**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
- quality of life at K

**Organismal Ecology**
Organismal ecology, which includes the subdisciplines of physiological, evolutionary, and behavioral ecology, is concerned with how an organism’s structure, physiology, and (for animals) behavior meet the challenges posed by its environment.

- How do hammerhead sharks select a mate?

**Population Ecology**
A population is a group of individuals of the same species living in an area. Population ecology analyzes factors that affect population size and how and why it changes through time.

- What environmental factors affect the reproductive rate of deer mice?

**Community Ecology**
A community is a group of populations of different species in an area. Community ecology examines how interactions between species, such as predation and competition, affect community structure and organization.

- What factors influence the diversity of species that make up a forest?

**Ecosystem Ecology**
Ecosystem ecology emphasizes energy flow and chemical cycling between organisms and the environment.

- What factors control photosynthetic productivity in a temperate grassland ecosystem?

**Landscape Ecology**
A landscape (or seascapes) is a mosaic of connected ecosystems. Research in landscape ecology focuses on the factors controlling exchanges of energy, materials, and organisms across multiple ecosystems.

- To what extent do the trees lining a river serve as corridors of dispersal for animals?

**Global Ecology**
The biosphere is the global ecosystem—the sum of all the planet’s ecosystems and landscapes. Global ecology examines how the regional exchange of energy and materials influences the functioning and distribution of organisms across the biosphere.

- How does ocean circulation affect the global distribution of crustaceans?
If all the people in the world lay head to toe, how long of a line would they make?

Lauryn Canna, Scarsdale, N.Y.

Marilyn responds:

Here’s an estimate: The global population is about 7 billion. If we assumed an average height of 5 feet (the group includes children and infants), we’d have about 35 billion feet of head-to-toe people. The Earth is about 24,900 miles around. Multiply that figure by 5,280 feet to arrive at a circumference of 131,472,000 feet. If you then divide the 35 billion feet of people by the distance around the planet, you’ll find that if everyone lay head to toe, the line of people would circle the globe more than 266 times!

* In the following slides, keep track of the year and the human population estimate.
How Many People Can the Earth Sustain?
*Bryan of Bethlehem, Pennsylvania, writes:*

So here's a question: If we presume that there are ultimately physical and biological constraints on growth, and that even in a near-perfect world where technology maximizes resources to the limits of those constraints, what is the maximum human population that the world can reasonably be expected to sustain for the next 10,000 years?

*Marilyn responds:*

Let's say that "sustain" means a good quality of life and that we value a wide-open environment and nature, with a great diversity of animal and plant life. Then maybe ten billion, depending on how people behave. If they behave foolishly, then maybe five billion. And yes, that means fewer people than we have now.
**Organisms** live in **populations** {& *kin groups & social groups*}

**a Population**

is a group of individuals in the same species living in the same general area interacting w/ each other through common resources &/or predators, parasites etc 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**.
Most species have relatively limited geographic ranges - limited by what?

I. Environmental conditions: each species & pop is adapted to a limited range of
    abiotic conditions incl. temp, humidity, mineral nutrients etc {fundamental niche}
    & biotic interactions, incl. prey, competitors, predators, parasites etc {realized niche}

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

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: the inhabitable hypervolume w/o competition, predation, & parasitism,
... realized niche: a smaller hypervolume occupied when the species is under biotic constraints.

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?}
Climate change prompts debate among experts about spread of tropical diseases.

By Arthur Allen Monday, January 10, 2011

The idea that climate change will bring malaria and other tropical killers to our door turns out to be an extremely controversial one among ecologists, climatologists and biologists … "It's a very complicated story,”…

The malaria map accompanied a 2000 article, … It helped influence a research agenda that last year resulted in more than 4,000 studies of climate change and disease.

Biological first principles suggest that warmer weather, by causing organisms to grow faster, will expand the range of disease-carrying insects and microbial pathogens. And some models published in the medical and scientific literature suggest that tropical illnesses such as Chagas, which spreads in Latin America through the feces of a beetle, and leishmaniasis, carried by sandflies, could soon find niches in the United States.
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 short nearest neighbor distances, or 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 aggregation at patchy resources and/or social attraction to each other

If there is too little variation in nearest neighbor distances, or in # indiv’s per quadrat, then reject the null model.
The distribution pattern is Uniform (or hyperdispersed) (Fig 53.4b)
Potential processes include resource competition and aggression.
{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.

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 **Birth, Immigration, Death & Emigration (BIDE)**

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 **describe past** patterns and to **predict future** patterns.

Begin w/ simple binary fission in bacteria.
Begin with **geometric growth**: Suppose we start w/ 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

\[
N_0 = 1 \\
2 \cdot N_0 = N_1 = 2 = 2^1 \\
2 \cdot N_1 = N_2 = 4 = 2^2 \\
2 \cdot N_2 = N_3 = 8 = 2^3 \\
\cdots \ 2 \cdot N_{t-1} = N_t = N_0 \cdot 2^t 
\]

The **geometric growth rate** per unit time is \( \lambda = (N_t / N_{t-1}) \).

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

Can you figure out \( \lambda \) per hour? \( \lambda_{\text{hr}} = 2^{(60/20)} = 2^3 = 8 \) per hr

Can you figure out \( \lambda \) per day? \( \lambda_{\text{day}} = 2^{(3 \cdot 24)} = 2^{72} = ? \)

"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 {was it?}) 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 $\lambda$?

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: \( N_t = N_{t-1} + \text{IN} - \text{OUT} \).

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

\[ \Delta N/\Delta t = N_t - N_{t-1} = \text{Births} - \text{Deaths} = b \cdot N - d \cdot N = (b - d) N \]

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

Then we have the differential form \( dN/dt = (b - d) N = rN \).
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 \( \rightarrow \) \( N \) ‘explodes’!

We can rearrange this to the form \( \frac{dN}{N} = r \, dt \), then integrate both sides to find:
\[
N_t = N_0 \, e^{rt}, \text{ the exponential growth model}
\]
(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 \( r \)? \( 45 = 0.69/r \) \( \rightarrow \) \( r = 0.69/45 = 0.0153 = 1.53\% \) 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 it is unsustainable; 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: $↑N \rightarrow \downarrow r$ via limiting resources (see Malthus ch 22) &/or, increased aggression, predation, disease …
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 $r = r_{\text{max}} (1 - N/K)$

The logistic growth model:
$$\frac{dN}{dt} = rN = [r_{\text{max}} (1 - N/K)] N$$
$$= [r_{\text{max}} ((K - N)/K)] N$$

{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**: $dN/dt \propto (K-N)$ = ‘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 \( N^* \)

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

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

This is the foundation for the concept of **Maximum Sustainable Yield** (MSY) in wildlife management (in practice, more sophisticated, age structured models used)
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 logistic model}.

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.

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 (pup guards) group size is of major importance and could create an Allee effect, (repro 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. (at n<5 can’t both hunt efficiently & guard pups)

A big challenge in conservation biology is to try to predict Minimum Viable Pop size for declining species before they drop below the MVP.
The Ecological Benchmark: How Much Nature is there per Global Citizen?

Adding up the biologically productive land per capita world-wide of 0.25 hectares of arable land, 0.6 hectares of pasture, 0.6 hectares of forest and 0.03 hectares of built-up land shows that there exist 1.5 hectares per global citizen; \(1 \text{ ha} = 2.47 \text{ acres}\)

Not all that space is available to human use as this area should also give room to the 30 million fellow species with whom humanity shares this planet.

… at least 12 percent of the ecological capacity … should be preserved for biodiversity protection.

Population boom threatens wildlife 25 July 2003 TOM CLARKE

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


'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'
Civil conflicts are associated with the global climate

Solomon M. Hsiang†, Kyle C. Meng† & Mark A. Cane‡

During an El Nino (Southern Oscillation) event, the tropics (red areas on map) become warmer and dryer. Mid-latitudes (blue) are less affected.

There is a correlation between risk of conflict and an index of temperature over El Nino cycles – the probability of new civil conflicts breaking out in El Niño years is double that seen in cooler La Niña years – in red areas of map.

- Do people start war simply because they are hot?
- What other proximate hypothesis might explain this pattern?
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?
How Many People Can the Earth Sustain?

Bryan of Bethlehem, Pennsylvania, writes:

So here's a question: If we presume that there are ultimately physical and biological constraints on growth, and that even in a near-perfect world where technology maximizes resources to the limits of those constraints, what is the maximum human population that the world can reasonably be expected to sustain for the next 10,000 years?

Marilyn responds:

Let's say that "sustain" means a good quality of life and that we value a wide-open environment and nature, with a great diversity of animal and plant life. Then maybe ten billion, depending on how people behave. If they behave foolishly, then maybe five billion. And yes, that means fewer people than we have now.