Fundamentals in Ecology

Week 4

Population ecology

Grossiord Charlotte

Bachelor 2 - SIE

Schedule of the lectures

Room for all lectures:

ELD020

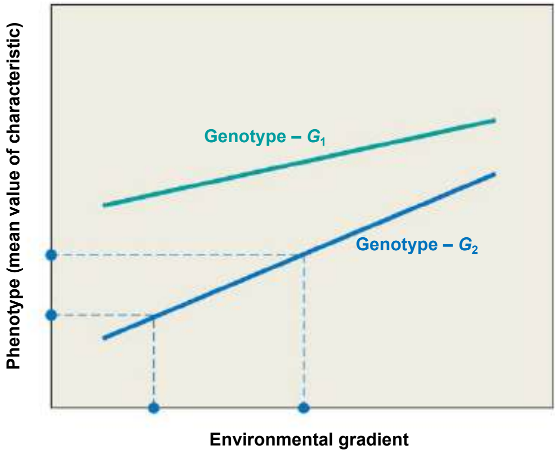
WEDNESDAY - LECTURES - ENV 220			Week	Teacher
19/2/2025	10h15-12h	The nature of ecology (introduction)	1	T. Battin
26/2/2025	10h15-12h	The physical environment	2	T. Battin
5/3/25	10h15-12h	Adaptations to the environment/Physiological ecology	3	C. Grossiord
12/3/25	10h15-12h	Population structure, dynamics, and regulation	4	C. Grossiord
19/3/25	10h15-12h	Community Ecology I	5	C. Bachofen
26/3/2026	10h15-12h	Community Ecology II	6	C. Grossiord
2/4/26	10h15-12h	Ecosystem ecology I	7	T. Battin
9/4/26	10h15-12h	Ecosystem ecology II	8	T. Battin
16/4/2026	10h15-12h	Biodiversity and conservation ecology	9	C. Grossiord
23/4/2025		Easter Holiday		
30/4/2025		ENAC Week		
7/5/24	10h15-12h	Climate Change impacts on terrestrial ecosystems	10	C. Grossiord
14/5/2024	10h15-12h	Climate Change impacts on aquatic ecosystems	11	T. Battin
21/5/2025	10h15-12h	Restoration ecology. Principles of ecosystem restoration, case studies	12	T. Battin
28/5/2025	10h15-12h	Applied ecology. Review and course wrap-up	13	C. Grossiord

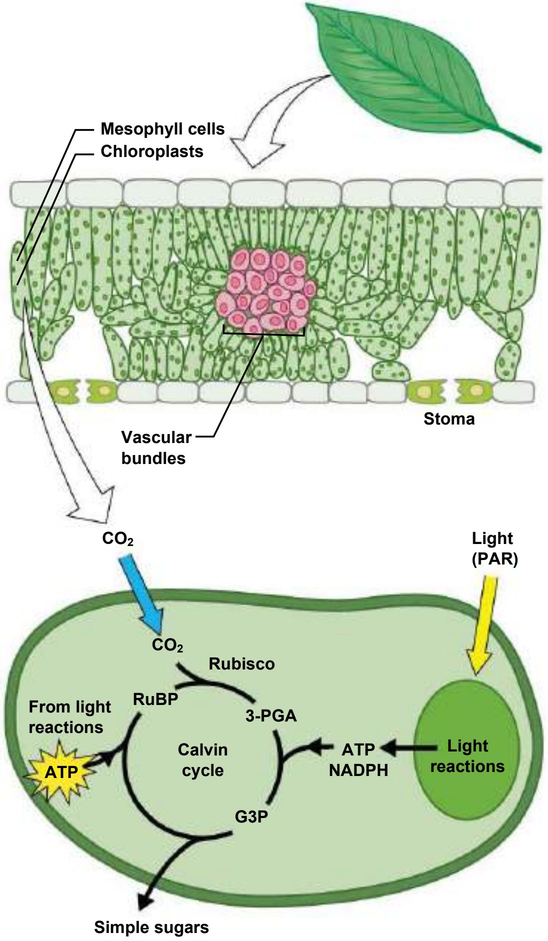
Schedule of the practicals

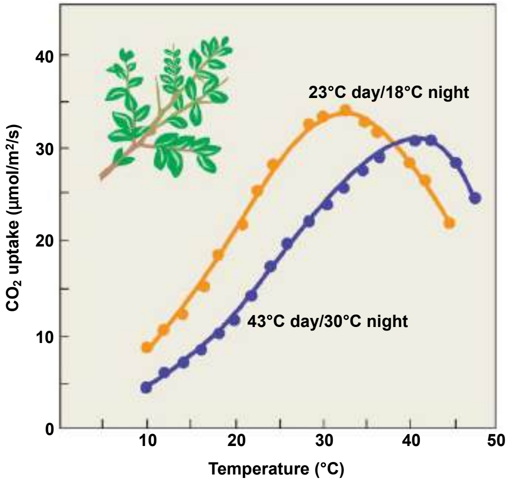
THURSDAY - PRACTICALS - ENV 220			Week	Important deadlines
20/02/25	11h15-13h	Introduction to practicals	1	
27/02/25	11h15-13h	Setting up experiments	2	**Inform the experimental setup to TAs by email by 26/02/25**
6/3/25	11h15-13h	How to write a report	3	
13/03/25	11h15-13h	Introduction to R	4	
20/03/25	11h15-13h	Field measurements 1	5	
27/03/25	11h15-13h	Data visualization in R	6	
3/4/25	11h15-13h	Field measurements 2	7	
10/4/25	11h15-13h	How to do statistical analyses	8	
17/04/25	11h15-13h	Field measurements 3	9	
24/04/25	**Easter Holiday**			
1/5/25	**ENAC Week**			
8/5/25	11h15-13h	Field measurements 4	10	
15/05/25	11h15-13h	Data Analysis/Interpretation	11	**Weighting of plant material in GR B2 423 before 15/05/25**
22/05/25	11h15-13h	Questions / Discussion	12	
REPORT SUBMITTED on MOODLE BY 06/06/25				

What you saw in the previous lecture

Adaptation to the Environment
–
Physiological Ecology

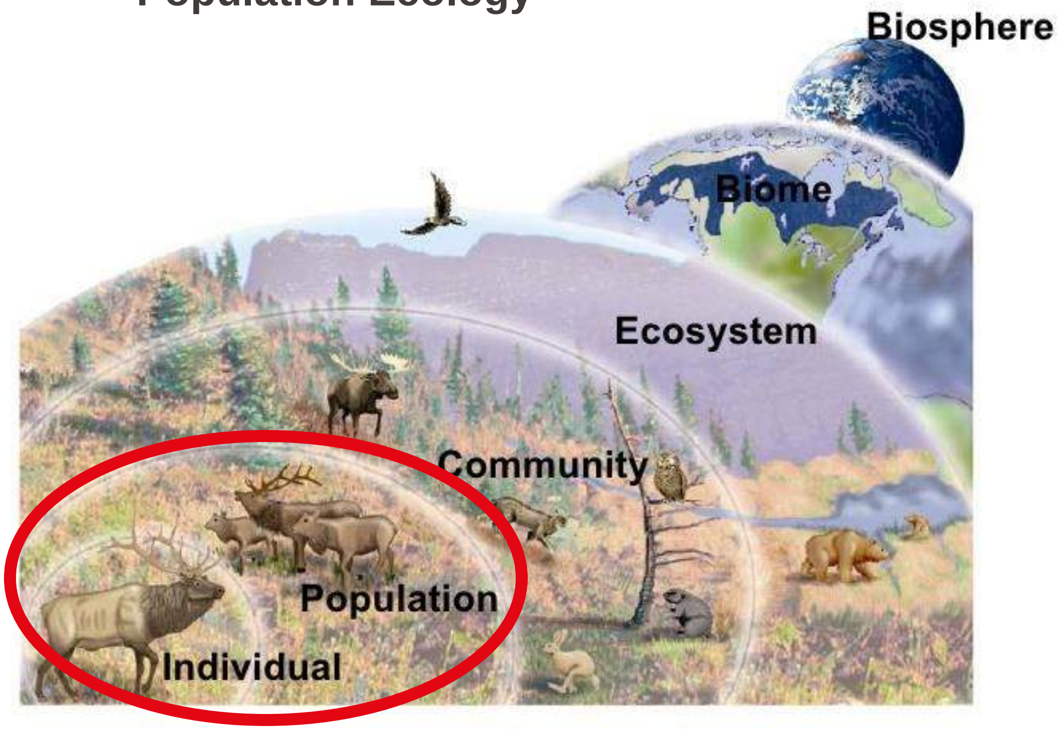






Overview of today's class

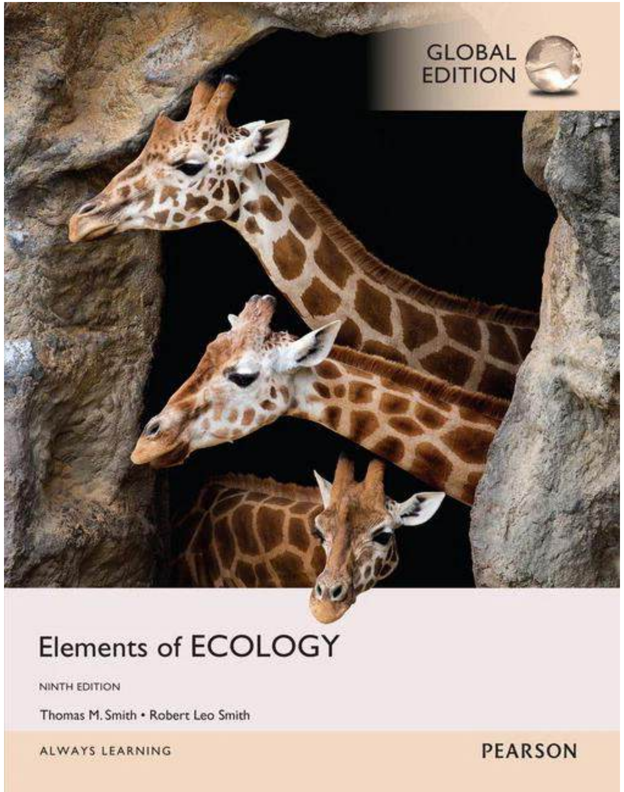
Population Ecology

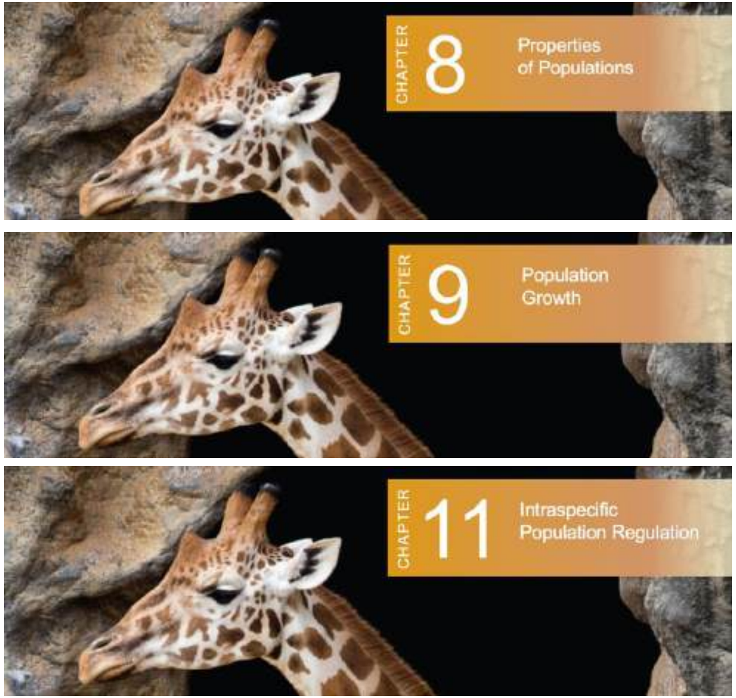


I. Properties of populations

II. Intraspecific population regulation

References to today's class





Smith, TM. & Smith RL. Elements of Ecology, Global Edition (Pearson)

1. Properties of populations

A **population** is a group of individuals of the **same species** that inhabit **a given area**.

1. Properties of populations

But what constitutes an individual?

- For **unitary organisms**, defining an individual is easy.

- In a **modular organism**, the zygote develops into a module, a unit of construction. This module then produces more, similar modules. Most plants are modular: they develop by branching, producing repeated structural units.

1. Properties of populations

The fundamental unit above ground is **the leaf**, with its axillary bud and internode. It produces more leaves with axillary buds.

Roots also show modular growth.

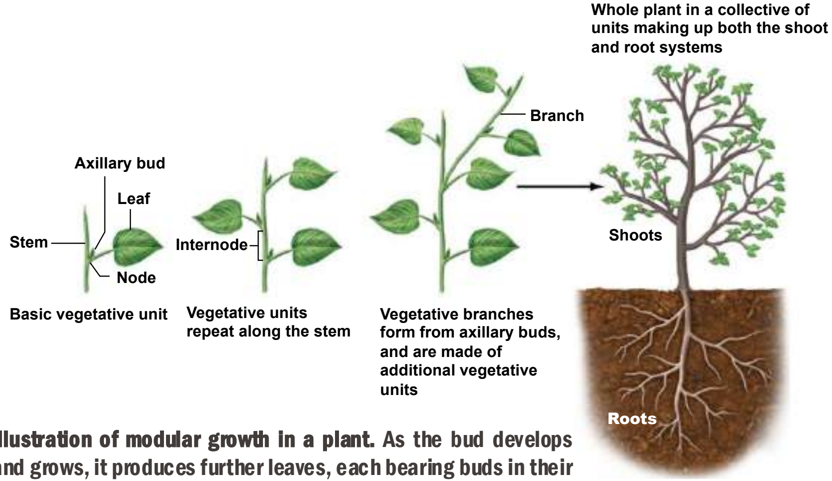
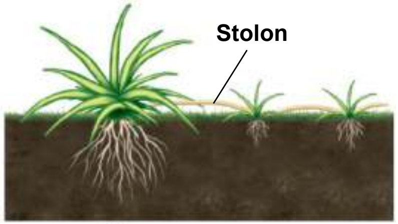


Illustration of modular growth in a plant. As the bud develops and grows, it produces further leaves, each bearing buds in their axils.



Plants produce a variety of forms through modular growth. Some may spread modules laterally as well as vertically:

- **Stolons** – specialized stems that grow aboveground.
- **Rhizomes** – specialized stems that grow belowground.

1. Properties of populations

The fundamental unit above ground is **the leaf**, with its axillary bud and internode. It produces more leaves with axillary buds.

Roots also show modular growth.

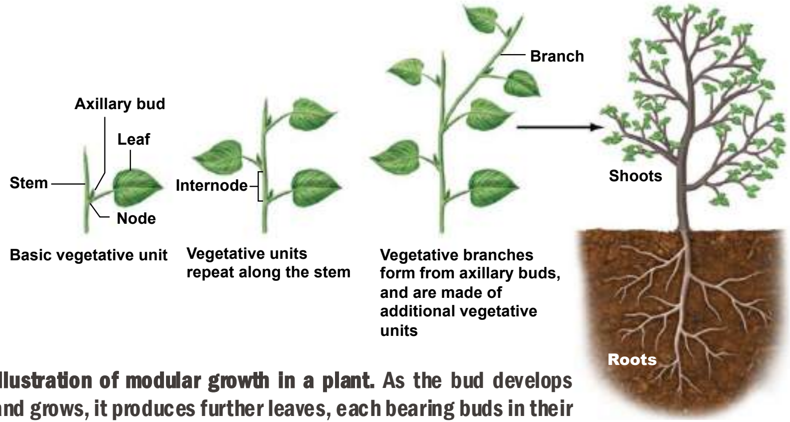
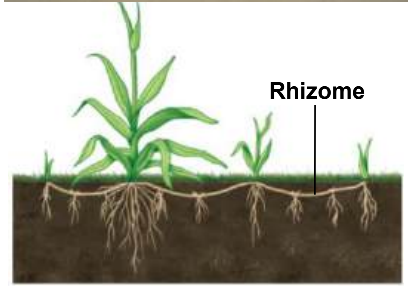


Illustration of modular growth in a plant. As the bud develops and grows, it produces further leaves, each bearing buds in their axils.



Plants produce a variety of forms through modular growth. Some may spread modules laterally as well as vertically:

- **Stolons** – specialized stems that grow aboveground.
- **Rhizomes** – specialized stems that grow belowground.

1. Properties of populations

- **Genet** – plant produced by sexual reproduction, a genetic individual.

- **Ramet** – module produced asexually by a genet (a clone).

A **clonal colony** is a group of ramets (genetically identical individuals).

Pando was once thought to be the world's largest organism. Each of the approximately 47,000 trees forming the clonal colony is genetically identical and all the trees share a single massive root system (Utah, USA).

Ramets can remain connected or separate. At that point, they are physiologically independent and may undergo sexual reproduction or asexual reproduction.

1. Properties of populations

By producing ramets, the genet covers a large area, and its life is extended.

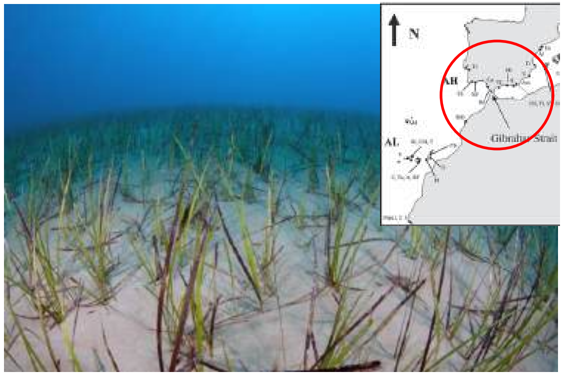
Other examples of modular organism are corals, sponges, bryozoans, many protists, and fungi.

The Humongous fungus is the largest living organism by area (covering 9.6 km^2). It is found in Oregon (USA). It is highly pathogenic to several tree species.

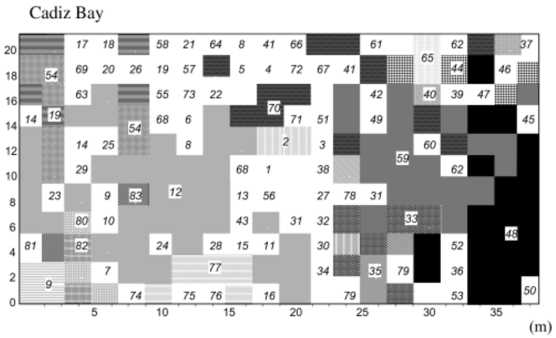
To study populations of modular organisms both the individual (genet) and module (ramet) must be recognized. This can be challenging. Molecular studies can distinguish between genets and ramets (see next slide).

For practical purposes, ramets are often counted as individual members of the population and they often function this way.

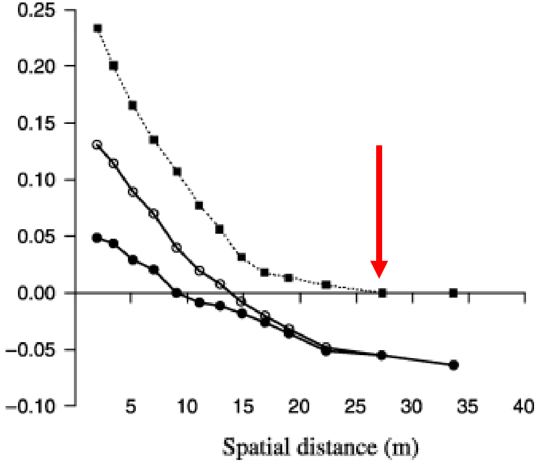
1. Properties of populations



Cymodocea nodosa



To study the structure of seagrass communities, scientists look at the genetic diversity of *C. nodosa* following a systematic grid (bottom left). The numbers in the figure show individual genets and their distribution.



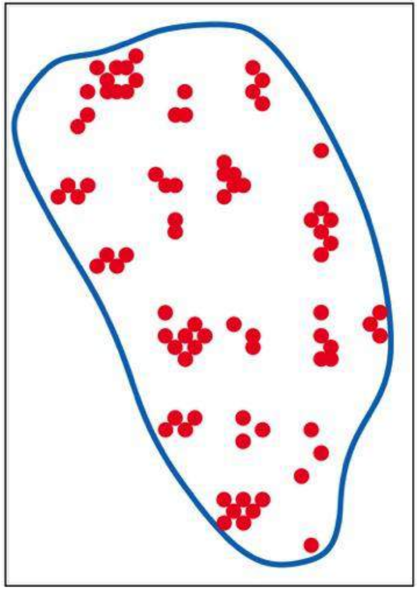
We can calculate the probability of clonal identity for the different distance classes (bottom right).

Data shows that the likelihood of clonal identity declines with increasing distance and that sampling shoots at 30m will ensure that samples are unique genotypes.

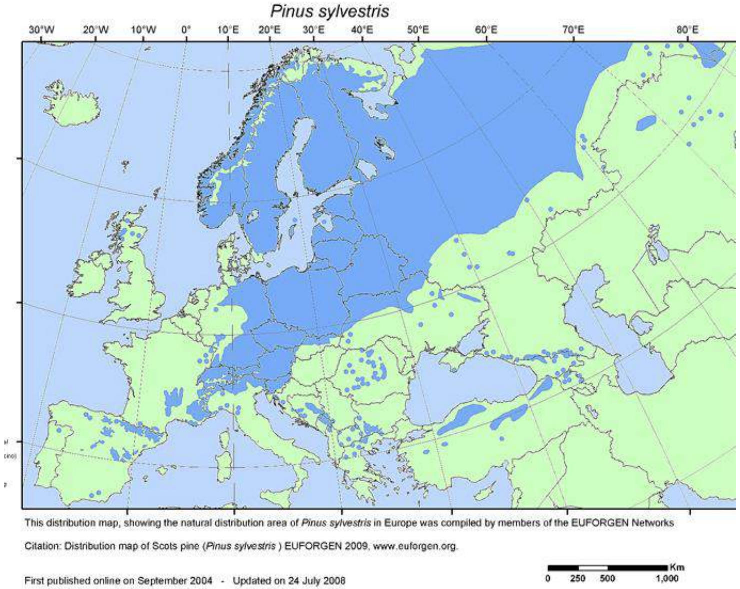
Alberto F et al., (2008). Journal of Biogeography

1. Properties of populations

The **distribution** of a population defines it spatial location - the area over which it occurs. The geographic distribution range of a species encompasses <u>all individuals of a species</u>.



A hypothetical population: each red dot represents an individual organism. The blue line defines the population distribution range.



Distribution range of Scots Pine (*Pinus sylvestris L.*). This widely distributed species is referred to as **<u>ubiquitous</u>**.

1. Properties of populations

A species with a high distribution range is defined as **ubiquitous**, while a species with a restricted range is referred to as **endemic**.

Many endemic species are endangered or threatened because of this.

The shale-barren evening primrose (*Oenothera argillicola*) is an endemic species found only on shale outcrops on south-facing mountain slopes in the Allegheny Mountains

1. Properties of populations

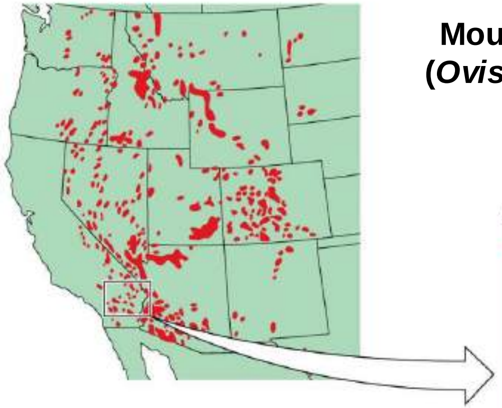
A species is rarely composed of a single, continuous interbreeding population. Instead, it is usually a group of **subpopulations** = local populations of interbreeding individuals linked by movement of individuals living in suitable habitat patches surrounded by unsuitable ones.

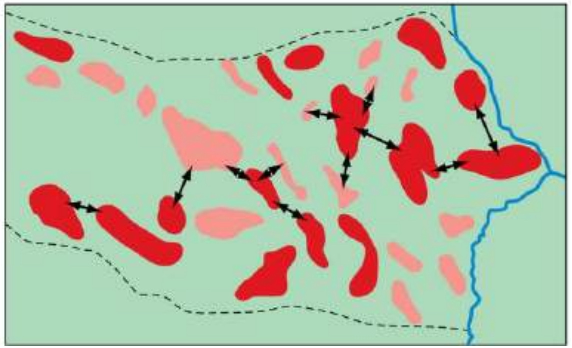
Genetic variation can be found:

- within subpopulations
- among subpopulations

A **metapopulation** is the collection of all local subpopulations.

Mountain sheep (*Ovis canadensis*)



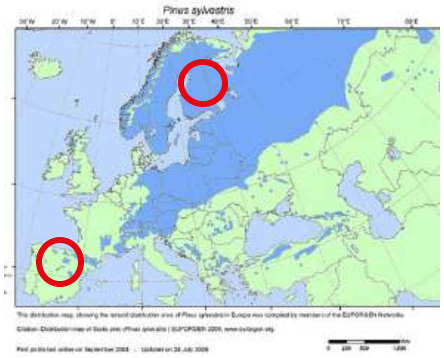


Geographical distribution of Mountain sheep in the western USA. The species is composed of several subpopulations.

1. Properties of populations

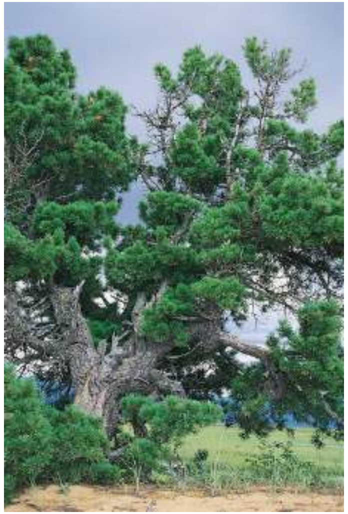
The distribution range is limited by tolerance to different environmental conditions, including temperature, soil moisture, and elevation.

Species with wide distribution ranges will encounter a broader range of environmental conditions than species with a more restricted distribution.



- Variation in environmental conditions leads to genetic variation due to different selective pressures in various situations.

- The farther apart populations live, the more pronounced this variation becomes


Spain

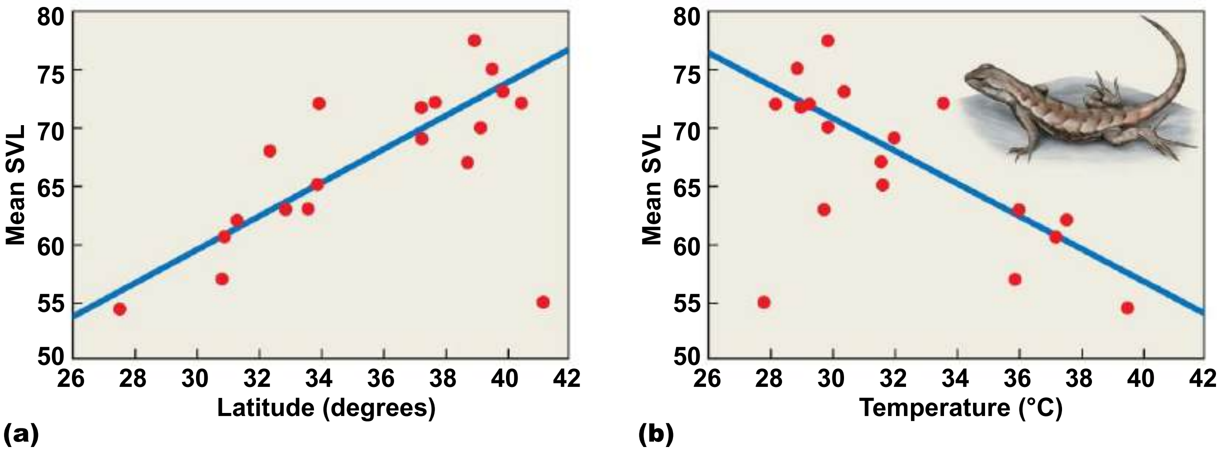

Finland

1. Properties of populations

Geographic variation within a species in response to changes in environmental conditions can result in the evolution of **clines and ecotypes.**

A **cline** reflects a change over a geographic region in a trait. Clines follow environmental gradients that varies continuously over the geographic region (e.g., elevation, latitude).

The fence lizard has a cline in body size (SVL) across its range.



1. Properties of populations

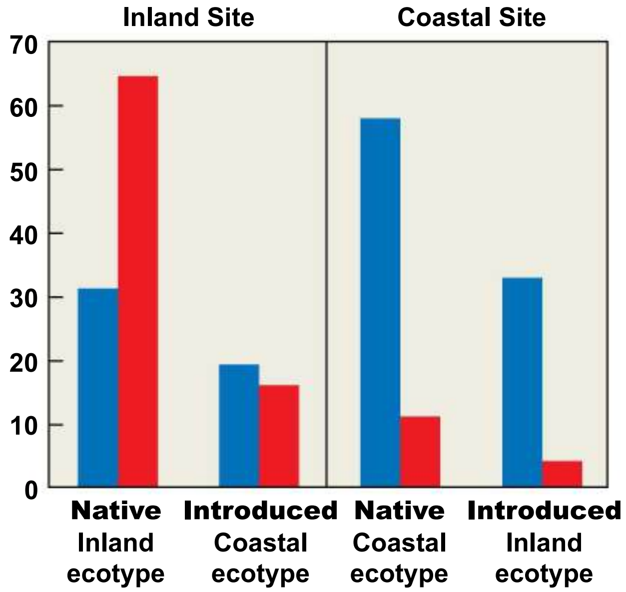
Step clines indicate abrupt changes in the environment and the phenotype and genotype organisms.

1. Properties of populations

Step clines indicate abrupt changes in the environment and the phenotype and genotype organisms.

These variants in different populations are called **ecotypes** - a population adapted to its unique local environmental conditions.

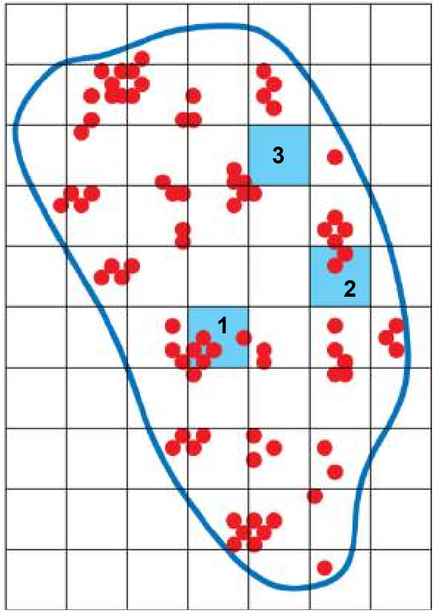
Ecotypes differ from other populations in several traits. They are an early stage of speciation, potentially leading to different subspecies under continued isolation and selection.



Estimates of fitness (plant size as measured by the number of leaves and seeds produced per plant) for inland agricultural sites and coastal ecotypes of the annual plant *Diodia teres* planted at each of the two sites. Ecotypes perform better in their native habitat.

1. Properties of populations

The **size** of a population is defined by its **abundance (the number of individuals)**.



Abundance depends on population density and the area over which the population is distributed.

- Abundance is the total number of individuals in the population (all red dots).
- Population density is defined as the number of individuals per unit area. If we assume that each grid cell is 1 m^2, the density of grid cell #1 is 5 individuals/m^2.

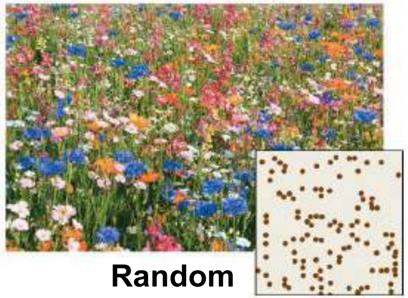
1. Properties of populations

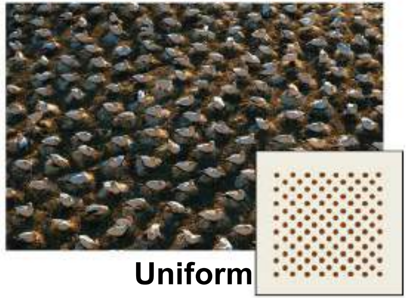
Individuals are not usually evenly distributed over the geographic range. There are 3 distribution patterns:

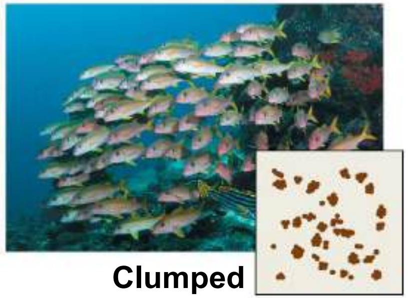
- **Random distribution:** the position of one individual is independent on the position of other individuals.

- **Uniform distribution:** organisms are found at a regular distance from one another. This is often the result of negative interactions among individuals.

- **Clumped distribution**, individuals are found in groups. This is the most common spatial distribution and results from a number of factors.





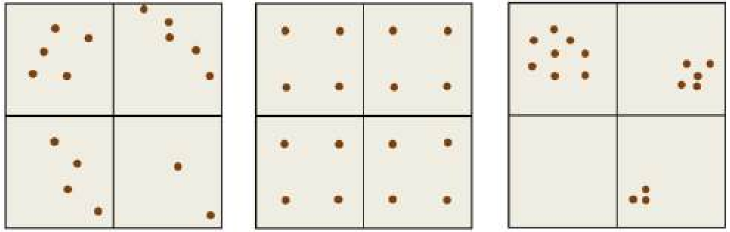


1. Properties of populations

How can we determine the abundance of a population?

Population size = population density × the area occupied

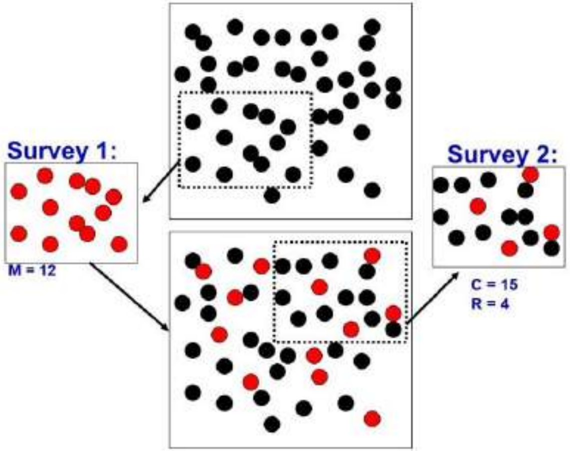
- A complete count may be possible if the abundance and area occupied are small.
- For larger areas, if an organism is sessile, sampling can be done using quadrats along transects.
- The accuracy of this method depends on the spatial distribution of individuals.



1. Properties of populations

For mobile organisms, **mark-recapture** is commonly used to measure population size. This method is based on:

- capturing several individuals in a population and marking them (t1)
- releasing marked individuals back into the population, and after an appropriate period (t2), recapture several individuals in the population.



$$\frac{N}{M} = \frac{n}{R} \Rightarrow N = \frac{nM}{R}$$

N = total individuals (unknown)

M = marked individuals at t1

n = captured individuals at t2

R = recaptured individuals at t2

Researchers using mark-recapture sampling to estimate the population of Bristle-thighed Curlews. Captured birds are marked with leg flags to estimate population size.

1. Properties of populations

Other methods include observations of the presence of organisms (e.g., counts of vocalization and animal tracks).

The observations are converted to number of individuals heard per hour or seen per kilometer. **These are indices of abundance, not estimates of actual abundance**.

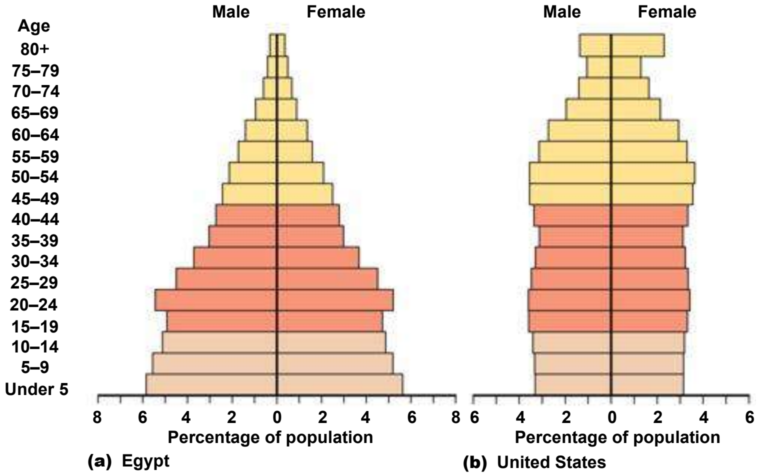
1. Properties of populations

Measures of population structure also include **age and developmental stage**.

- A population with non-overlapping generations does not have an age structure: individuals reproduce and die within a single season like in annual plants and some insects.
- A population with overlapping generations has an age structure:

-there are individuals in different age classes
-reproduction is restricted to certain age classes
-mortality is common in certain age classes

An age pyramid is a graphical representation of the age structure of a population. The shape of the pyramid can provide information on future population growth.



1. Properties of populations

The movement of individuals in a population directly influences subpopulation density and maintain gene flow between subpopulations.

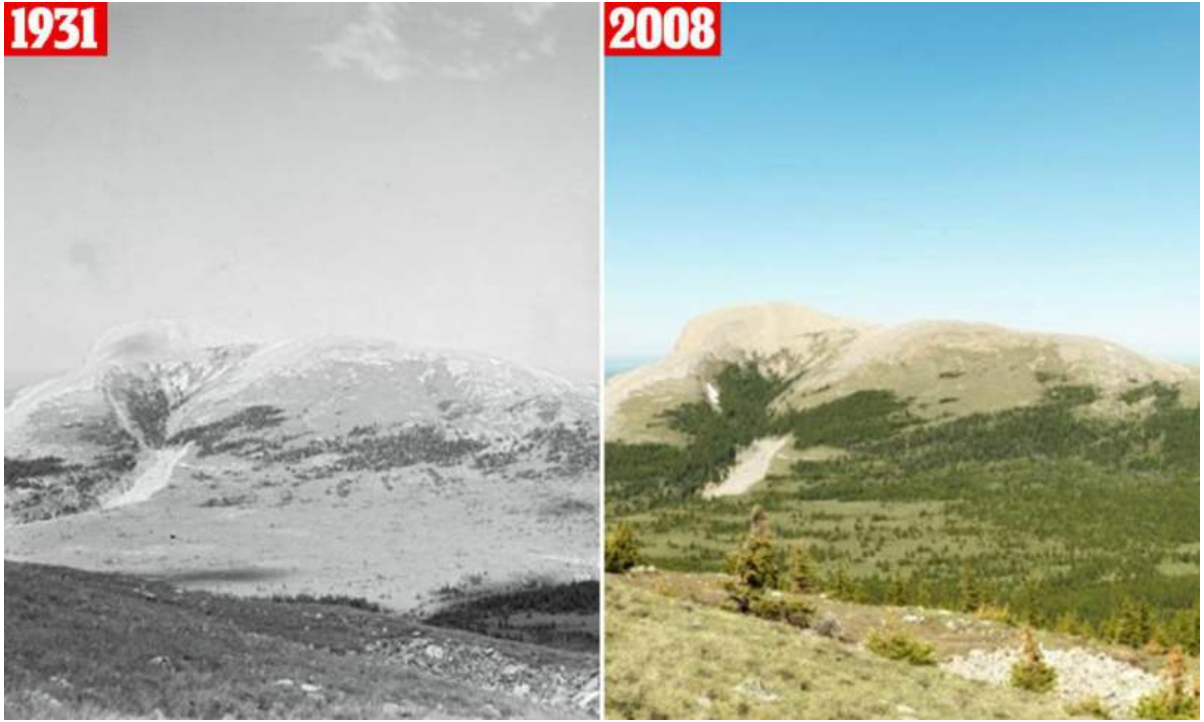
- **Dispersal** is the movement of individuals in space that can shift or expand the geographic distribution range of a population.

Many organisms depends on **passive dispersal** (wind, water, gravity, animals):

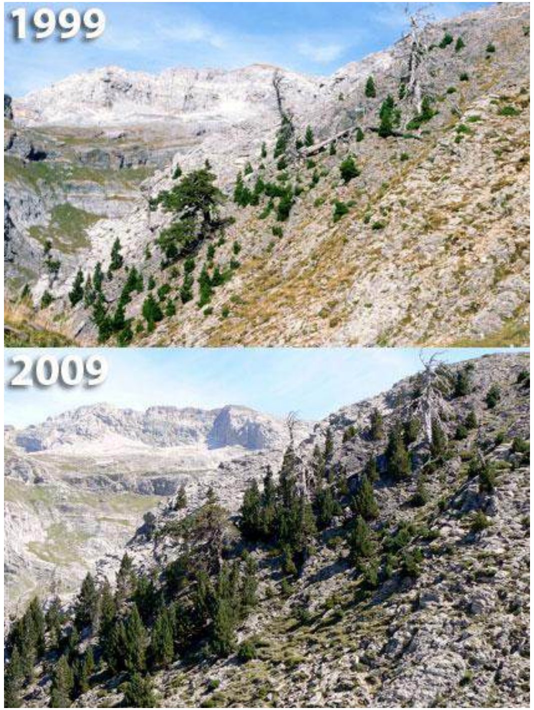
- Seeds of most plants fall near the parent plant. Generally, the heavier the seed, the shorter the dispersal distance. Wind can carry light seeds.
- Animals can be important dispersers of plant seeds. Some seeds are dispersed when an animal eats fruits and the seeds they contain. Seeds pass through the gut and are deposited in feces.
- Some seeds have spines or hooks that attach to animal fur or bird feathers.

1. Properties of populations

Shift in the tree line: because of warming, plant dispersal to higher elevations is occurring



Rocky mountains, Colorado, USA



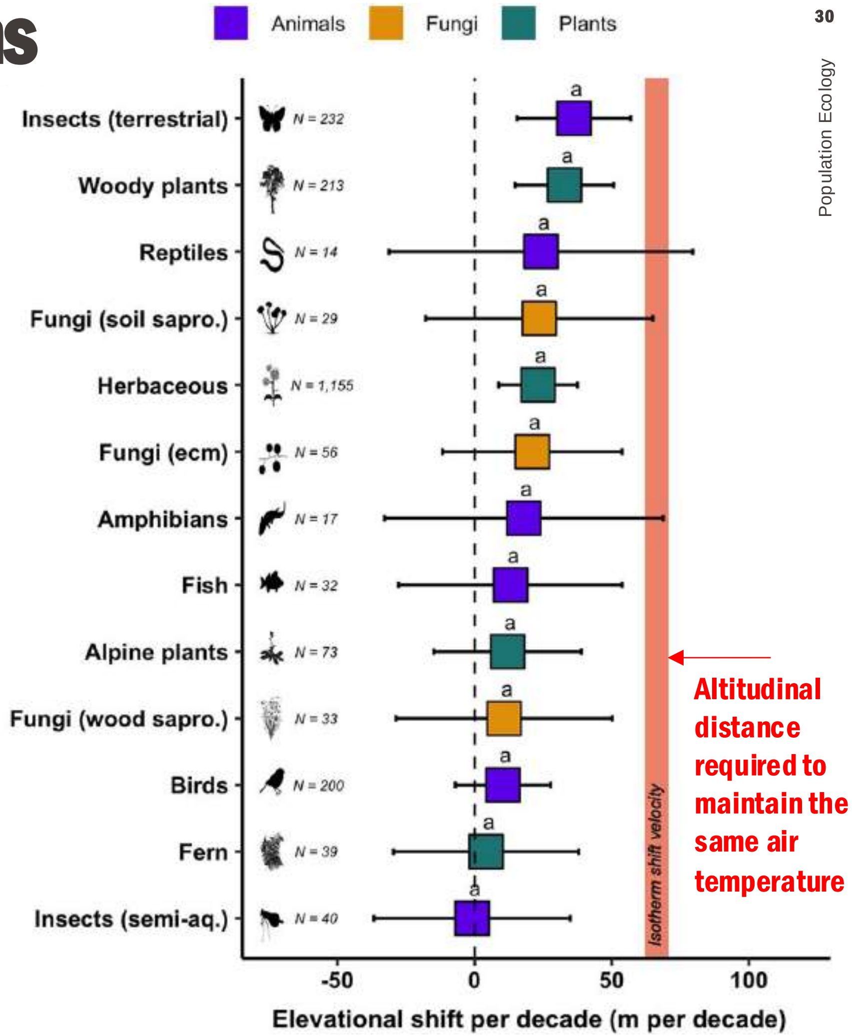
Alps, Switzerland

1. Properties of populations

- Land-use changes could explain some trends, but the consistent upward shift over the Alps is likely reflecting the substantial warming and the receding of snow cover that has taken place over recent decades.

- Except for insects, the upward shift of organisms seems too slow to track the pace of **isotherm shifts** induced by climate warming.

- Species interactions are likely to change over multiple trophic levels through phenological and spatial mismatches.



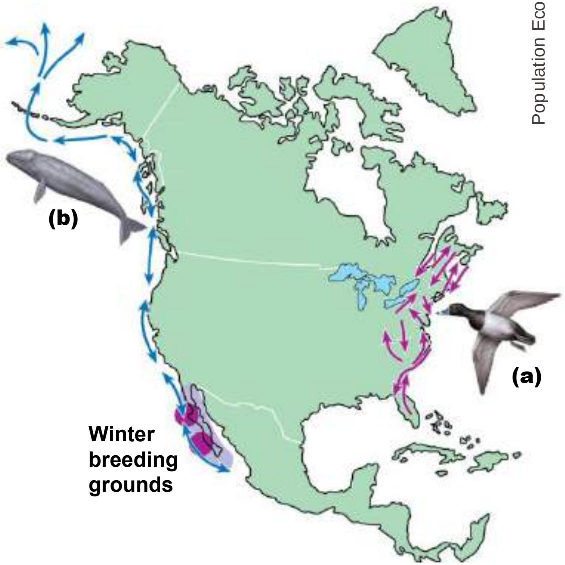
Vitasse et al., (2021) Biological Reviews

1. Properties of populations

Migration is the movement of organisms that is round-trip. These trips may be daily or seasonal.

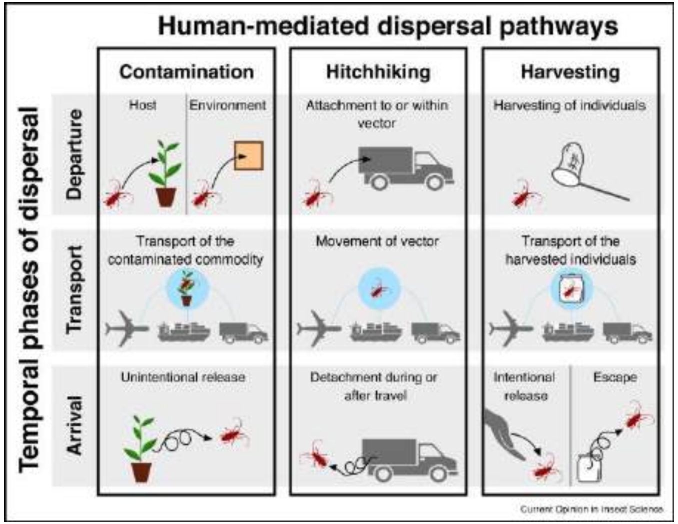
Examples:

- zooplankton move in the water column; lower depths during the day and the surface at night (predator avoidance)
- bats leave caves at dusk, move to feeding areas, then return at dawn
- earthworms move deep into the soil for winter to avoid freezing, then move back up in the spring
- gray whales feed in the Arctic during the summer, winter off the California coast where calves are born.

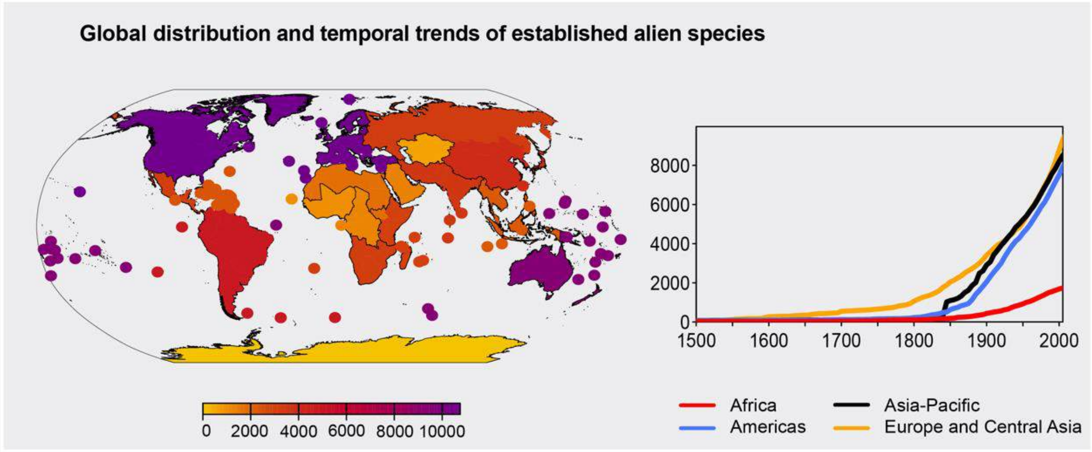


(a) Ringnecked ducks (*Aythya collaris*) breeding in the northeast migrate in a corridor along the coast to wintering grounds in South Carolina and Florida. **(b)** The gray whale (*Eschrichtius robustus*) summers in the Arctic and Bering seas; it winters in the Gulf of California and the waters off Baja California.

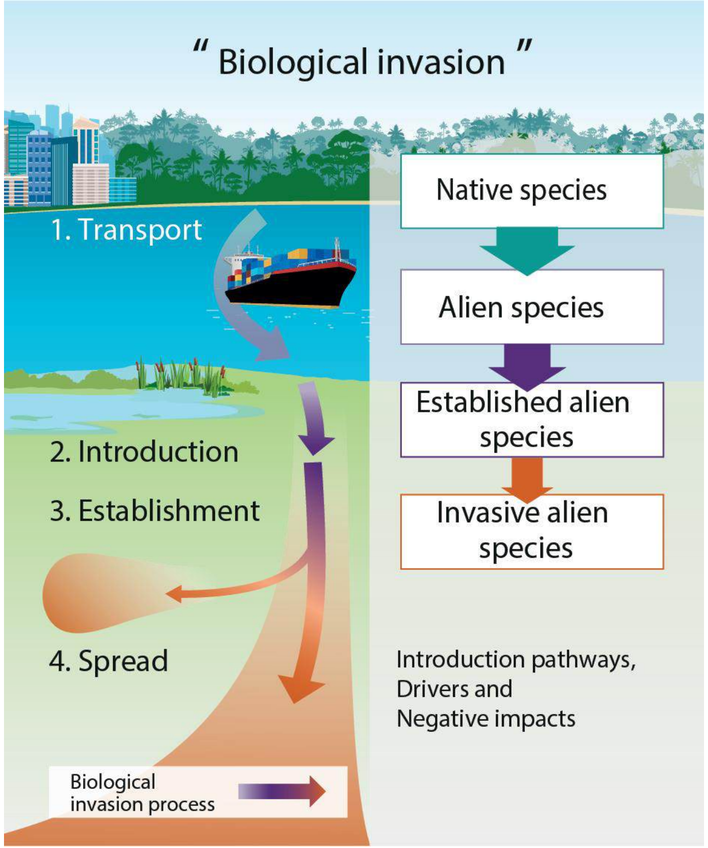
1. Properties of populations



Dispersal by humans has also led to the redistribution of species on a global scale. Freed from the constraints presented by their predators, parasites, and competitors in their native range, many species have become established and spread.



1. Properties of populations

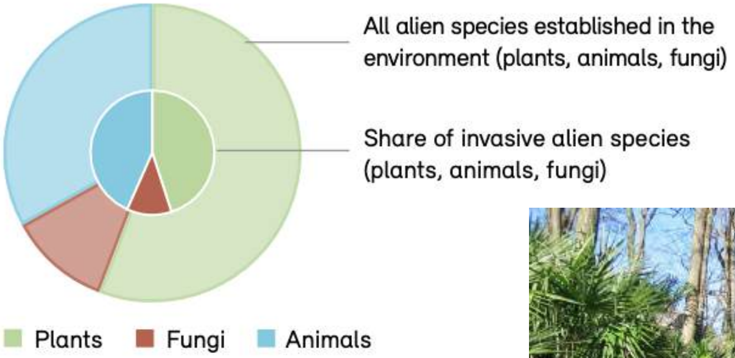


Invasive species – organisms successfully introduced to places they have never occurred. Sometimes the introduced species are harmless, but more often they have negative effects on native species and ecosystems.

Since they were first introduced in Australia by European settlers in the 17th century, feral cats have helped drive an estimated 20 mammal species to extinction.

1. Properties of populations

The windmill palm (*T. fortunei*) is one of the 800 exotic species present in Switzerland and it's highly invasive (107 species were considered invasive in Switzerland in 2006).



The palm spreads from gardens to forests, where it excludes native plant species and reduces local biodiversity. The mechanisms by which it outperforms native species are unclear.

1. Properties of populations

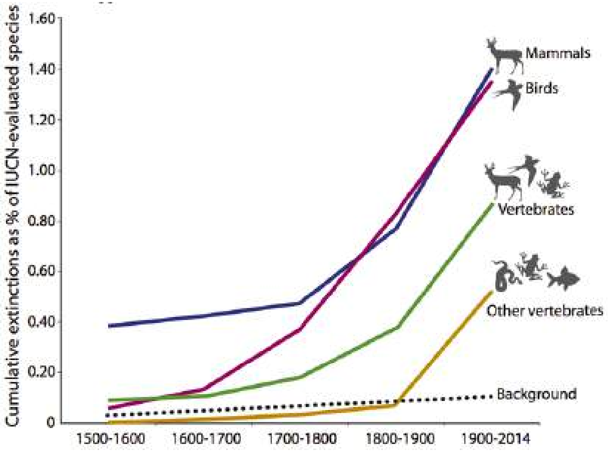
Populations that are declining in size (deaths exceed births) can eventually become extinct.

Small populations are more vulnerable to extinction because of **loss of genetic variability** and increased vulnerability to:

- **Demographic stochasticity -** the random variation in birth and death rates
- **Environmental stochasticity -** the random variation in the environment that can influence birth and death rates in a population.

Extreme environmental events can increase mortality and reduce population size. If environmental conditions exceed the bounds of tolerance for the species, an extreme event could lead to extinction.

Human activities are causing massive extinction rates (cf. lecture 10).



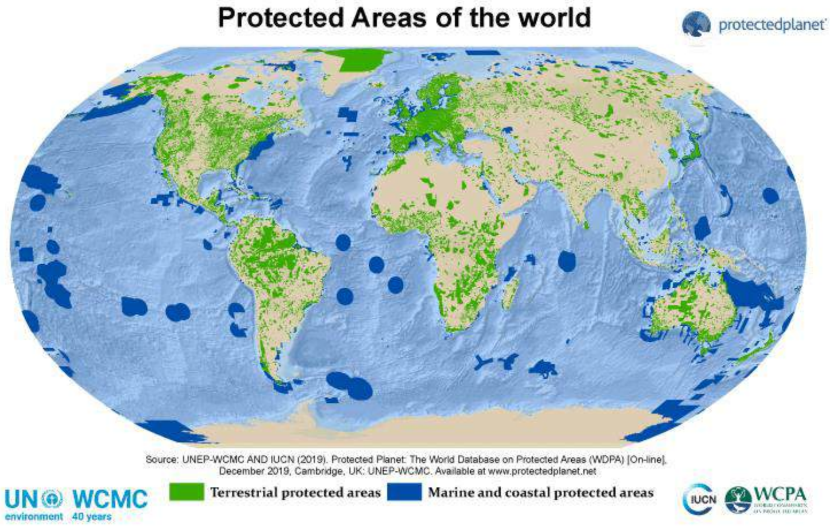
1. Properties of populations

<u>Applications:</u> Human activities often affect other organisms through loss or degradation of their habitat. Currently about 5000 animal and 7000 plant species are classified as vulnerable. Many vulnerable populations are restricted to protected areas.

How can we decide how large these protected areas must be to keep a population viable?

(1) Determine the Minimum Viable Population (MVP) – the number of individuals necessary to ensure the long-term survival of a species.

The number of individuals must be large enough to withstand chance variations in:
- births and deaths
- environmental changes
- genetic drift

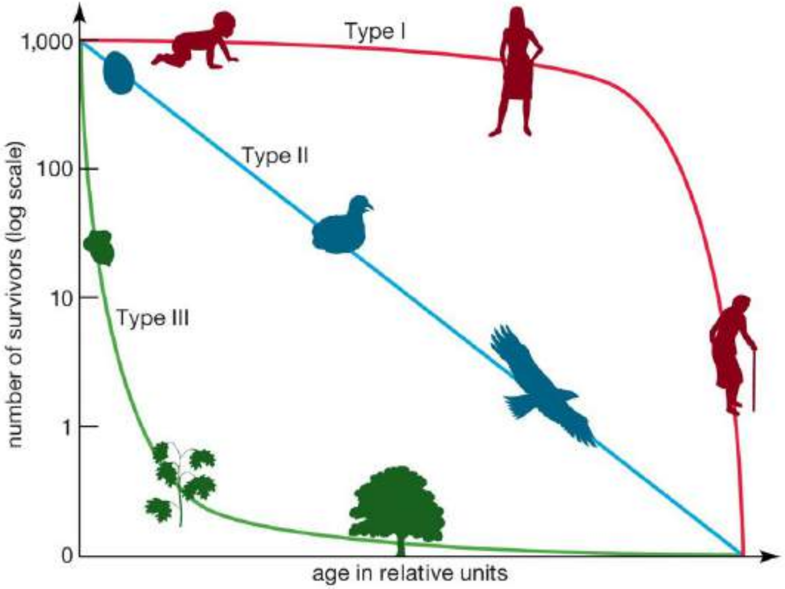


Map of protected areas. UNEP-WCMC (2019). Available at: www.protectedplanet.net

1. Properties of populations

How is the Minimum Viable Population (MVP) determined?

It depends on the **life history** (i.e., the patterns of survival and reproduction) of the species and the **ability of individuals to disperse** among habitat patches.



1. Properties of populations

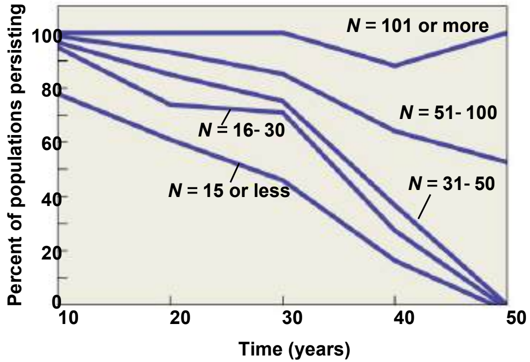
Relationship between the percentage of bighorn sheep populations persisting and time (years). *N* represents population size.

How is the Minimum Viable Population (MVP) determined?

It depends on the **life history** (i.e., the patterns of survival and reproduction) of the species and the **ability of individuals to disperse** among habitat patches.

Genetic models suggest that populations of **less than 1000 individuals are highly vulnerable to extinction**. For species that have large fluctuations in population size (many annual plants), the estimated MVP is 10,000.

This study on bighorn sheep populations provides one of the best-documented cases of MVP size (Berger, 1990, University of Montana). They examined 120 populations.



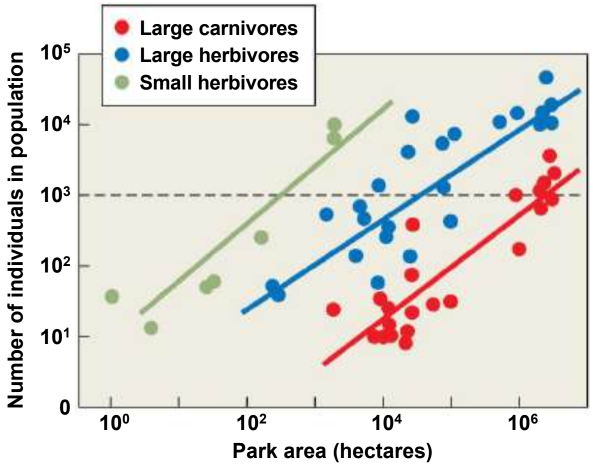
1. Properties of populations

(2) Once the **MVP** for a species has been determined, the area needed to support the population must be estimated.

This is the **minimum dynamic area** (**MDA**). It needs to consider:

- Carrying capacity of the habitat (nb. of individuals the resources available in a habitat can support)
- The home range size of individuals (amount of space used).

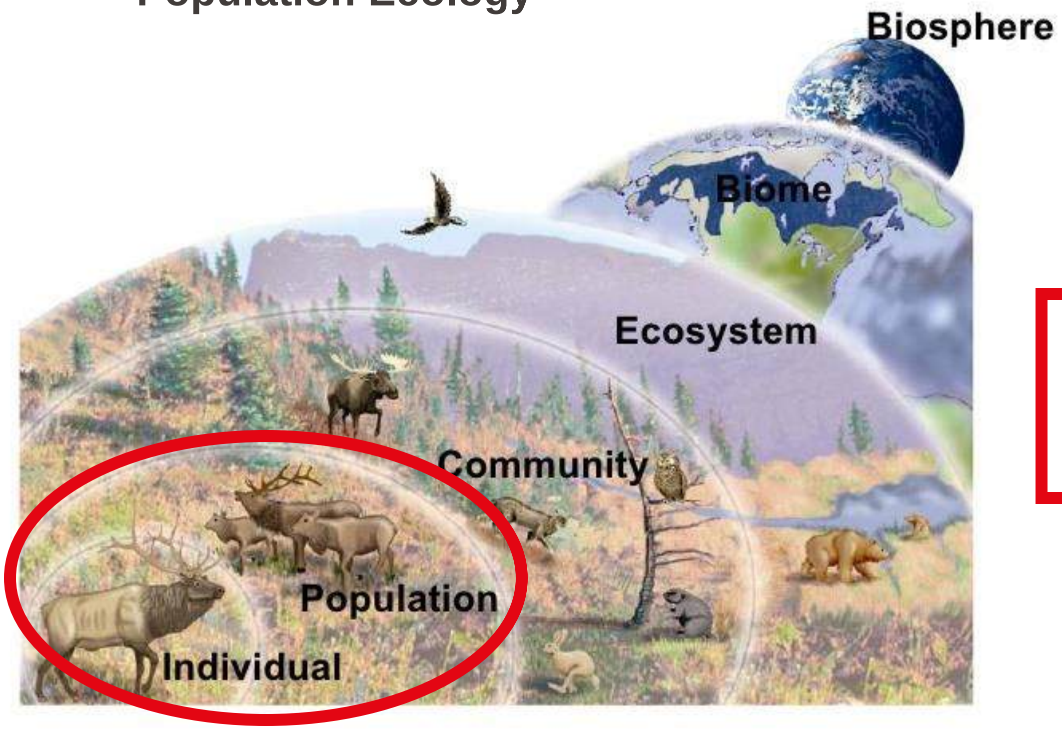
MDA gives an estimate of the area requirement per individual. With an estimate for both MDA and MVP, the area needed to maintain a viable population can be determined.



Large parks contain larger populations than small parks; only the largest parks may contain long-term viable populations of many large vertebrate species. If a species's minimum viable population (MVP) is 1000 (dashed line), parks of at least 100 ha will be needed to protect small herbivores. More than 10,000 hectares will be required to support populations of large herbivores, and parks of at least 1 million hectares will be needed to protect large carnivores.

Overview of today's class

Population Ecology

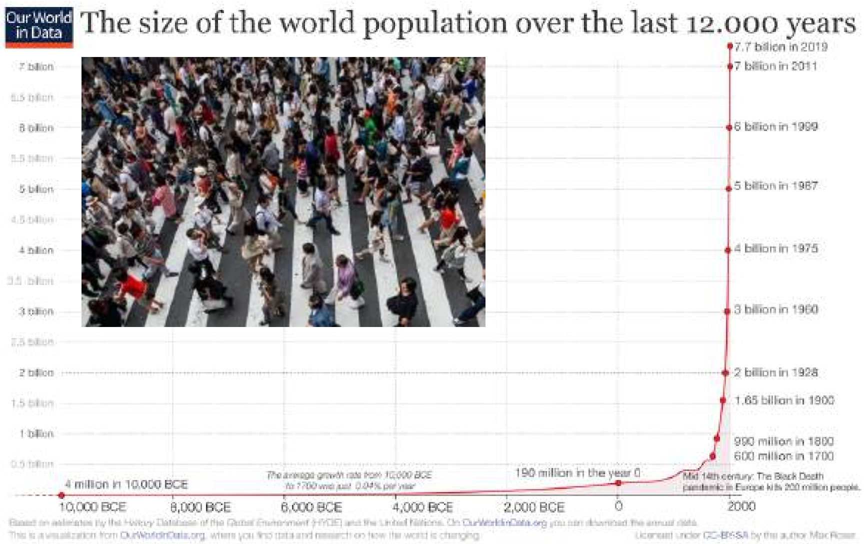


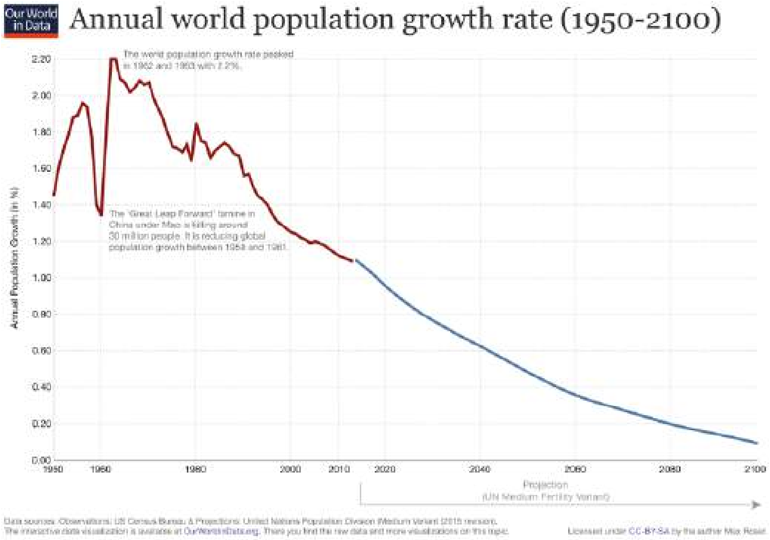
I. Properties of populations

II. Intraspecific population regulation

1. Properties of populations

No population can grow indefinitely. As the population density increases, resource availability per capita decreases. Eventually, this reduced availability will regulate population growth.



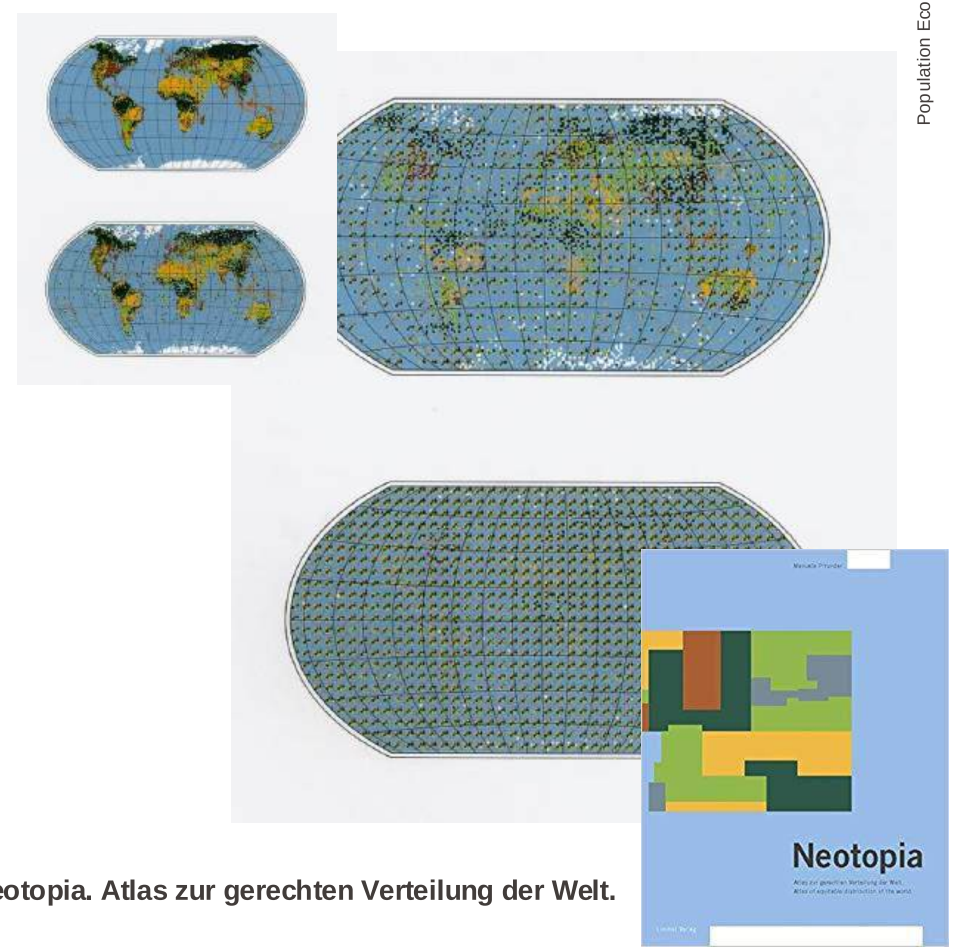


For the last half-century, the population growth rate (percentage change in population per year) has been declining. The UN projects that this decline will continue in the coming decades (blue line). Over two centuries, the sevenfold increase in the world population amplified humanity's impact on the natural environment.

1. Properties of populations

What would the world look like if everyone had the same resources as everyone else?

- 8.5 kg meat and 20 kg fish per year
- One coffee every 60 days
- 8 g cheese per year
- 19 L beer per year
- A new pair of jeans every 70 years
- We are refugees for 5 months; half of this time, we are less than 10 years old
- We suffer from hunger 60 days per year…

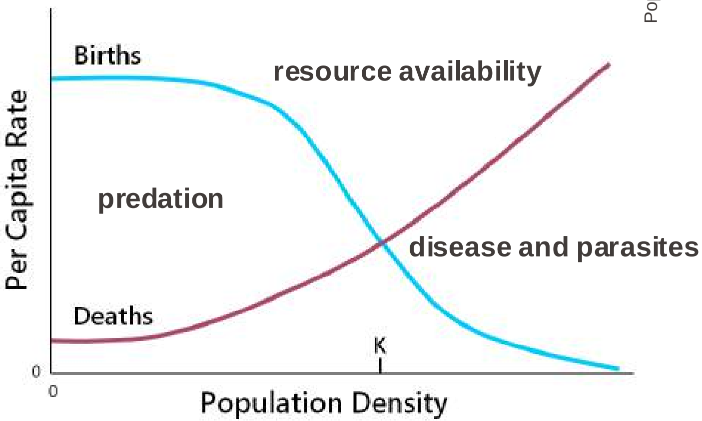


Pfrunder 2002. **Neotopia. Atlas zur gerechten Verteilung der Welt.**

1. Properties of populations

Density-dependent population regulation affects a population in proportion to its size. Density can regulate population size in two ways:

- **Density-dependent mortality** - As population density increases, the rate of mortality increases
- **Density-dependent fecundity** - As population density increases, the rate of fecundity decreases



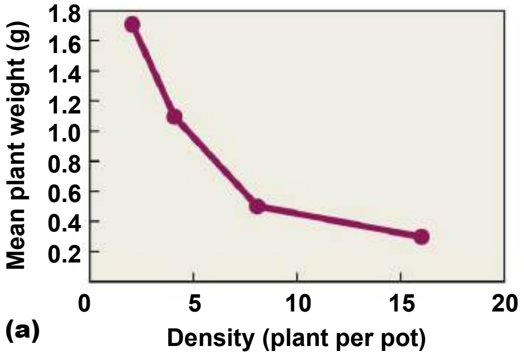
Factors that affect density-dependent regulation include reduced resource availability, changes in predation patterns, or the spread of disease and parasites.

Density-independent regulation factors - environmental events that affect the population regardless of the number of individuals (e.g. , floods, fires, storms).

1. Properties of populations

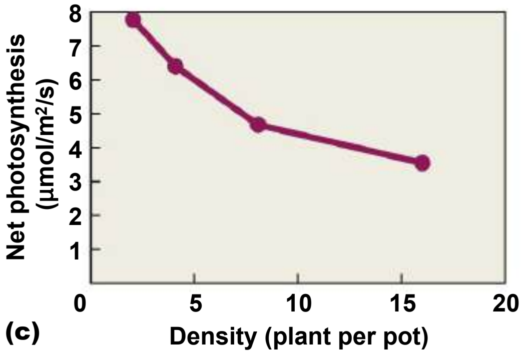
Intraspecific competition affects **growth and development**. As population density increases, resources become limited. Either some or all individuals reduce their use of resources, generally slowing growth and development first.

Example:



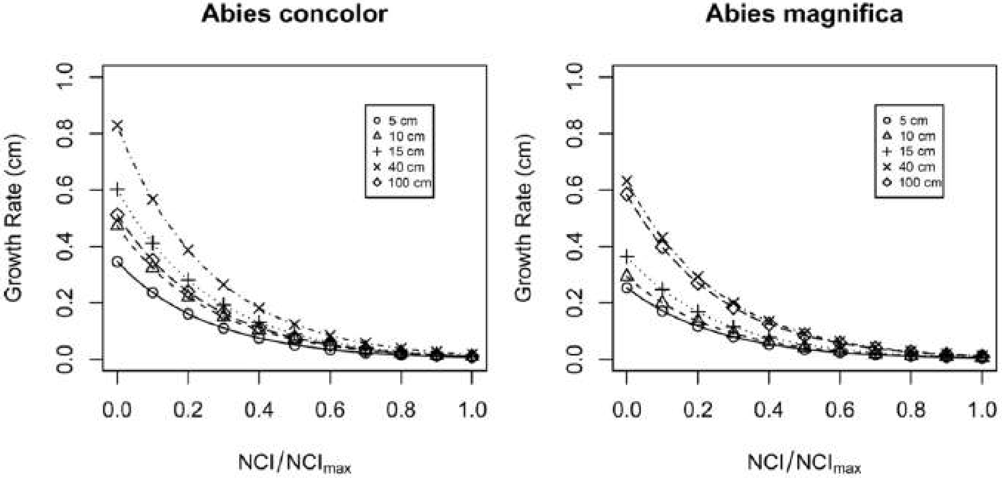
Salt marsh spear-leaved orache plants were grown in growth chambers at different densities. After four weeks, photosynthesis and plant weight were measured.

High-density plants showed reduced weight and photosynthesis compared to the lowest density. This result could suggest that growth inhibition at high density is partially the result of a decline in the net rate of carbon uptake (fewer carbohydrates are allocated to growth).



1. Properties of populations

Example: Change in growth rate with competition. Growth rate with competition was calculated for trees of six different diameters (5, 10, 15, 40, and 100 cm). The competition index (NCI) is scaled against the maximum value seen in the data.



Competition index:

$$NCI_{focal} = (DBH_{focal})^{\gamma} \sum_{i=1}^{s} \sum_{j=1}^{n_i} \lambda_i \frac{(DBH_{ij})^{\alpha}}{(distance_{ij})^{\beta}}$$

DBH_{focal} is the diameter at breast height of the focal tree, $_i$ is a species- or group-specific coefficient that ranges from 0 to 1 and allows the competitive strength to vary for each species or group, DBH_{ij} is the diameter at breast height of the competitor tree *j* of species *i*, $distance_{ij}$ is the distance between the focal tree and competitor tree *j* of species *i*.

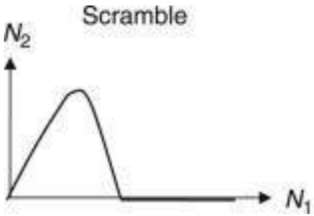
1. Properties of populations

Competition happens when individuals use a limited shared resource.

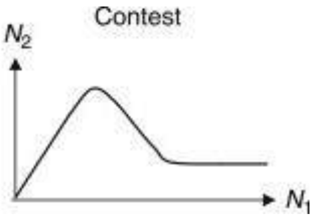
Intraspecific competition is competition among individuals of the **same species**. Members of the same species usually have very similar resource requirements.

Two responses to limited resources:

Scramble competition – as competition becomes more intense, growth and reproduction are depressed equally among all individuals. Scramble competition can result in all individuals having insufficient resources lead to extinction of the population.



Contest competition – some individuals claim enough resources for themselves while denying others a share of those resources. Contest competition only negatively affects the unsuccessful individuals; the successful individuals continue to survive and reproduce.



N_1=size of population before competition; N_2=size of population after competition

3. Exercices

Question: You have been tasked with setting up a protected area that could host a vulnerable population of a large predator species (grizzly bear). Describe (1) how you would estimate the number of individuals you would establish in the protected area and the associated risks to consider regarding the population size, and (2) how large the protected area should be and what needs to be considered to establish the size of the area. *At the exam in 2023*

Answer: When setting up a protected area, the first step is to determine the minimum viable population, i.e., the number of individuals necessary to ensure the long-term survival of the species. This number must be large enough to withstand chance variations in births and deaths, environmental changes, genetic drift and catastrophic events. As the grizzly bear is a predator species, one could use the information from genetic models that suggest a minimum of 1000 individuals.

The second step is to estimate the minimum dynamic area, i.e., the area needed to support the population. This area depends on the carrying capacity of the habitat (the number of individuals the resources available in the habitat can support) and the home range size of the individuals (the amount of space needed). Typically for a population of 1000 grizzly bears, this area needs to be about 2 million km2.

3. Exercices

Short Answer Questions (*at the exam in 2023*)

1) An individual tree or plant produced by sexual reproduction and thus arising from a zygote is a genetic individual, known as a(n) _________.

Answer: Genet

Next week

Community ecology