Populations

1

LIFE on Earth

- chemical basis (carbon-based life on water-planet)
  - proteins, sugars, fats, nucleotides
- genetic code (DNA)
  - replication, transcription, translation
  - four bases (2 bit (binary digit) code)
- cellular organization (membranes, organelles, nuclei)
  - basic units of life
- evolution (natural selection, survival of fittest)
  - mutation, recombination
- symbioses (living together)
  - organelles (SET)
  - organisms (life styles)

$\rightarrow$ collective co-existence (ecology)

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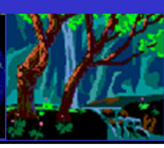
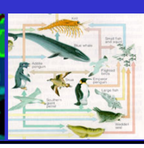
Ecology (hierarchy)

- biosphere (all environments on Earth inhabited by life)
- ecosystems (all living and non-living things within given area)
  (matter recycles while energy flows through)
- communities (all species within given area)
  (interactions between species, e.g. food chains, competition, predation, herbivory, disease)
- populations (all individuals of single species)
  (single species distribution and abundance)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Review - BIOLOGY

(study of life)

- organisms
  - species — stage-classified — (matrices)
  - biodiversity — species-area — (power fn)

- populations
  - growth — unconstrained — (exponential fn)
    — constrained — (logistic model)
  - interactions — predator-prey — (DE) [L-V]
    — epidemiology — (DE) [SIR]

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Population ecology

- distribution
  - temporal (any time frame, but esp. seasonal)
  - spatial (any space, but esp. regional)
- abundance
  - size (number)
  - density (number/area)
  - concentration (number/volume)
  - intensity (e.g. number parasites/host)
  - prevalence (e.g. proportion infected)
  - incidence (change in prevalence over time)

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Population growth

- vital statistics of populations (changes over time)
- individuals join (births and immigration)
- individuals leave (deaths and emigration)

$P_2 = P_1$ + (births + immigration) - (deaths + emigration)

- assume closed population (no migration)

$P_2 = P_1$ + (births - deaths)

that is, population is proportionate to:

- current size (P_i)
- growth rate (r) (= birth rate – death rate)

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Population growth

Seal lecture room with 100 students inside

Count changes in number over one year

Five births

Two deaths

No escapees (closed pop.)

$POP_{(2012)} = POP_{(2011)} + births - deaths$

$POP_{(2012)} = 100 + 5 - 2 = \underline{103}$

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Population growth

Alternatively, determine rates (change over one year):

birth rate = 5 / 100 = 0.05 (= 5%)

death rate = 2 / 100 = 0.02 (= 2%)

Growth rate = birth rate - death rate

= 0.05 - 0.02 = 0.03 (= 3%)

$POP_{(2012)} = POP_{(2011)} \times growth\ rate$

$POP_{(2012)} = 100 \times 1.03 = \underline{103}$

⇒ POP now = POP previous x growth rate

sounds ominously mathematical!

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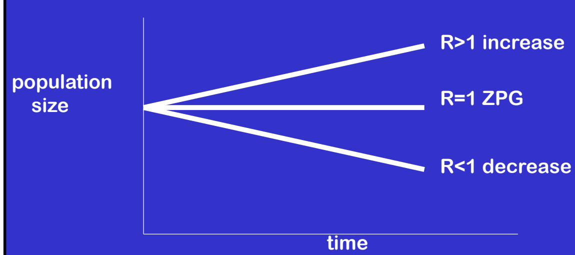
Population growth rate, R



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Population characters

- demography (categorize!)
  - biology (age, sex, breed, size ...)
  - other (income, postcode, religion, ...)

↓

- life tables
  - age/stage-structure, numbers
  - births, deaths, migrations

↓

- survivorship curves
  - life expectancy

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Exemplar: age/stage population structure

Fleas (itchy-scratchy syndrome)

the dangers of not wearing shoes!

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Flea Life History

egg

↓

larva

↓

pupa

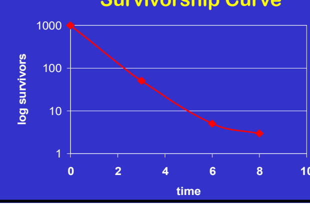
↓

adult

Life Table

Age (weeks)	Dev. Stage	Number alive	Proportion alive
0-2	eggs	10,000	1.00
3-5	larvae	500	0.05
6-7	pupae	50	0.005
8-20	adults	30	0.003

Survivorship Curve



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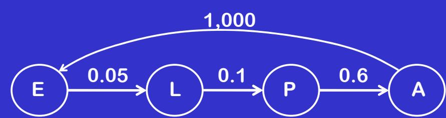
Stage-structured diagrams

- used to depict life-cycles
- arrows show proportion in transition

Time period	Flea developmental stage	Number alive
1	Eggs	10,000
2	Larvae	500
3	Pupae	50
4	Adults (50% female) (females lay 2,000 eggs)	30



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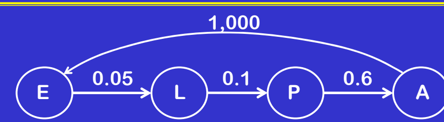
Simultaneous equations



$E_{i+1} = 0\,E_i + 0\,L_i + 0\,P_i + 1{,}000\,A_i = 1{,}000\,A_i$

$L_{i+1} = 0.05\,E_i + 0\,L_i + 0\,P_i + 0\,A_i = 0.05\,E_i$

$P_{i+1} = 0\,E_i + 0.1\,L_i + 0\,P_i + 0\,A_i = 0.1\,L_i$

$A_{i+1} = 0\,E_i + 0\,L_i + 0.6\,P_i + 0\,A_i = 0.6\,P_i$

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Matrix operation

$$\begin{matrix} E_{i+1} = \\ L_{i+1} = \\ P_{i+1} = \\ A_{i+1} = \end{matrix} \begin{pmatrix} 0\,E_i + & 0\,L_i + & 0\,P_i + & 1{,}000\,A_i \\ 0.05\,E_i + & 0\,L_i + & 0\,P_i + & 0\,A_i \\ 0\,E_i + & 0.1\,L_i + & 0\,P_i + & 0\,A_i \\ 0\,E_i + & 0\,L_i + & 0.6\,P_i + & 0\,A_i \end{pmatrix}$$

transition matrix

$$\begin{pmatrix} 0 & 0 & 0 & 1{,}000 \\ 0.05 & 0 & 0 & 0 \\ 0 & 0.1 & 0 & 0 \\ 0 & 0 & 0.6 & 0 \end{pmatrix}$$

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Matrix multiplication

assume population N_0 = 100 E, 50 L, 10 P, 2 A
calculate N_1

$$\begin{pmatrix} 0 & 0 & 0 & 1{,}000 \\ 0.05 & 0 & 0 & 0 \\ 0 & 0.1 & 0 & 0 \\ 0 & 0 & 0.6 & 0 \end{pmatrix} \times \begin{pmatrix} 100 \\ 50 \\ 10 \\ 2 \end{pmatrix} = \begin{pmatrix} 2{,}000 \\ 5 \\ 5 \\ 6 \end{pmatrix}$$

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ALGAL BLOOMS

Cyanobacteria (pond scum)
- aquatic swimmers
- with chloroplasts (need sunlight)
- bloom populations (organic-enrichment)
- biotoxic pigments (blue-green algae)

Dairy cows – liver disease – cirrhosis (///alcoholics)
- liver fluke infestation? (no evidence on pm)
- toxicology - herbicides X
  - CB hepato-toxins ✓
- causative agents (Annie, Fannie, Mike & Noddy)

(Anabaena, Aphanizomenon, Microcystis, Nodularia)

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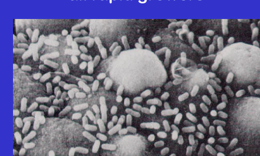
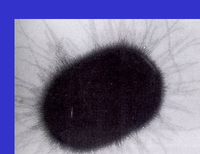
Escherichia coli

- Gram-negative rod bacteria
- up to 10^{12} bacteria per gram faeces (~ 10% wet weight)
- minimum infective dose 10^4-10^6
- virulent strains in g-i tract of mammals
  - ETEC = entero-toxigenic *E.c.*
  - EPEC = entero-pathogenic *E.c.*
  - EHEC = entero-haemorrhagic *E.c.*
  - EIEC = entero-invasive *E.c.*
- all rapid growers!!!!





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Epidemiology?

Like ecologists, epidemiologists seek to understand:
- species richness (biodiversity)
- species abundance (populations/communities)
- species distribution (temporal, spatial)

Study human pathogens = epidemiology
Study animal pathogens = epizootiology

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Epidemiology/Epizootiology

Study of occurrence, spread and control of diseases
(descriptive) (analytical) (experimental)

- Prevalence (number infected)
- Incidence (change in prevalence over time)
- Distribution (density, intensity, concentration,..)

exhibit longitudinal fluctuations (esp. seasonal)

influenced by many factors:
- demographic, socioeconomic, behavioural
- geographic, climatic

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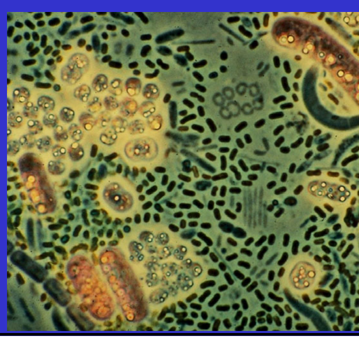
INFECTIOUS DISEASES

What percentage of the world population believes in the GERM theory?



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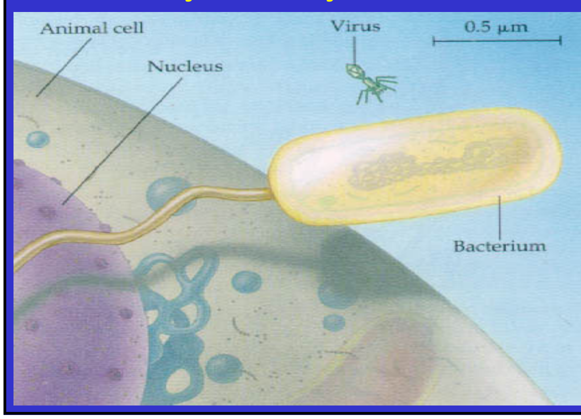
Eukaryote - Prokaryote Domains



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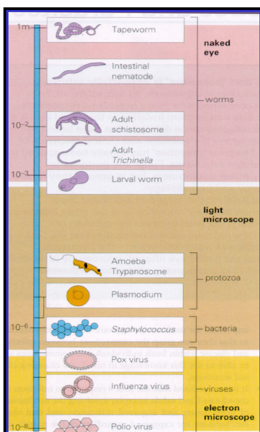

Infectious diseases

pathogens

arthropods, helminths — macro-parasites
- cumulative
- slow cycles
- chronic disease

protozoa, fungi, bacteria, viruses — micro-parasites
- multiplicative
- fast cycles
- acute disease

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Epidemiological studies

Four main types:	Maths
• Case series (descriptive) – index, incidental, miscellaneous	not quantitative
• Case control studies (retrospective) – cases + controls interviewed	statistics Odds Ratio
• Cohort studies (prospective) – cohort followed forward in time	statistics Relative Risk
• Outbreak studies (predictive) – rate of change in population	calculus Differential Equations

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OR and RR

	CASES	CONTROLS
EXPOSED	A	B
UNEXPOSED	C	D

Odds Ratio (OR) = AD / BC

Relative Risk (RR) = [A / (A+B)] / [C / (C+D)]

>> 1	causative?
~ 1	no association
<< 1	protective?

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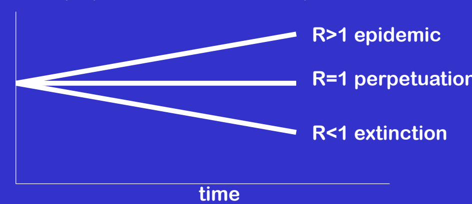
OUTBREAKS

Pathogens must reproduce themselves to survive (reproduction rate = R)



Basic (case) reproduction rate (Ro)
= average number of secondary infections resulting from primary case in susceptible population

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BUT, nothing is IDEAL

Population varies in susceptibility

- proportion just infected (latent)
- proportion patent (infectious)
- proportion immune (resistant)
- proportion lose resistance (susceptible)
- proportion die
- proportion migrate
- etc

⇒ all influence Ro
⇒ need to stipulate model

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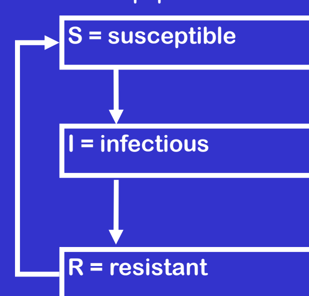
SIR model (long-term immunity)

Identify three states in population

Movement shown by differential equations



dS/dt

dI/dt

dR/dt

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Infectious Disease Models

Micro-parasites
(viruses, bacteria, protozoa)

- reproduce quickly
- high intensity of infection
- acute transient diseases
- strong protective immunity

population dynamics driven by:
- transmission rate
- recovery rate

SIR model

Macro-parasites
(helminths, arthropods)

- reproduce slowly
- aggregated distribution
- chronic persistent diseases
- little protective immunity

population dynamics driven by:
- exposure to free-living stages
- overdispersion in hosts

HPW model

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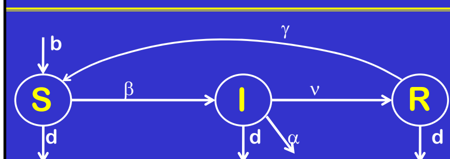
SIR model
(N = Susceptible + Infected + Recovered/immune)



β = infection rate
ν = recovery rate
γ = immunity loss
b = births
d = deaths
α = infection mortality

	in	out		
S' =	bN + γR	- dS	- βSI	
I' =	βSI	- dI	- αI	- νI
R' =	νI	- dR	- γR	

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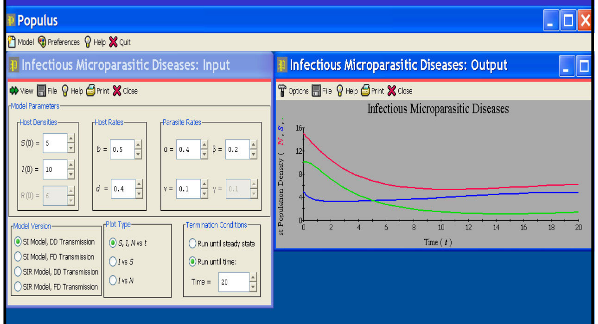

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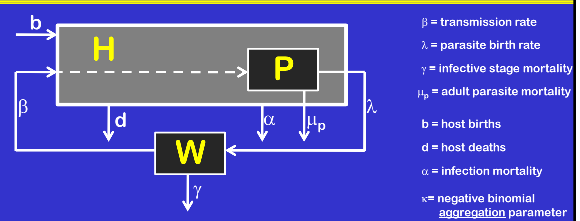
Anderson & May HPW model

Host population, Parasite population (adults), free-living stages (W)



	in	out
H' =	bH	- dH - αP
P' =	βWH	- μ_pP - αP - dP - $\alpha P^2/H[(\kappa+1)/\kappa]$
W' =	λP	- γW - βWH

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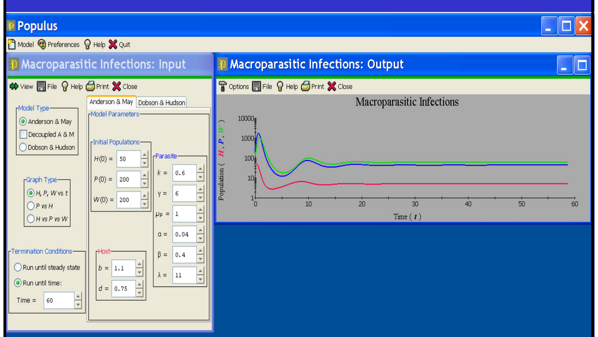

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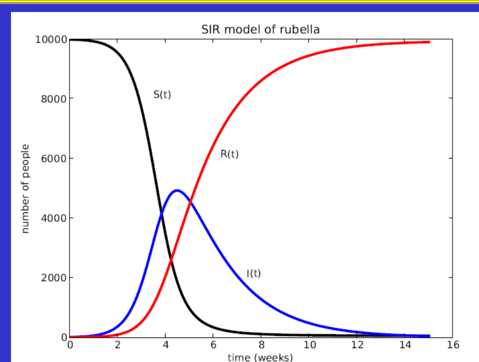
Disease prediction models



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Global Burden of Disease

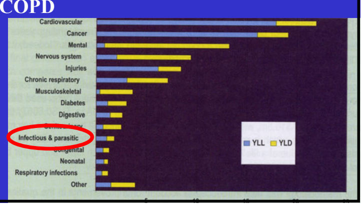
(YLL = morbidity; YLD = morbidity)

Recent shift in distribution of deaths:

- from younger to older ages
- from communicable/maternal/perinatal/nutritional causes to noncommunicable disease causes

Leading causes:

- ischaemic heart disease
- cerebrovascular disease/hypertension
- respiratory infections/COPD
- infectious diseases
- perinatal diseases
- diarrhoeal diseases
- cancer
- road traffic crashes
- diabetes
- kidney diseases



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