Lecture 4: Demography

Demography is the description and prediction of population growth and patterns in age/size structure.
Derived from the deme = population
Demography derives the vital statistics for a population which include:
Probability of survival

- mortality
- fecundity

Roots of demographic considerations started with Malthus in 1826 period of time when human population began to show exponential growth. He noted human populations were increasing exponentially but food supply only increased in a linear fashion. Predicted human population would eventually be limited by resources.

Malthus influenced Darwin thinking at the time. Noticed that fluctuation in natural populations on natural systems lead him to derive the concept that the "struggle for existence " drives the process of natural selection (i.e. variants in a population that enhance their ability to garner scarce resources) will lead to differential survival and "select" for such traits.

More contemporary, the statistical development of demography was founded by insurance companies (actuaries). Interest in deciding how much individual would need to pay based on age-specific probability on illness or death.

Demography is used in ecology (particularly population and evolutionary ecology) as the basis for population studies.

- helps to identify the stage(s) in the life cycle that affects population growth.
- application to conservation/exploitation (e.g. fisheries management).
- assess potential competitive abilities, colonization.
- basis for understanding evolution of life history traits.
- currency of fitness

In ecology demography allows us to predict actual or potential changes in population size.
Start with basics – need to know:

- birth rates
- death rates
- age at 1st reproduction
- immigration rate (coming in)
- emigration rate (going out)

How do we do this?
To study the dynamics of the population need to know how large the population is.
If population is small one can count individuals directly. e.g. grizzly bears, whooping cranes.
Most studies require an estimate of population size by sampling (exercise in lab):

1. **Transects, quadrats** - good for sedentary or sessile organisms.
2. **Mark & recapture** - mobile species.
   (# marked) / (# in population) = (#marked recaptured) / (total number retrapped)
   e.g. 10/x = 1/10, therefore x=100 individuals in population.
   Assumes probability of capturing marked and unmarked organisms are the same.
3. **Relative density measurements**
   individuals/unit effort (e.g. trapping, observation/unit time
   stream 1 - 8 individuals/10 tows
   stream 2 – 40 individuals/ 10 tows
   relative density of stream 2 is 5x that of stream 1.

Once you've estimated population size you may want to know - what factors are determining population size? Is it stable, increasing, decreasing?

To answer this you need to know rates of births and deaths.
Definition of terms: Types of reproduction
Semelparous - organisms which have only a single reproductive event during its lifetime, e.g.: salmon

Iteroparous – organisms which has more one than reproductive event. e.g. possible for a population of semelparous individuals to have more than one reproductive event if they have overlapping semelparous events (e.g. 2 year and 3 year events – e.g. cicadas.

Periodicity of reproduction
Discrete – one reproductive event/unit time with individuals synchronous, e.g. deer, fruit flies.
Continuous – reproduction is continuous over time. Individuals in population not synchronous.

Generations
Overlapping generations - individuals in population represent different generations. e.g. elephants.
Non-overlapping generation – all individuals represent single generation.
e.g. locust, annual plants.

Possible combinations

	Periodicity of sexual reproduction
	discrete ------ continuous
Nonoverlapping	annual plants ------ bacteria
Overlapping	Vertebrate ---------- humans and higher plants ------fruit flies

Semelparous - mostly discrete reproductive events and nonoverlapping, but some can have overlapping generations. e.g. non-overlapping, seasonal - annual grasses, overlapping, bienniel plants – growth in one season, reproduce in next with cohorts staggered.

Iteroparous - discrete or continuous, always with overlapping generations.
discrete – birds (seasonal)
continuous – rodents (nonseasonal)

For semelparous organisms with nonoverlapping generations demography is simple, as follows:

$N_{(t)}=N_{(o)} R$

R=fundamental net reproductive rate = average number of offspring (usually number of female offspring).

General: $N_{(t)}=N_{(o)}R^{(t)}$

To examine more complex life history we'll construct a life table.
e.g. iteroparous, discrete breeders with overlapping generations.
Sstart with a cohort – a group of individuals in the population with the same age. Then, follow the cohort through time.

Model based on age-specific schedule of both and death rates – use females, since population changes as a function of female population size, also offspring refer to number of females.

Let's define:
x= age-specific interval
a(x) = number of individuals surviving at start of interval x.

Age	a(x)
0	100
1	50
2	10
3	5
4	0

Follow cohort for 3 years, by year 4 all members are dead.
$l_{(x)}$ = proportion of original cohort surviving to
Start of interval x -> $a_{(x)}/a_{(0)} = a_{(x)}/100 = 1$

Age	$a_{(x)}$	$l_{(x)}$	$d_{(x)}$	$q_{(x)}$	$m_{(x)}$	$l_{(x)}m_{(x)}$
0	100	1.0	0.5	0.5	-	-
1	50	0.5	0.4	0.8	2	1
2	10	0.1	0.05	0.5	3	0.3
3	5	0.05	-	-	4	0.2
					g.r.r= 9	sum 1.5

$_{(x)}$ = proportion of *original* cohort surviving to interval (x)
$d_{(x)}$ = proportion of original cohort dying during interval
$q_{(x)}$ = mortality rate per interval (x)
$m_{(x)}$ = interval specific birth rate, number of offspring per individual.

Gross reproductive rate (GRR) =sum $m_{(x)}$ or 9, expected number of offspring expected that survive to last age of reproduction.

Net reproductive rate (R_o) = sum $l_{(x)}$ $m_{(x)}$ or, average # of offspring produced by an individual.
(R_o) can tell us whether the population is increasing or decreasing <u>but</u> not how fast, unless reproduction in the population is a semelparous, nonoverlapping mode.

With life tables parameters we can also calculate life expectancy of age past (x). Life expectancy from birth to death is defined approximately as the age at which 50% of the cohort survives.

<u>Let's say:</u>
Age-specific life expectancy = $L_{(x)}$ =# of individuals alive on average during the interval x to x+1.
$L_{(x)} = a_{(x)} + a_{(x+1)}/2$

Define $T_{(x)}$ = sum $L_{(x)}$ = sum of individuals alive on average over all time intervals.
So, $e_{(x)}=T_{(x)}/a_{(x)}$ = average expectation of life past age x

From our example above – $L_{(o)}$ thru $L_{(4)}$
$E_{(o)}$ $= a_{(o)} + a_{(1)}/2 + a_{(1)} + a_{(2)}/2 + a_{(2)} + a_{(3)}/2 + a_{(3)} + a_{(4)}/2 / 100$
$= 150/2 + 60/2 + 15/2 + 5/2 /100 = 1.15$ years

How do we calculate the rate of increase in a population? (given an $l_{(x)}$, $m_{(x)}$ schedule which remains constant).

R - # of offspring produced by an individual over its lifetime, multiplication factor which converts original population to new population size one generation later.

How do we calculate the rate of increase in a population?

<u>In the simplest case</u>:
semelparous reproduction - the net reproductive rate R is the rate of increase and can be described by:
$\mathbf{N_{(t)}=N_{(o)}\ R^t}$

R - *# of offspring produced by an individual over its lifetime*. It is the multiplication factor which converts original population to new population one generation later.

Links population size $N_{(o)}$, rate of increase (R) and time (t).
However for a population with overlapping generations, R alone is not sufficient to estimate the rate of increase in a population. R_o only refers to the *average number of offspring produced by an individual*.

We have to link R_o with generation time.

So, we need to manipulate this equation before we can describe the rate of population growth.

We can derive the relationship that links population size, rate of increase and time.
R_o (net reproductive rate) and generation time (defined as lasting T interval of time).
R_o is the multiplication factor that converts one population size to another size *one generation later*, i.e. T time interval later.

So, $N_T = N_{(o)} R_o$
From general equation, $N_T = N_{(o)} R^t$
Therefore, $R_o \simeq R^t$

Taking natural logs (ln) of both sides
$\ln R_o = T \ln R$

ln R is generally denoted by "r" - the intrinsic rate of natural increase.
So, $r= \ln R_o/T$

With discrete generations (non-overlapping)
$R_o = R$, but R is different with overlapping generations.
So, we now have the relationship between average number of offspring produced by an individual in its lifetime R_o ; the increase in population size per time r (=ln R) and generation time (T).

Higher or larger Ro and shorter T means faster growing population. Also earlier age at reproduction means faster growth. (analogy: putting more money in the bank, more often yields higher returns)

More precise method for estimating growth rate:

<u>Euler equation:</u>
- for discrete breeders sum $e^{-rx}\ l_{(x)}\ m_{(x)} =1$
- for continuous breeders integral $e^{-rx}\ l_{(x)}\ m_{(x)} =1$

Problem: cannot be solved directly, only by iteration.

For example,

X	$l_{(x)}$	$m_{(x)}$	$l_{(x)}\,m_{(x)}$	$X\,l_{(x)}\,m_{(x)}$
0	1.0	-	-	-
1	0.5	2	1	1
2	0.1	3	0.3	0.6
3	0.05	4	0.2	0.6
			Ro=1.5	2.2

T = generation for a cohort,= sum X $l_{(x)}$ $m_{(x)}$ / sum $l_{(x)}$ $m_{(x)}$ = R_o
(Note regarding calculation of generation time of cohort. It takes the average length of time between the birth of an individual and the birth of one of its own offspring. Like any average it is the sum of all those lengths of time from all offspring, divided by the total number of offspring.)

so,

T= 2.2 /1.5= 1.46
r = ln R_o /T = ln1.5/1.46 = 0.27

when r=0, population is stable, r>0 increasing, r<0 decreasing.

Intuitively, rate of increase of population will be sensitive to both new reproductive rate R_o and generation time - faster generation time and higher reproductive rate, more rapidly the population grows.

<u>Contrast</u>

r - instantaneous rate of population growth

lamda - finite rate on population increase

r ranges from - infinity to + infinity

lamda ranges from 0 to infinity

Finite rate lamda= e^r ; r=ln lamba

lamda= R_o when semelparous, nonoverlapping

for example: a population increases from 100 to 150 after 1 year.

lamda= 150/100 = 1.5 per individual per year

r = ln 1.5 = 0.405 instantaneous rate of increase