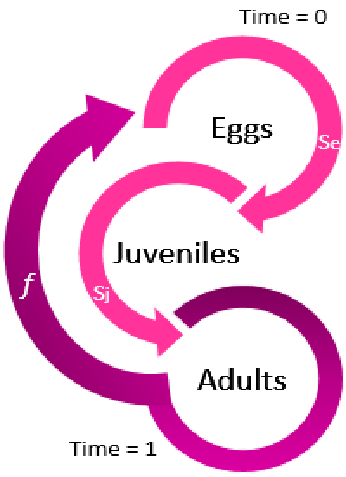
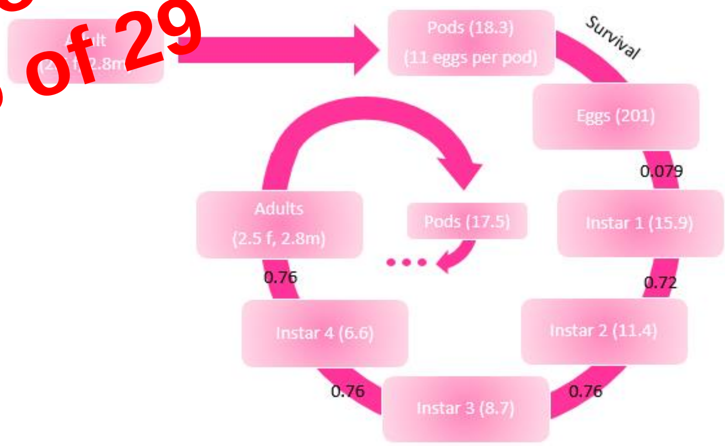
- Sink populations - when λ > 1 (population is growing) because immigration is large, but deaths > births, like Germany

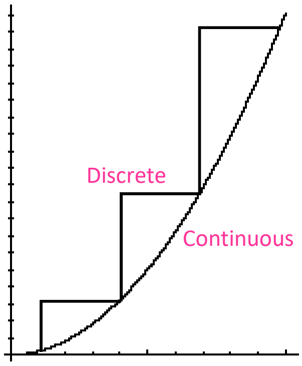


- To understand population change we must understand life cycles. Here is a simple life cycle, where only the adults are reproductive (f represents fecundity, Se the survival of the eggs, and Sj the survival of the juveniles). To gain understanding it is best to follow a cohort (all born at the same time). The time from egg to adult is normally counted as one time step.
- Age-specific life history - organism becomes mature and sexually active at a certain age (and may reach an age of senescence). The only limitation on reaching the correct age is survival. Normally humans and mammals.
- Stage-specific life history - organism must progress through stages (progression determined by size), eg instars, before they can reach maturity. Progression is not related to time, and the limitation is the probability of reaching the correct size. Normally insects and plants.
- Modular growth - adds modules of same type (eg sponges, tapeworms) - indeterminate
- Unitary growth - grow towards single body form (eg us – don't randomly add new arms). Can be indeterminate (will grow to infinity like fish) or determinate (stop at a certain age like us)
- Reproductive strategies may be monoecious or dioecious (one or two sexes), hermaphrodites (gastropod molluscs, polychaetes), sequential hermaphrodites (transition from one gender to another), asexual, or alternate generations (eg asexual and sexual, haploid and diploid). Ferns alternates between gametocytes and spermatocytes. Whiptail lizards and invertebrates may use parthenogenesis (apomixis for plants) - reproduction from an unfertilised egg



- Animal ecology tends to focus on determinate growth and separate sexes
- Life cycles can have overlapping generations or non-overlapping generations
- Non-overlapping generations - usually insects, where adults lay eggs and die (therefore there are no adults of different generations at the same time), discrete. Eg crickets, shown per 10m^2. There is a huge mortality event at the egg stage, most likely due to dessication. This population is a static population at equilibrium, as G1 = G2

- Key factor analysis - analysing what factors are most responsible for the change in population size (eg, what life stage is responsible for the change in population size?). Can add up K values for each stage and plot to give the relative intensity of mortality. Key factors may include territories (eg territorial disputes/resources), density-dependant mortality, and behaviour.
- Growth rate is determined by λ in discrete time, and r in continuous time
- Exponential growth:
  - In discrete time, $\lambda = N_{t+1}/N_t$ or $N_{t+1} = \lambda N_t$ (time is treated as a discrete variable/may remain constant).
  - In continuous (proper) time, must differentiate $N_{t+1}=N_t+N_tB-N_tD+N_tI-N_tE$ to give $dN/dt=N(b-d+i-e)=$ $dN/dt=rN$ (where $r=\ln\lambda$, therefore the rate of change is $\Delta=\ln(\lambda)N$). r is the instantaneous, intrinsic rate of population increase, and is called the Malthusian parameter. Δ signifies a small step in time.



- The Malthusian growth model is a model for exponential increase, named after Thomas Malthus, who discovered that humans were following this pattern in 1998. Growth pattern humans are currently following.
- From life tables we can get mathematical values for survival (l_x) and fecundity (b_x) (and time). We can put these together to get the net reproductive rate/lifetime reproductive success: $R_0 = \sum(l_x b_x)$. If $R_0 = 1$, the population is at replacement rate (not growing or shrinking). $R_0 > 1$ then the population is exponentially increasing as each organism is more than replaced by its offspring, and < 1 is exponentially decreasing. $R_0 = \lambda$ in non-overlapping generations.
- r can be found from life tables with the Euler equation. X is equal to time.
  - Discrete time: $1 = \sum e^{-rx} l_x b_x$
  - Continuous time: $1 = \int e^{-rx} l_x b_x dx$
- With λ or r, we can calculate the doubling time for a species (don't need formula). As a rule, doubling time increases as r is smaller, or as the body size is larger.
- Growth is exponential when there is no competition for resources (or other density dependant issues), eg when a new species invades (succession) or recovery after a natural disaster etc.
- Matrix models are more accurate as they do not lump ages or stages together (eg in terms of survival (s or l_x) or fecundity (f or b_x)). So in a normal model $N_{t+1}=\lambda N_t$, which in a matrix model we replace λ with A ($N_{t+1}=AN_t$).

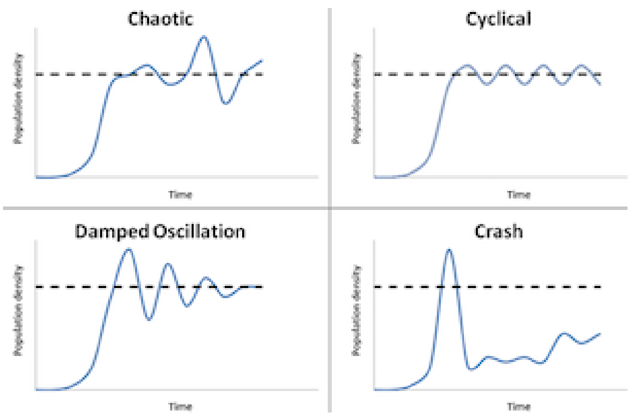
With a Leslie matrix, A = $\begin{matrix} f_1 & f_2 & f_3 & f_4 \\ s_1 & 0 & 0 & 0 \\ 0 & s_2 & 0 & 0 \\ 0 & 0 & s_3 & 0 \end{matrix}$ and Nt = $\begin{matrix} N_1\ (eg\ eggs) \\ N_2\ (larvae) \\ N_3\ (pupae) \\ N_4\ (adults) \end{matrix}$

$$\begin{bmatrix} n_1 \\ n_2 \\ n_3 \\ n_4 \end{bmatrix}_{t+1} = \begin{bmatrix} f_1 & f_2 & f_3 & f_4 \\ s_1 & 0 & 0 & 0 \\ 0 & s_2 & 0 & 0 \\ 0 & 0 & s_3 & 0 \end{bmatrix} \cdot \begin{bmatrix} n_1 \\ n_2 \\ n_3 \\ n_4 \end{bmatrix}_t$$

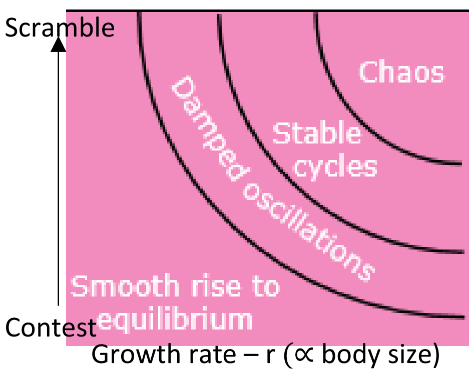
To calculate N_{t+1} it is simply $(F_1 \times N_1)+(F_2 \times N_2)+(F_3 \times N_3)+(F_4 \times N_4) = N_{1t+1}$, and so on.
Example: So for the below example: $N_{1t+1} = 14.8 = (0\times14)+(0.3\times8)+(0.8\times12)+(0.7\times4)+(0.4\times4)+(0\times0)$ and $N_{2t+1} = 8.4 = (0.6\times14)+(0\times8)+(0\times12)+(0\times4)+(0\times0)+(0\times0)$ etc

After 3 months

$$\begin{bmatrix} 0 & 0.3 & 0.8 & 0.7 & 0.4 & 0 \\ 0.6 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0.9 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0.9 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0.8 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0.6 & 0 \end{bmatrix} \begin{bmatrix} 14 \\ 8 \\ 12 \\ 4 \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} 14.8 \\ 8.4 \\ 7.2 \\ 10.8 \\ 3.2 \\ 0 \end{bmatrix} \begin{matrix} \leftarrow \text{0-3 month pop.} \\ \leftarrow \text{3-6} \\ \leftarrow \text{6-9} \\ \leftarrow \text{9-12} \\ \leftarrow \text{12-15} \\ \leftarrow \text{15-18} \end{matrix}$$

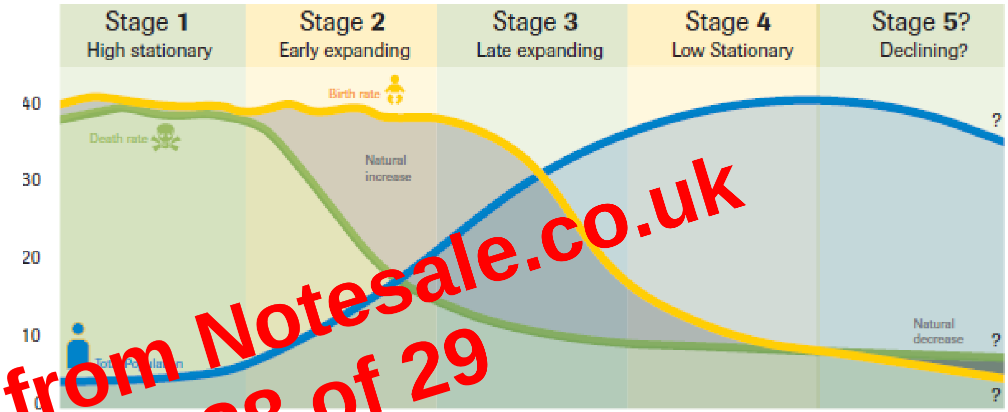


- Maximum sustainable yield – highest rate of removal that can be matched by recruitment, maximum which can be caught without causing a population crash, normally around half the carrying capacity. Where the growth rate is negative, harvesting is still sustainable because taking from here reduces density dependant effects.
- There are 3 main patterns in population dynamics. Chaos – not mathmatically predictable without knowing the equation, no apparent pattern. Cyclic – has cycles, may be irregular, annual, related to sunspots etc. Stable – has logistic growth with an equilibrium, may still have damped oscilations due to overshooting the carrying capacity.
- Biotic Deterministic forces - Patterns may be caused biotically by basic density dependance, time lags, non-linear $b_x$responses to density, or other interactions such as between ages and life stages.
- Abiotic fluctuations can also be responsible – large scale and low frequency via the climate, such as El Nino southern oscillation (temperature changes in the pacific) or random events such as the North Atlantic oscillation (pressure changes in the atlantic leading to changes in storm paths etc, with no apparent pattern). Or stochastically, small scale and high frequency. Environmental effects such as global warming.
- A variation on the logistic equation takes into account the variable amount of resources and therefore the variable carrying capacity. $\bar{N} = \bar{K} - \frac{\sigma_K^2}{2}$ – the average population size = the average carrying capacity – half the variance of K (var = σ^2). A high r (intrinsic growth rate) leads to tracking the carrying capacity (oscillates about K), and a low r leads to averaging the carrying capacity (smoother following of K). High σ_K^2 → low $\bar{N}$.
- Time lags (τ) are often equivalent to generation time. r determines the response time to a variable (τ = 1/r). $\frac{dN}{dt} = rN\left(1 - \frac{N_{t-\tau}}{K}\right)$. For example if a mahogany trees produces seeds at whatever rate it wants, then the density dependance which acts on the seeds is what affects reproduction in 100 years (generation). A large τ (tor) means that the organism is responding to something further back.
- Numerical response – change in consumer density according to food density
- Functional response – change in consumer's rate of consumption according to food density
- A low τr gives a smooth logistic graph, an average τr gives damped oscillations, and a high τr gives cycles with a period of 4τ (the general rule of cycles).
- Long cycle lengths → stable, and short cycles → chaos.
- An example of interactions between ages and stages is egg cannibalism in flour beetles. With egg cannibalism, the adult populations stays relatively steady, but the larvae and pupae have cycles. Without egg cannibalism, all life stages were relatively stable.
- Types of competition are and example of non-linear responses to density. It is an allometric relationship – different body sizes gives different responses to types of competition.



law will not be related to a mother-in-law's offspring (and yet the mother in law will be related to the DIL), so the DIL is under greater evolutionary pressure to 'win' the conflict (although this depends on dispersal). This makes the effect strongest in patrilocal dispersals.

- Matrilocal – the man moves to the woman's household. Leads to shorter and easier peri-menopause (pre) and later menopause.
- Patrilocal – the woman moves to the man's household (when in-law reproductive conflict takes effect).
- This shows that conflict is enough to 'cause' the menopause – not necessarily the grandmother effect. Intergenomic conflict between male and female derived genes causes unpleasant symptoms
- Homosexuality is common in the animal kingdom, but only humans show life-long homosexuality. May be linked to an increase in offspring in females on the maternal side (X-linked allele which increases female LRS at cost of male LRS). Alternatively it could be due to recognition errors (in animals, same sex mountings decrease with a higher % male environment – due to more knowledge of own sex, and is almost non-existent in predominately female environments)
- Demographic Transition - model of population history. Has led to a massive decrease in family size, and therefore average LRS.



- Menarche – start of the menstruation cycle. It has decreased due to better nutrition (modern !Kung women are equivalent to 1850 Glasgow factory workers).
- Lactational amenorrhea – the stopping of cycles due to breastfeeding. Happens because there is not enough energy to menstruate and breastfeed (therefore is not effective in well-nourished women), and in !Kung who breastfeed for 4 years (long time) limits their LRS considerably. Hutterites provide an example of modern women with no contraception – with a very high LRS (depending on age of marriage).