Lecture 1

An Introduction to Population Biology and Modeling

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Outline

1. General course info
2. Introduction to population biology
    - Population ecology
    - Modeling
3. Course outline

Course Info

- Population ecology, October 2012 - January 2013.
- Language:
  - Slides in English.
  - Lecture and exam in Hebrew.
- Dr. Ido Filin, ifilin@univ.haifa.ac.il
- Office hours: Thursday 14:15-16:00,

  Room 241, Multipurpose build.
- Time: Mondays, 08:15-10:00.
- Place: Computer room, Rabin 7036.
- Exam: Open book, in front of computer.
- מועד א': 31 ינואר. מועד ב': 05 מרץ.

Course Info

- Population ecology, October 2012 - January 2013.
- חובת הגשת תרגילים: 7 תרגילים, אחד כל שבועיים.
- הגשה עד תאריך שבדף התרגיל.
- ציון סופי: 30% תרגילים, 70% בחינה.
- All of the course material will be available on the Highlearn system.
- **Reading:** selected pages from the literature listed in the syllabus, and possibly from other sources.
  Available through HighLearn.

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Prologue: Population within the scales of biology

Intracellular processes

Cell biology, Molecular biology

Intraorganismal processes

Physiology, Developmental biology

Whole organism

Animal behavior

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Ecology ← → **Evolution**

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Population genetics

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Ecology ⟵ ⟶ **Evolution**

Population genetics

Species

Microevolution, Speciation theory

Higher taxa

Macroevolution – Paleontology, Taxonomy and Systematics

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Population ecology
Community
Community ecology
Ecosystem
Macroecology, (Eco)system ecology

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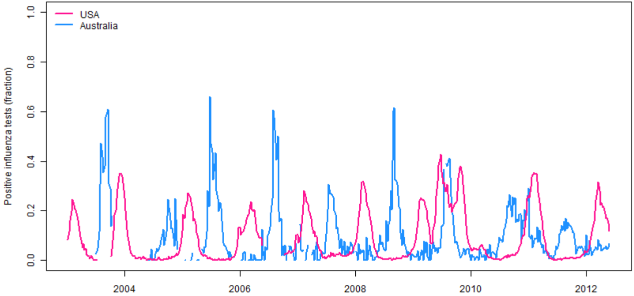
Why population ecology?

- Basic science → natural populations exhibit general patterns – research of natural phenomena.
- Conceptual basis for community ecology.
- Analytical tools to compare performance of different organisms, different populations, same organism under different environmental circumstances, etc.
- For example:
  - Controlling growth of microorganisms used in food industry – by varying temperature, pH, etc.
  - Controlling populations of agricultural pests – dose and timing of pesticide application.

Why population ecology?

- Economic applications
  - Sustainable harvesting – avoiding overexploitation of natural resources; overfishing, overhunting, etc.
  - Human demography – workforce vs. dependents, population aging, infrastructure planning (schools, hospitals, roads, etc.).
- Public health – understanding and controlling outbreaks of disease; vaccination policies.



Why population ecology?

- Nature conservation – endangered species:
  - Evaluating success – do conservation measures work?
  - Measuring and predicting population recovery or extinction risk.
  - Minimum viable population size.
  - Metapopulations.
- Population ecology provides the conceptual basis for studying evolution by natural selection.

Modeling in the natural sciences

This course is about mathematical modeling of natural populations.

> *The **sciences** do not try to explain, they hardly even try to interpret, they mainly **make models**. By a model is meant a **mathematical construct** which, with the addition of certain verbal interpretations **describes observed phenomena**. The justification of such a mathematical construct is solely and precisely that it is **expected to work**.*
>
> *John von Neumann*

> *Essentially, all models are **wrong**, but some are **useful**.*
>
> *George Box*

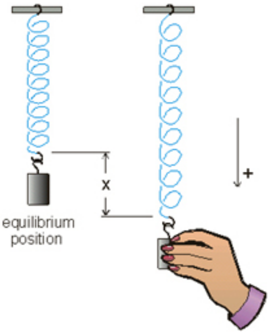
Modeling in the natural sciences

- Example: Classical Newtonian mechanics is **wrong**.
- It is only an **approximate** description of nature – there is always an error, unexplained phenomenon, or deviation from model-based prediction.
- Newtonian mechanics is not a very good description of nature for very high speeds, very large masses, or at the atomic or molecular scale.
- However, Newtonian mechanics is still **useful** for everyday life: building bridges, designing cars, launching satellites or playing "angry birds".
- As science progresses, we develop better approximations – in this case, relativity and quantum mechanics.
- But those are still only approximate descriptions – some difference remains between prediction and observation.

Modeling in the natural sciences

- Science deals with observed phenomena – nature, "reality"– not with truth (whatever truth is).
- Science tries to find general patterns in nature and to describe them – to bring together disparate observations under a unified conceptual framework.
- Sooner or later this process leads to a **mathematical model**.
- A mathematical construct that approximately describes (mimics) nature.
- A mathematical model is **useful** because:
  1. It is a **compact description** of a set of observed phenomena.
  2. Provides **quantitative** results that can be compared to observed values.
  3. Can **predict** future (not yet observed) occurrences of the natural phenomena it attempts to describe.

State variables: compact description of nature



Mass on a spring.

The state of the system is described by displacement from equilibrium point.

We denote it by x.
We measure x in units of length.
(mm, cm, inches, etc.)

The spring-mass system can be in
Extension state: $x > 0$.
Compression state: $x < 0$.
Equilibrium state: $x = 0$.

By comparing values of x we can compare different springs, or the state of the same spring in different times.
We can also look for rules in the way x changes over time
$\rightarrow$ predict the state of the system in the future.

State variables: compact description of nature

- A **state variable** is that element of the mathematical model that relates to a **property of the natural system** that we are interested in.
- Usually, it relates to a property that changes, or at least may change, over time.
- Examples:
  - x – displacement of the mass-spring system.
  - State of matter: solid, liquid, gas.
  - p – allele frequency in a population.
  - Percentage of infected people in a population.
- Can be continuous:
  - $x = 1$cm, -2.3mm, 10.9m.
  - $p = 0.5, 0.99, 0.01, 1, 0.$
- or discrete:
  - solid/liquid/gas.
  - extended/compressed/at equilibrium.

State variables: compact description of nature

In population ecology we have two basic state variables:

1. Population size, N.
   - The number of individuals in a population.
   - Discrete, $N = 0, 1, 2, 3, \ldots$.
2. Population density, n.
   - The number per unit area/volume.
   - Continuous, $n = 16.2\text{km}^{-2}$, 8673.3cm^{-3}, $\ldots$.

As populations grow or decline, population size/density changes over time.

Nature is complex: many state variables

Rarely does a single state variable fully captures the relevant properties of a natural system.

We usually require several. For example:

- A more complete description of the spring-mass system requires both displacement, x, and velocity, v.
- A thermodynamic system is described by volume, pressure and temperature.
- Allele frequencies of several alleles/loci/genes.

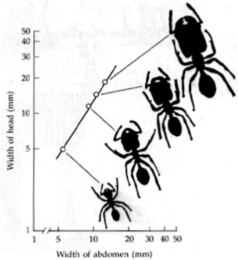
In population ecology:

- Population structure –
    - Age-structure – how many 1yo, 2yo . . . , 80yo . . .
    - Stage-structure – separate numbers for eggs, larvae, juveniles, adults.
- Species interactions – separate population sizes/densities for each species.

Laws of nature

Empirical laws – describe how several state variables change together, or covary.

- Usually derived from observations / data, using statistical analysis, or a good guess.
- Examples:
  - Kepler's third law: $T_1^2/T_2^2 = R_1^3/R_2^3$
  - Gas law: $PV = RT$.
  - Allometry: $(trait\ 1) = a(trait\ 2)^b$ ⟶
  - Other scaling laws.



- It is a static description – does not describe or predict how state variables change over time.
- Only allows to predict the coordinated change in several state variables, if one of them changes.
- Underlying mechanism, or process, is not always known.

Laws of nature

Conservation laws – quantities that remain constant (conserved), despite state changes of the natural system.

- Conservation of mass.
- Conservation of energy.
- Conservation of momentum.
- ...

However, there are very few such quantities.

Most quantities in nature change through time, and in particular, the state variables that describe a natural system.

Laws of nature

Dynamics laws – Provide description of how state variables change or expected to change over time.

Ability to predict future state, based on previous / current observations of the natural system.

They describe specific mechanisms and processes.

Therefore more fundamental and useful than empirical laws.

Often provide the underlying reasons for empirical laws:

- Newton's law of gravitation leads to Kepler's law.
- From kinetic theory of gases we get the gas law.
- Growth gradients lead to allometry.

Dynamics in discrete vs. continuous time

- We can measure time in **discrete steps**: day 0, day 1, day 2, . . . ; year 1999, year 2000, year 2001, . . .
- Assume we know N_t, the value of the state variable at time-step t.
- The value at the next time-step is obtained by a **recursion relation**: $N_{t+1} = \ldots$
- or by a **difference equation**: $\Delta N = \ldots$
- The recursion relation and difference equation are related of course, because $\Delta N = N_{t+1} - N_t$ and $N_{t+1} = N_t + \Delta N$.
- We can repeatedly use the recursion or difference equation to obtain also $N_{t+2}, N_{t+3}, N_{t+4} \ldots$
- And also go backward in time to derive past values: $N_{t-1}, N_{t-2}, \ldots$

Dynamics in discrete vs. continuous time

- We can also measure time along a **continuous scale**: 21.3 sec since beginning of experiment; 1.7 years since birth, . . .
- In such cases, a law of dynamics takes the form of a **differential equation**
- For example, Newton's second law of motion and law of gravitation.
- In mathematical form: $dN/dt = \ldots$
- It describes the time-derivative (= rate of change) of the state variable.
- By solving, we get the the time-trajectory $N(t)$.
- $N(t)$ = a function of time that provides the value of the state variable for every value of the time coordinate, t.

Dynamics in discrete vs. continuous time

A note about units.

- In discrete time we have a difference equation:
  (next value) - (current value) = ...
- in continuous time we have a differential equation:
  (rate of change) = ...
- In the former case, we measure change (difference) using the same units as the state variable.
- In the latter case, we measure change as a rate
  $\longrightarrow$ units of state over units of time.
- Example – the spring-mass system:
  - state variable is displacement, x,
    measured in meters (units of length).
  - Discrete time dynamics: $\Delta x = \ldots$; Δx also measured in meters.
  - Continuous time dynamics: $dx/dt = \ldots$; dx/dt measured in meters/sec (i.e., units of velocity).

Dynamics in discrete vs. continuous time

In population ecology:

- Discrete time dynamics: $\Delta N = \ldots$; has no units – a pure number.
- Continuous time dynamics: $dN/dt = \ldots$; measured in 1/sec (or, in general, 1/(unit of time)).
- If we use density, n, as a state variable, the units are then, for example, km^{-2} and km^{-2}sec^{-1}, respectively.
- The choice of a discrete time vs. continuous time description of a natural population depends on many factors:
  - Seasonal organisms or seasonal breeding vs. breeding year-round.
  - What are we interested in, as scientists – estimates or predictions of population size at specific times? or a continuous time-trajectory of population size?
  - Essentially, all models are wrong. But which description would be more **useful**?

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1. Introduction to population biology and modeling.
2. Mathematical modeling, computer simulation, statistical analysis and graphics, using R.
3. Basic models of population growth – BIDE and geometric/exponential growth – identical individuals, density-independence.
4. Discrete time vs. continuous time models.
5. Population regulation, density-dependence and intraspecific competition.

...

Course Outline

6. Variability among individuals within populations – size-, stage-, age-, state-structure.
7. Life tables and life history.
8. Comparison and fitting to empirical data – model inference and prediction.
9. Population fluctuations and population cycles.
10. Stochastic (random) effects in population dynamics; population extinction.
11. Community ecology: interspecific competition and predator-prey interaction.

Course Goals

1. Learn fundamental terminology and basic modeling approaches in population ecology.
2. Acquire knowledge about the many processes that influence dynamics of natural populations.
3. Gain basic skills in mathematical modeling, statistical analysis and graphics, using R.