I. Single Species Growth.
   A. In an unlimited environment,
      \[
      \frac{dN}{dt} = rN
      \]  
      \[N(t) = N_0 e^{rt}\]  
      
1. \(N\) is population size (density).
2. \(r\) is the \textit{per capita} rate of increase (birth – death rate).
3. \(r > 0 \Rightarrow\) unbounded growth.
4. \(r < 0 \Rightarrow\) collapse.

B. Equations (1) assume all individuals identical.

C. Regarding accompanying diagram:
   1. “Lag phase” due to biochemical “gearing-up.” – \textit{e.g.}, synthesis of inducible enzymes.
   2. Exponential growth sometimes called “log phase,” \textit{i.e.},
      \[
      \ln N(t) = \ln N_0 + rt
      \]  
      
3. “Stationary phase” – cells survive but can’t reproduce.
II. Age Structure.

A. In most cases, individuals not the same. The young and the old typically manifest
1. increased mortality;
2. decreased fertility.

B. Survivorship curves idealized as Types I (man); II (birds); III (insects, fish).

C. Variation in mortality reflects
1. Vulnerability of the young.
2. Senescence (aging).

D. Variation in fertility reflects
1. Delayed onset of reproductive maturity – inevitable.
2. Senescence.

E. Rate of population increase determined by age-specific schedules of reproduction and survivorship:

\[ r \approx \frac{1}{T} \ln R_0 \]

1. \( R_0 \): Life time expectation of offspring.
2. \( T \): Generation time.
F. **Stable Age Distribution** (SAD).

1. With constant rates of reproduction and mortality, age structure approaches SAD in the limit of large time.

\[
\frac{n_x}{n_0} = \frac{l_x}{e^{rx}}
\]  

(3)

2. Distinguish between age distribution at *any particular time* and the SAD (as \( t \to \infty \)).

G. **Demographic Transition.**

1. Economic development typically accompanied by
   a. Reduced mortality;
   b. Reduced fertility.

2. Result is shifting of age structure toward older age classes.

3. Economic implications an unexpected consequence of ZPG.
H. What about the **Population Bomb**?

1. Dire predictions of the 1960s-70s:
   
a. “The battle to feed all of humanity is over. In the 1970s and 1980s hundreds of millions of people will starve to death ... . At this late date nothing can prevent a substantial increase in the world death rate..." PB xi.

   b. "a **minimum** of ten million people, most of them children, will starve to death during each year of the 1970s. But this is a mere handful compared to the numbers that will be starving before the end of the century." PB 3.

   c. “A cancer is an uncontrolled multiplication of cells; the population explosion is an uncontrolled multiplication of people. Treating only the symptoms of cancer may make the victim more comfortable at first, but eventually he dies ... . A similar fate awaits a world with a population explosion if only the symptoms are treated. We must shift our efforts from treatment of the symptoms to the cutting out of the cancer.” PB 152.

2. Predictions failed because Ehrlich, Club of Rome, *etc.*, imagined
   
a. Continuing population growth
   
b. Constant or declining availability of resources.
III. Life Tables Evolve.

A. Reproductive Value.

1. Quantifies contributions of different age classes to long-term population growth.

\[
\frac{v_x}{v_0} = \frac{e^{rx}}{l_x} \sum_{i=x}^{\infty} e^{-r(i+1)}l_i m_i
\]  

(4)

2. With \( r = 0 \) (constant population), reproductive value of an \( x \) year-old is the expectation of current and future offspring.


1. Between resources allocated to current reproduction / survival and future reproduction / survival.

2. Two formulations:
   a. Reproductive effort theory of life history evolution emphasizes current reproduction vs. post-reproductive survival and future reproduction / survival.
   b. Pleiotropic theory of aging emphasizes current survival vs. future survival.

C. Optimal life history

1. Maximizes \( v_x/v_0 \) at each age class.

2. Equivalently, \( m_x + p_x (v_{x+i}/v_0) \).

D. Simple example

1. Individuals the same. Population multiplies at rate \( \lambda \).

2. Reproduction and survival depend on energy expended thereto

3. \( \dot{\lambda}(E) = B(E) + p(E) \)
4. Accounts for evolution of “Big-bang” reproduction (semelparity) vs. repeated reproduction (iteroparity).

5. Optimal response to increasing density depends on age-specificity of density-dependent mortality.
IV. Finite Environment.

A. Replace Equation 1 with

\[ \frac{dN}{dt} = F(N) \]  \hspace{1cm} (5)

1. Reflects resource limitation, etc.

2. Simplest formulation is so-called logistic.

\[ \frac{dN}{dt} = rN(1 - N/K) \]  \hspace{1cm} (6)

a. \( K \) is the “carrying capacity” of the environment.
b. \( r \) as before.

B. Gause Experiments – yeast, paramecia, other microorganisms.

C. With time delays added to Eq (5), equilibrial behavior can give way to cycles / chaos.
D. Childhood diseases good example of complex dynamics in ecological systems. Illustrate

1. Sensitivity to Initial Conditions (SIC)
2. Long-term statistical invariance.