would only take about 1100 years—assuming 35 years per generation—to develop that present world population of six billion people. … All of which indicates that the evolutionary scenario, which assumes that human populations have been on the earth for about a million years, is absurd.

The whole universe could not hold all the people!

What is wrong with this story?

Did Darwin assume unlimited geometric growth with constant λ?

From reading Malthus (Text ch 22) Darwin concluded that geometric pop growth results in a relentless “struggle for existence” as demand for resources exceeds the supply.

What is missing from the geometric growth model?
A compartmental model w/ fluxes and standing stocks (or pools)

If we have things in a compartment (ex: indiv’s in a pop; molecules in a lake, etc) and a conservation property, then:  \( N_t = \) 

\[ \text{IN} = \text{births} + \text{immigration (ignore for now)} \]

\[ \text{OUT} = \text{deaths} + \text{emigration (ignore for now)} \]

\[ \Delta N/\Delta t = N_t - N_{t-1} = \text{IN} - \text{OUT} = \text{Births} - \text{Deaths} \quad \text{(assuming no migration)} \]

Now, we are interested in processes and these are easier to see if we convert absolute number of Bs & Ds, into the per capita (per individual) rates \( b \& d \): \( B = b \cdot N \) & \( D = d \cdot N \), then

\[ \Delta N/\Delta t = N_t - N_{t-1} = \text{Births} - \text{Deaths} = \]

Let \( \Delta t \) get small & let \( (b - d) = r = \text{instantaneous per capita population growth rate}. \)

Then we have the differential form \( dN/dt = \)
We have derived \( \frac{dN}{dt} = rN \),

where \( r \) = instantaneous per capita population growth rate.

(it’s also the compound interest rate)

Notice that the rate of change in \( N \) is proportional to \( N \);
the bigger \( N \) is the faster it increases; this is + feedback → \( N \) ‘explodes’!

We can rearrange this to the form \( \frac{dN}{N} = r \) \( dt \), then integrate both sides to find:

\[
N_t = N_0 e^{rt}
\]

(Conveniently, \( e^r = \lambda \), the geometric growth rate)

We can rearrange \( N_t = N_0 e^{rt} \) to isolate \( t = \ln(N_t/N_0)/r \)
and then see that the pop doubles every \( t_d = \ln(2)/r = 0.69/r \) units of time.

The human pop doubled between 1930-1975 (45 yrs).
What was ave \( r \)? \( 45 = 0.69/r \) → \( r = 0.69/45 = 0.0153 = 1.53\% \) per yr

The human \( r \) is not constant (Fig 53.23), declines w/ “demographic transition” (Fig 53.24)
Many pop’s will start a pattern of **exponential growth**, but at some point, birth rates must decline &/or death rates increase, resulting in a decline of the rate of increase $r$ with increasing density.

Recall that $r = b - d$; the decline in $r$ w/ increasing density results from **decreasing $b$** &/or **increasing $d$** (decreasing survival).

**Density dependent population regulation** = - $FB$: $\uparrow N \rightarrow \downarrow r$

via

&/or,
To make our exponential growth model more realistic, we need to make the rate of increase $r = b - d$ decline as the pop size $N$ approaches the carrying capacity $K$; Want $r = r_{\text{max}}$ at $N$ near 0 {ex: no competition} & $r = 0$ as $N$ approaches $K$ {ex: lots of competition}.

A simple way to model that is to let $r = \frac{b - d}{K - N}$.

The logistic growth model:
$$\frac{dN}{dt} = rN = \frac{b - d}{K - N}$$

{note that $dN/dt$ is the slope of $N$ vs $t$; this is a ‘dynamical equation’ describing how a system changes over time}

Notice that this regulates $N$ by negative feedback, $\frac{dN}{dt} \propto (K-N) = \text{‘error signal’}$ the set point is $K$; when $N<K$, $r>0$; when $N>K$, $r<0$; the pop $N$ should approach or cycle around $K$, but the dynamics can get chaotic!
The logistic growth model: \( \frac{dN}{dt} = rN = r_{\text{max}} (1 - N/K) \) \[N\]

If you want to find the pop size \( N^* \) where \( \frac{dN}{dt} \) is at maximum (growing fastest), take the derivative of \( \frac{dN}{dt} \) with respect to \( N \), set it equal to 0 & solve for \( N^* \)

\[
0 = r_{\text{max}} (1 - N/K) [1] + r_{\text{max}} (-1/K) [N] \\
0 = 1 - N/K - N/K = 1 - 2N/K \\
N^* = \frac{K}{2}
\]

The population reproduces fastest
below that, too few females to max rate;
above that, too much intraspecific competition

This is the foundation for the concept of \textbf{Maximum Sustainable Yield} (MSY) in wildlife management (in practice, more sophisticated, age structured models used)
We’d like to see a map of \( N(t) \),
to visualize the population dynamics predicted by the logistic model.
Unfortunately, it is ‘difficult’ to solve the equation
\[
\frac{dN}{dt} = \left[ r_{\text{max}} \left( 1 - \frac{N}{K} \right) \right] N
\]
for \( N(t) = \) an explicit function \( f(K, r_{\text{max}}, N_0, t) \).

So, let’s go back to a discrete approximation:
\[
N_t = \left[ \mu \left( 1 - \frac{N_{t-1}}{K} \right) \right] N_{t-1},
\]
where \( \mu \) corresponds to the instantaneous rate \( r_{\text{max}} \)
integrated over the discrete interval \( t \).

Simplify further by dividing both sides by \( K \), so that \( x_i = \frac{N_i}{K} = \) pop size relative to \( K \).

Now we have a discrete logistic model:
\[
x_t = \left[ \mu \left( 1 - x_{t-1} \right) \right] x_{t-1},
\]
that we can explore w/ a spreadsheet.

\[\text{at small } \mu (2.0), \text{ nice logistic growth}\]
\{a simplifying quirk: approaches } K/2\}

\[\text{However, as } \mu \text{ gets larger (4.8), strange things begin to appear; all chaos breaks loose!}\]
µ = 2.0: asymptote to 1 stable pt

µ = 2.8: damped oscillations

µ = 3.2: stable limit cycle w/ 2 pts

µ = 3.5: stable limit cycles w/ 4 pts

µ = 4.8: ‘chaotic meandering’
What is Chaos?
… in the 1960's, a meteorologist named Edward Lorenz … was attempting to simulate weather patterns in a mathematical model. These patterns did not follow any "predictable" evolution as the simulation progressed, he eventually realized that his model was extremely sensitive to his starting conditions; & slight variations in numerical precision …

The model Lorenz had created exhibited a property of nonlinear systems sensitive dependence on initial conditions \'{the butterfly effect}' … the hallmark of what has now become known as DETERMINISTIC CHAOS, a phenomenon that has been recognized within a variety of physical systems such as plasmas, fluid dynamics, and biological processes.

The big picture: simple deterministic processes can generate very complex patterns; so complex that they look ‘random.’ it can be difficult to infer the generating process from the very complex resulting pattern.

Gleick's "Chaos" will change the way you look at the world. This is as much a testament to Gleick's powerful prose as it is to the profound implications of chaos theory
Most multicellular organisms grow for a while, then they reproduce, if they survive, if they are female.

We can usually make much better predictions and management decisions if we develop **age (or stage) structured demographic models**, based on the number of females at each age $x$, the probability of surviving to age $x = l_x$, and the average reproduction if she does survive to $x = b_x$.

People all around Lake Michigan are asking questions about the nine-year decline in yellow perch populations. (1990s)

... few young perch are surviving to adulthood.

... the average age of the population is increasing quickly.

... the percentage of females in the population has declined swiftly during the 1990s. In 1998, females ... constituted only 20 percent of the perch population.

... new females are not replacing the old ones lost to fishing and natural mortality. With few females available to spawn, the yellow perch population could collapse.

The Lake Mi perch pop has small proportion of females and too few young age classes to replace older age classes as they die off.

{fishing restrictions $→$ recent recovery of perch pop}
A big challenge in conservation biology is to try to predict Minimum Viable Pop size for declining species.

In logistic model pop growth $r$ is max as $n \to 0$; realistic?

Small pack size imposes a trade-off between hunting and pup-guarding in the painted hunting dog Lycaon pictus.


The painted hunting dog or African wild dog, Lycaon pictus, is one of the most endangered large carnivores in Africa.

It has been hypothesized that because of their need for helpers, group size is of major importance and could create an Allee effect, where reproductive rate $r$ declines at small $n$; creating a Minimum Viable Population size; see ch 56.

We present a simple model showing how pup-guarding imposes a cost because it implies that less food per hunt is brought back to more individuals at the den. We complete these analyses with empirical tests of the effect of pack size on the probability of pup-guarding, from field data from Zimbabwe.

Our model, as well as our 5 years of empirical data, suggest a critical threshold at about 5 individuals.
Population boom threatens wildlife

Sheer numbers of people is the dominant threat to biodiversity, a controversial new model suggests.

Forecasting global biodiversity threats associated with human population growth.

Conservation offers hope for biodiversity decline

Though almost 20% of vertebrate species are in danger of extinction, conservation efforts are having an impact, a study calculates.

Joseph Milton

A fifth of vertebrate species are at risk of extinction, but biodiversity decline would have been considerably worse without conservation efforts, an analysis published today suggests.

The study, published in Science, which summarizes the status of more than 25,000 mammals, birds and amphibians, was released to coincide with the UN Convention on Biological Diversity meeting in Nagoya, Japan, where delegates this week are expected to set targets to halt loss of the world’s biodiversity by 2020 (see ‘Biodiversity hope faces extinction’).

“We've failed in meeting the 2010 targets [to cut species loss 'significantly' by this year],” says Michael Hoffmann of the International Union for the Conservation of Nature (IUCN) in

'Optimists' argue that technology & increased yields have outpaced population growth and will continue to do so. 'Pessimists' (we prefer the term 'ecological realists') see practical limits to global carrying capacity in agriculture, and maintain that the world is close to these limits.

We investigate the yield growth for major cereal crops, and present evidence that the growth pattern is logistic \{yield is leveling off, approaching a max\}, not exponential \{growth rate would be constant\}. This pattern is consistent with ecological limits on soil fertility, water availability & nutrient uptake. Projections based on a logistic rather than an exponential model of yield growth imply that the world is indeed close to carrying capacity in agriculture.

A supply-side strategy of increased production has already led to serious problems of soil degradation and water overdraft, as well as other ecosystem stresses. Demand-side issues of population policy & efficiency in consumption are crucial to the development of a sustainable agricultural system.
Global patterns in human consumption of net primary production
MARC L. et al. Nature 429, 870 - 873 (24 June 2004);

Net primary production NPP

the net solar energy converted to plant organic matter through photosynthesis
represents the primary food energy source for the world's ecosystems.

A compelling measure of humanity's impact on Earth's ecosystems
is the fraction of NPP that we appropriate for our own use.

We present a global map of
the amount of NPP
acquired by humans …
& derive a spatial balance sheet
of 'supply' & 'demand' for the world.
Globally humans appropriate
~20% of terrestrial NPP

… varies spatially from almost zero
to many times the local NPP.
…reveal the uneven footprint
of human consumption and
related environmental impacts,
indicate the degree to which
human populations depend on
net primary production 'imports'
Humans are not exempt from natural processes. **No population, including the human population, can grow indefinitely.**

Attempts to estimate earth’s K for humans dissolve into questions about ‘quality of life.’

http://www.popexpo.net/eMain.html

World POPClock

‘What will life be like when we reach K?’
‘How will we cope with the aggression triggered by resource competition related to variation in the quality of life?’

Disease dynamics?

Env degradation and declining K?