Ecological Principles and Biodiversity for Sustainability

Dr. Ankur Awadhiya, IFS

5. Introduction to Behavioural Ecology

Definitions

Behavioural Ecology: Behavioural ecology is the study of the evolutionary basis for animal behaviour due to ecological pressures.

Behaviour: The ways that organisms respond to each other and to particular cues in the environment are called behaviours.

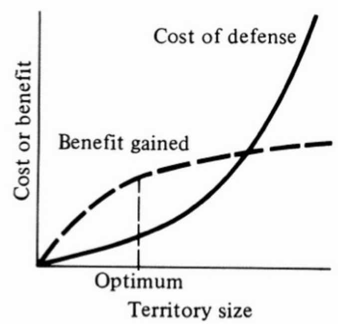
Ethology: The scientific study of animal behaviour

Some topics of study

1. foraging behaviours
2. anti-predator behaviours
3. social behaviours
4. mating behaviours, etc.

The Cost-Benefit approach

Cost-Benefit analysis: An assessment to determine whether the cost of an activity is less than the benefit that can be expected from that activity.



(Pianka, Evolutionary Ecology)

Costs and benefits of group-living for lions

Table 1: Costs and benefits of group-living for lions

Sex	Cost	Benefit
Male	Sharing of paternity	1. Increased access to mates 2. Protection of offspring against infanticide
Female	Lower rate of food intake	1. Help from kin 2. Territorial defense

Why do herbivores live in groups?

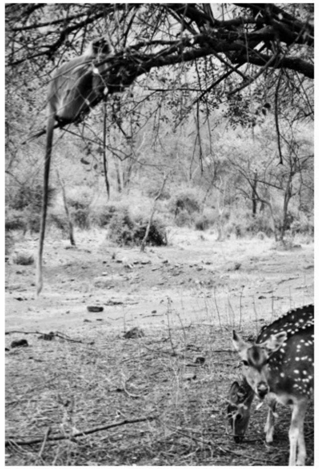
(Ankur Awadhiya 2016 Kaziranga TR)

Potential benefits and costs of group-living animals

Table 2: Potential benefits and costs of group-living animals

Potential costs	Potential benefits
Competition for food Increased risk of disease Increased risk of parasites	Increased foraging efficiency
Attraction of predators	Reduced predation: Safety in group
Loss of paternity Brood parasitism	Increased access to mates
Loss of individual reproduction	Help from kin: defence and raising

Langur-chital association



(Ankur Awadhiya 2017 Sariska TR)

When do squirrels call?

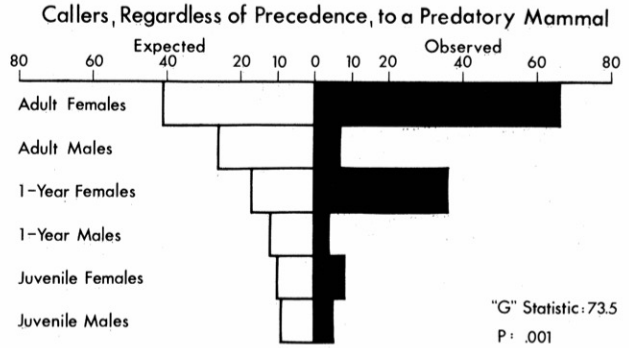


Fig. 3. Expected and observed frequencies of alarm calling by various sex and age classes of Belding's ground squirrels. "Expected" values were computed by assuming that animals call randomly, in direct proportion to the number of times they are present when a predatory mammal appears. The overall significance of both comparisons is largely due to females calling more often than "expected" and males calling infrequently. Data are from 102 interactions between ground squirrels and predators (1974–76).

(Sherman 1977 *Science*)

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Concept of kin selection

Kin selection: The evolution of traits that increase the survival, and ultimately the reproductive success, of one's relatives.

Group selection: Natural selection for traits that favour groups rather than individuals.

Because group selection operates much more slowly than individual selection, it is a much weaker selective force in most circumstances.

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Hamilton's rule

Genes increase in frequency when

$$rB > C$$

where

r = the genetic relatedness of the recipient to the actor, often defined as the probability that a gene picked randomly from each at the same locus is identical by descent.

B = the additional reproductive benefit gained by the recipient of the altruistic act,

C = the reproductive cost to the individual performing the act.

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Hamilton’s rule: Haldane’s statement

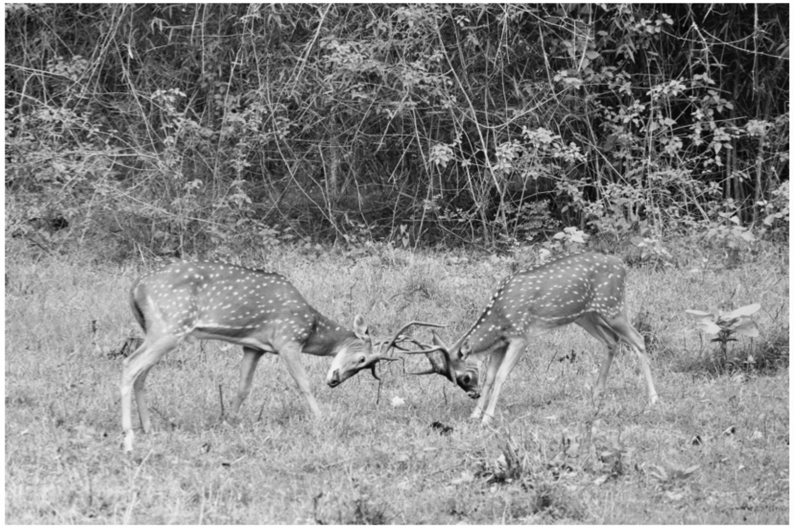
If an individual loses its life to save two siblings, four nephews, or eight cousins, it is a “fair deal” in evolutionary terms, as siblings are on average 50% identical by descent, nephews 25%, and cousins 12.5%.

Territoriality in animals

Definition: Territoriality is a type of intraspecific or interspecific competition that results from the behavioural exclusion of others from a specific space that is defended as a territory.

Purpose: Animal territoriality aims at excluding conspecifics (or, occasionally, animals of other species) from certain areas through the use of auditory, visual or olfactory signals as well as aggressive (or ritualised) behaviours.

Chital fighting



(Ankur Awadhiya 2018 Mudumalai TR)

Blackbuck fighting

(Ankur Awadhiya 2018 Velavadar NP)

Rhinoceros fighting

(Ankur Awadhiya 2018 Kaziranga TR)

Penguins fighting

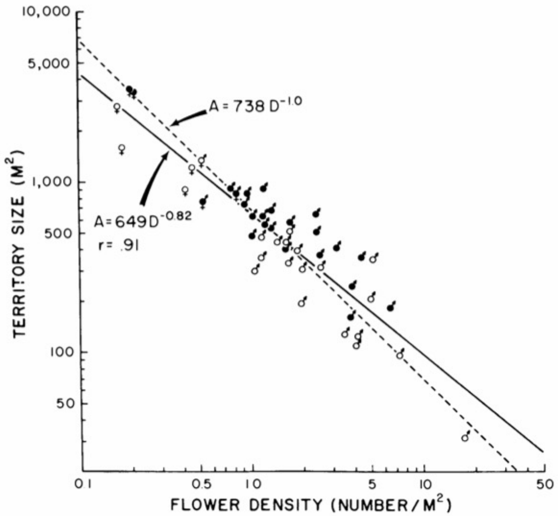
(Ankur Awadhiya 2018 Boulders NP)

Costs and benefits of territorial behaviour

Table 3: Costs and benefits of territorial behaviour

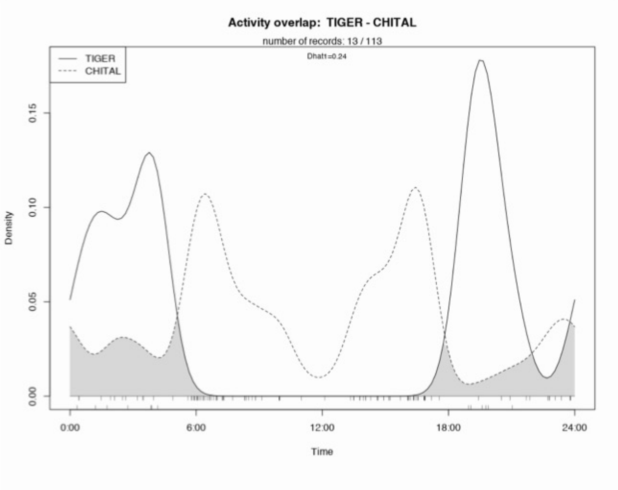
Costs	Benefits
1. Increased energy usage	1. Exclusive access to resources
2. Increased risk of predation	2. Regulates the size of population
3. Increased time demands	3. Once established, territory reduces competition

Territoriality: A behaviour regulated by the environment?



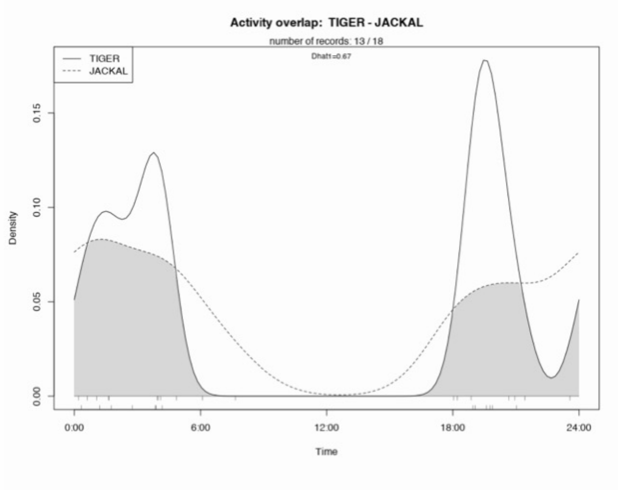
(Kodric-Brown and Brown 1978 *Ecology*)

Methods: Information from activity patterns



(Ankur Awadhiya 2017 Sariska TR)

Tiger-jackal interaction



(Ankur Awadhiya 2017 Sariska TR)

Methods: Ethograms

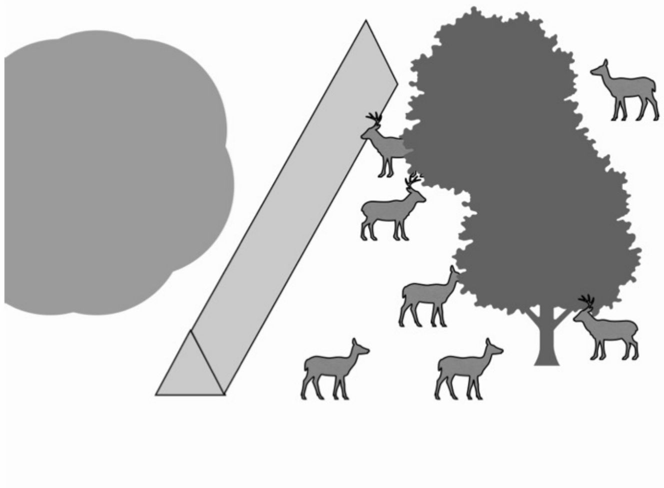
An ethogram is an inventory of behaviours exhibited by an animal during a behaviour exercise.

Making ethograms

Steps:

1. Description of study site
2. Defining behaviours
3. Scan sampling
4. Focal animal study
5. Time budget analysis

Description of the study site and setting



(Ankur Awadhiya 2017 Sariska TR)

Defining acts

Sitting: Abdomen touching ground, legs folded, stationary

(Ankur Awadhiya 2017 Sariska TR)

Defining acts

Standing: All hooves touching ground, legs straight, animal stationary, a sub-dominant interval during walking or feeding

(Ankur Awadhiya 2017 Sariska TR)

Defining acts

Walking: Animal moving at slow pace with at least one hoof touching ground at all times

(Ankur Awadhiya 2017 Sariska TR)

Defining acts

Looking: Animal stationary, ears raised in alert position, actively looking around

(Ankur Awadhiya 2017 Sariska TR)

Defining acts

Feeding: Mouth towards ground, eating grass

(Ankur Awadhiya 2017 Sariska TR)

Defining acts

Running: Animal moving at fast pace with at least some times where all hooves are above ground

(Ankur Awadhiya 2017 Sariska TR)

Defining acts

Auto-grooming: Scratching or licking some part of own body

(Ankur Awadhiya 2017 Sariska TR)

Defining acts

Allo-grooming: Scratching or licking some part of other's body

(Ankur Awadhiya 2017 Sariska TR)

Scan sampling

In the scan sampling method, we noted the beginning time of observation, and then scanned the complete group, noting the activities that different individuals were displaying.

Scan sampling

Obs: Ankur Awadhiya	Date: 06/12/2017	Weather: Cloudy
TR: Sariska	Range: Sariska	Beat: Karnikavas
Location: Water hole	Start: 15:14 hours	End: 15:47 hours
Species: Chital	Terrain: Flat	

Time in	Adult Male	Adult Male	Adult Male	Sub-adult Female	Juvenile Female	Juvenile Female	Juvenile Female	Time out
14:55	Walking	Feeding	Feeding	Feeding	Feeding	Looking	Walking	14:56
14:57	Feeding	Feeding	Walking	Feeding	Walking	Feeding	Feeding	14:57
14:58	Feeding	Looking	Running	Running	Feeding	Looking	Alert	14:59
15:00	Feeding	Feeding	Running	Feeding	Feeding	Walking	Feeding	15:00
15:00	Walking	Looking	Walking	Walking	Walking	Feeding	Feeding	15:01
15:02	-	Standing	Standing	Feeding	Looking	Feeding	Running	15:03
15:04	-	Walking	Feeding	Walking	Walking	Feeding	Feeding	15:05
15:06	-	Walking	Walking	Standing	Walking	Feeding	Feeding	15:06
15:07	-	Looking	Running	Feeding	Walking	Feeding	Feeding	15:08

Focal animal study

In the focal animal sampling, one individual is observed carefully for a set time (say, of 5 minutes). In this period, the times spent by the animal in different activities were recorded.

Focal animal study

Obs: Ankur Awadhiya		Date: 06/12/2017	Weather: Cloudy	
TR: Sariska		Range: Sariska	Beat: Karnikavas	
Location: Water hole		Start: 15:14 hours	End: 15:47 hours	
Species: Chital		Terrain: Flat		
Individual 1: Adult male				
S. No.	Behaviour	Start	End	Time spent
1	Feeding	15:14:40	15:15:05	25s
2	Walking	15:15:05	15:15:27	22s
19	Walking	15:19:30	15:20:00	30s
20	Running	15:20:00		
Individual 2: Adult male				
S. No.	Behaviour	Start	End	Time spent
1	Looking	15:24:43	15:25:59	1m 16s
2	Walking	15:25:59	15:26:09	10s
19	Walking	15:31:01	15:31:20	19s
20	Feeding	15:31:20		
Individual 6: Juvenile female				
S. No.	Behaviour	Start	End	Time spent
1	Feeding	15:41:59	15:43:20	1m 21s
2	Walking	15:43:20	15:43:45	25s
19	Feeding	15:46:45	15:46:47	2s
20	Walking	15:46:47		

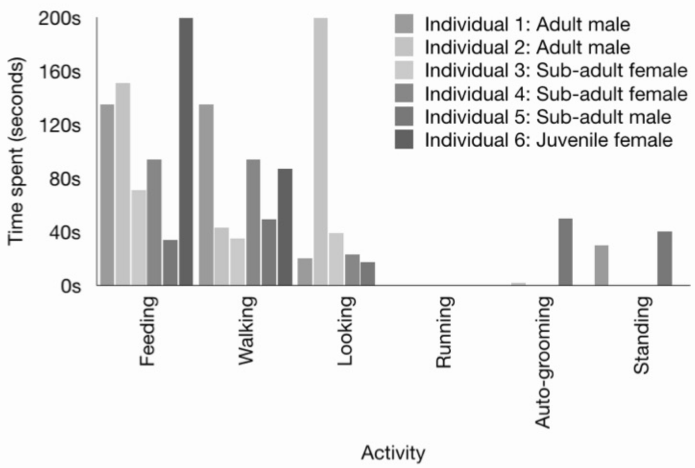
Time budget table

Table 4: Summary of times spent by individuals on different activities

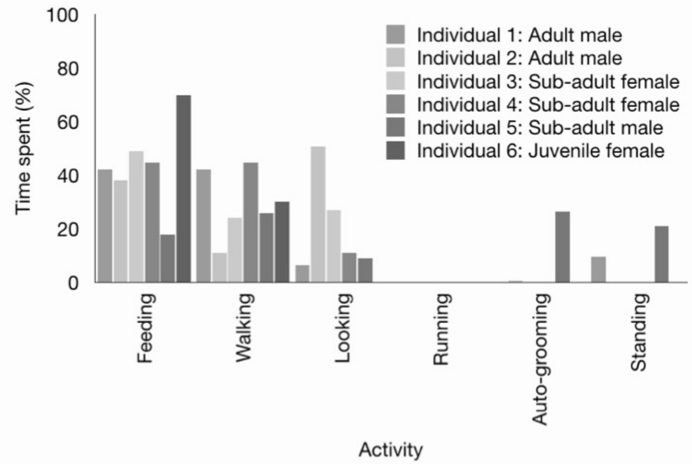
Activity	Individual 1: Adult male	Individual 2: Adult male	Individual 3: Sub-adult female
Feeding	135s	151s	71s
Walking	135s	43s	35s
Looking	20s	3m 21s	39s
Running	0	0	0
Auto-grooming	0	2s	0
Standing	30s	0	0
Time spent	5m 20s	6m 37s	2m 25s

Activity	Individual 4: Sub-adult female	Individual 5: Sub-adult male	Individual 6: Juvenile female
Feeding	94s	34s	3m 21s
Walking	94s	49s	87s
Looking	23s	17s	0
Running	0	0	0
Auto-grooming	0	50s	0
Standing	0	40s	0
Time spent	3m 31s	3m 10s	4m 48s

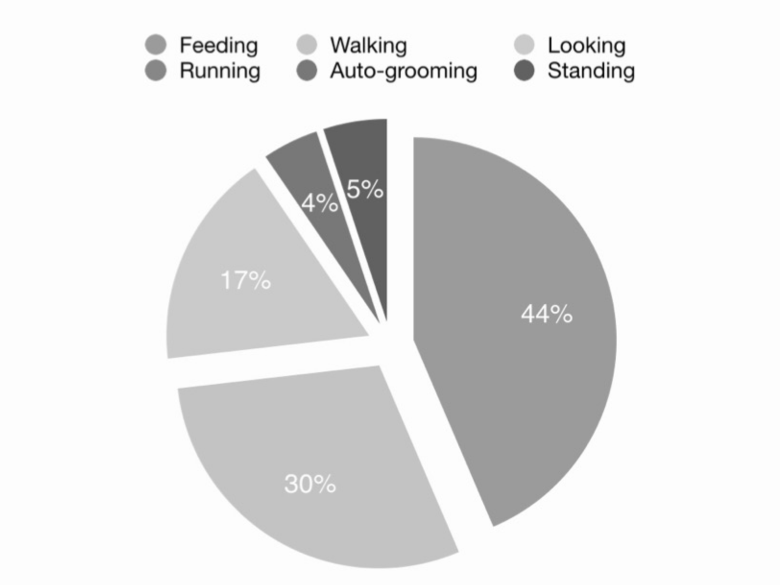
Time budget graph: seconds



Time budget graph: percentage



Time budget graph: Pie chart



Some observations

1. Dominant behaviours: feeding, walking, looking
2. Juveniles spend less time looking than adults and sub-adults, possibly because of parental protection
3. Sub-adult male spent considerable time in auto-grooming

In this way, ethograms and time-budget analyses can help us record and understand the behaviours of animals, with important implications for Ecology.

Thank you

6. Ecological Energetics – Introduction, food chains, food webs, and trophic levels

Energetics

Energy is the ability to do work.

All organisms require energy to carry on their life processes.

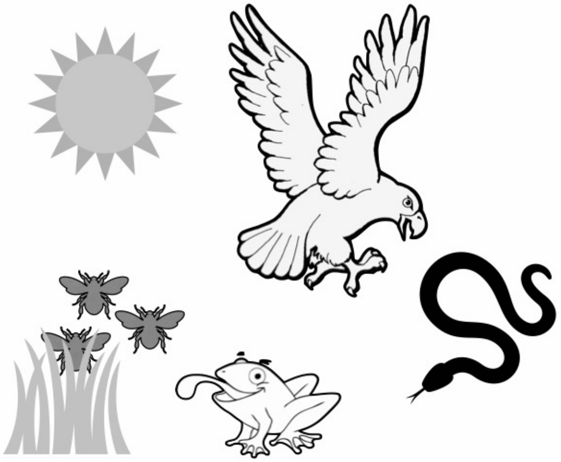
The branch of science that studies energy is known as energetics.

It deals with "the properties of energy and the way in which it is redistributed in physical, chemical, or biological processes."

Ecological Energetics

Ecological Energetics is the discipline that concerns itself with how energy (and matter) moves through different organisms in an organised manner, through food chains and webs.

Food chain



Food chain

The transfer of food energy from its source in plants through herbivores to carnivores, detritivores (waste or debris feeders) or decomposers is referred to as the food chain.

Definitions

Autotrophs: The organisms responsible for primary production. Also known as primary producers. Examples include trees, plants and algae.

Heterotrophs: Organisms that cannot produce their own food, relying instead on the intake of nutrition from other sources of organic carbon, mainly plant or animal matter. Examples include most animals.

Definitions

Photoautotrophs: Photoautotrophs are organisms that use light as a source of energy to manufacture organic molecules and food.

Photo = light, auto = self, troph = nourishment.

e.g. most plants

Chemoautotrophs: Chemoautotrophs are organisms that use chemical reactions as a source of energy to manufacture organic molecules and food.

Chemo = chemical, auto = self, troph = nourishment.

e.g. *Hydrogenovibrio crunogenus* bacteria found in deep-sea hydrothermal vents.

Definitions

Producer: An organism that makes its own food. e.g. autotrophs

Consumer: An organism that consumes some other organism for food.

Definitions

Primary consumer: An organism that only consumes the producers.

e.g. grasshopper

Secondary consumer: An organism that consumes the primary consumer.

e.g. frog

Tertiary consumer: An organism that consumes the secondary consumer.

e.g. snake

Quaternary consumer: An organism that consumes the tertiary consumer.

e.g. hawk

Definitions

Herbivore: An organism that eats only plants. They are primary consumers.

e.g. cow

Carnivore: An organism that eats other animals. They are secondary, tertiary, or quaternary consumers.

e.g. tiger

Omnivore: An organism that eats both plants and other animals. They are generally secondary or tertiary consumers.

e.g. bear

Decomposer: An organism that converts dead material into soil and recycles nutrients.

Decomposers

Decomposers include detritivores and microorganisms.

Detritivores consume detritus (decomposing plant and animal parts as well as faeces), and make it more exposed to the action of microbial decomposers such as bacteria and fungi that further break it down.

Kinds of food chains

1. Grazing food chain: It starts from a plant base, goes through herbivores to carnivores. Grazing food chains can be:
   a. predator food chains e.g. Grass → Chital → Tiger The size of organisms generally increases as we move up the chain.
   b. parasite food chains e.g. Rat → Flea → Parasitic protozoa The size of organisms generally decreases as we move up the chain.
2. Detritus food chain: It starts from detritus, goes through detritivores to carnivores. e.g. Fallen leaves of mangroves → Detritivores → Detritivore consumers e.g. small fish or insect larvae → Small fish → Large fish → Piscivorous birds

Differences between grazing and detritus food chains

CHARACTERISTIC	GRAZING FOOD CHAIN	DETRITUS FOOD CHAIN
Primary source of energy	Sun	Detritus
First trophic level	Herbivores	Detritivores
Length	Generally long chains	Generally shorter chains

Definitions

Food web: "A system of interlocking and interdependent food chains"

Trophic level: "Each of several hierarchical levels in an ecosystem, consisting of organisms sharing the same function in the food chain and the same nutritional relationship to the primary sources of energy"

Food web

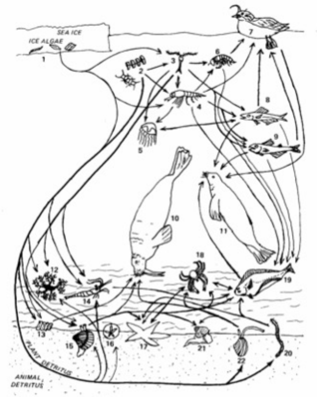


Fig. 1. Simplified representation of Bering Sea food web. Organisms and assemblages of organisms depicted are as follows: 1: ice algae; 2: phytoplankton; 3: copepods; 4: mysids and euphausids; 5: medusae; 6: hyperiad amphipods; 7: sea birds; 8 and 9: pelagic fishes; 10: walrus; 11: seals; 12: basket stars; 13: ascidians; 14: shrimps; 15: filter-feeding bivalves; 16: sand dollars; 17: sea stars; 18: crabs; 19: bottom-feeding fishes; 20: polychaetes; 21: predatory gastropods; 22: deposit-feeding bivalves

(McConnaughey, T. and McRoy, C.P., 1979. Food-web structure and the fractionation of carbon isotopes in the Bering Sea. Marine biology, 53(3), pp.257-262.)

Food web

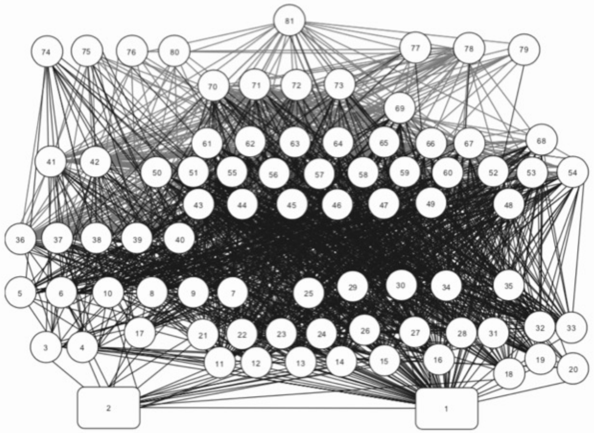


Fig. 1. Species and links of the northwest Atlantic food web. This tangled 'bird's nest' represents interactions at the approximate trophic level of each species, with increasing trophic level towards the top of the web. The left side of the web generally typifies

(Link, J., 2002. Does food web theory work for marine ecosystems?. Marine ecology progress series, 230, pp.1-9.)

Definitions

Ecological pyramid: "A graphical representation designed to show the biomass, numbers, or energy at each trophic level in a given ecosystem"

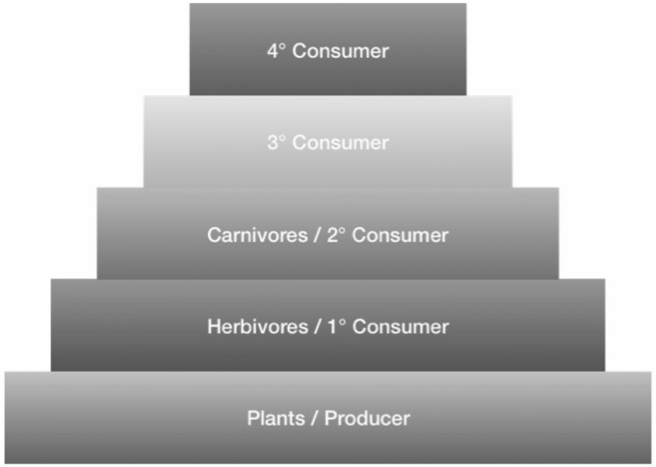
Also known as

1. trophic pyramid
2. eltonian pyramid
3. energy pyramid
4. food pyramid

Kinds of pyramids

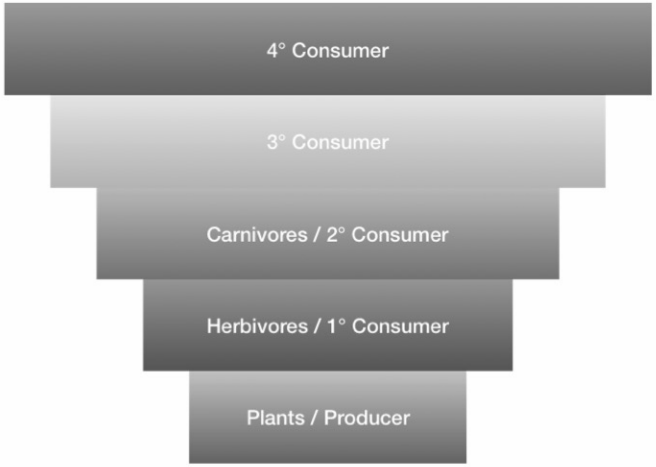
1. Pyramid of numbers: Numbers of organisms at each trophic level.

Pyramid of numbers



(Ankur Awadhiya, Principles of Wildlife Conservation 2021)

Inverted pyramid of numbers



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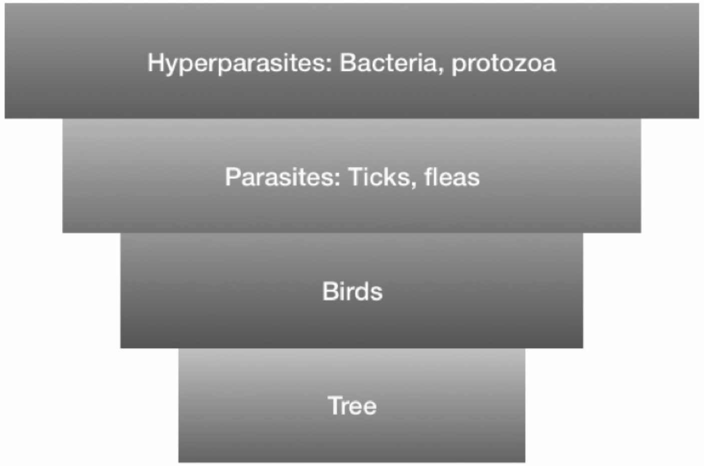
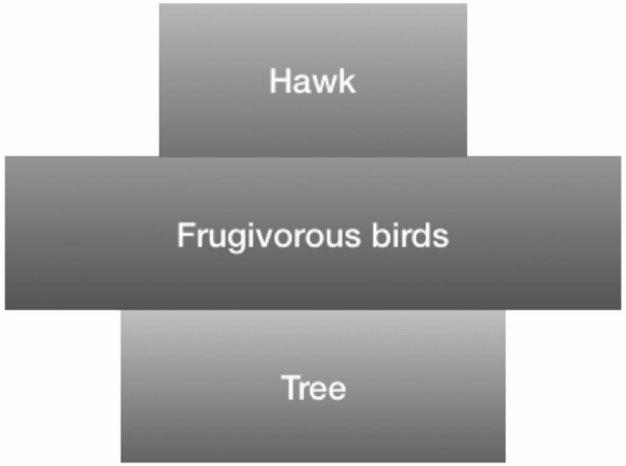
Inverted pyramid of numbers



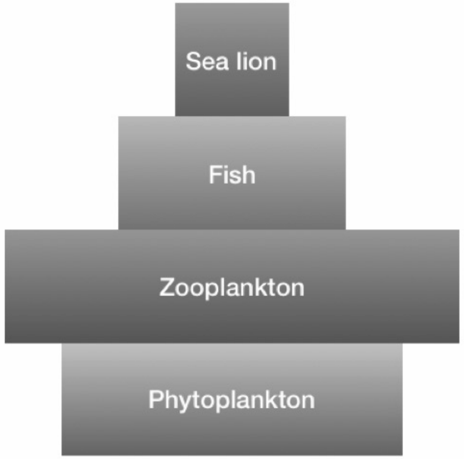
(Ankur Awadhiya, Principles of Wildlife Conservation 2021)

Spindle pyramid of numbers



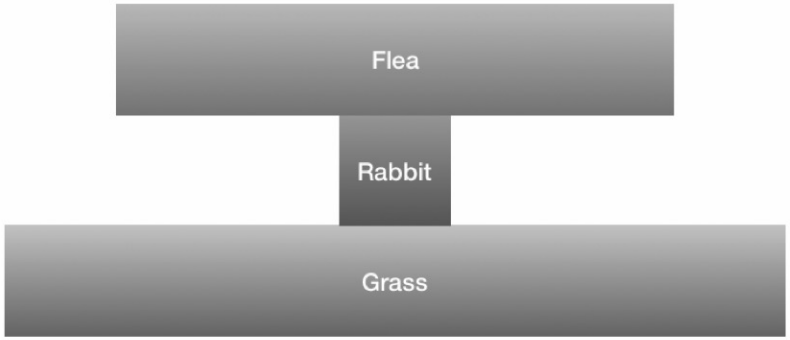
(Ankur Awadhiya, Principles of Wildlife Conservation 2021)

Spindle pyramid of numbers



(Ankur Awadhiya, Principles of Wildlife Conservation 2021)

Dumb-bell shaped pyramid of numbers

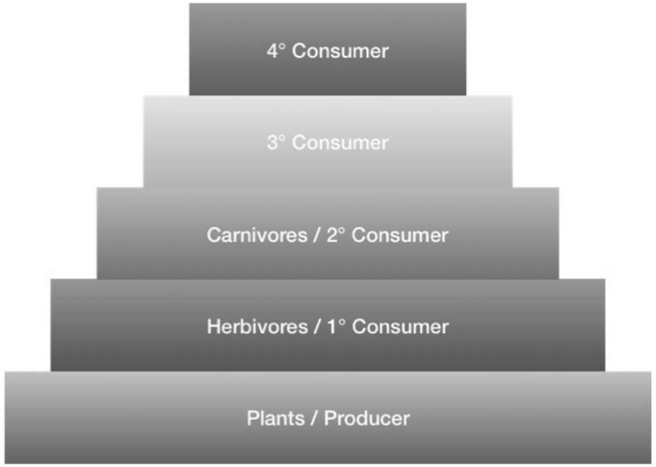


(Ankur Awadhiya, Principles of Wildlife Conservation 2021)

Kinds of pyramids

1. Pyramid of numbers: Numbers of organisms at each trophic level.
2. Pyramid of energy: Energy contained in organisms at each trophic level.

Pyramid of energy

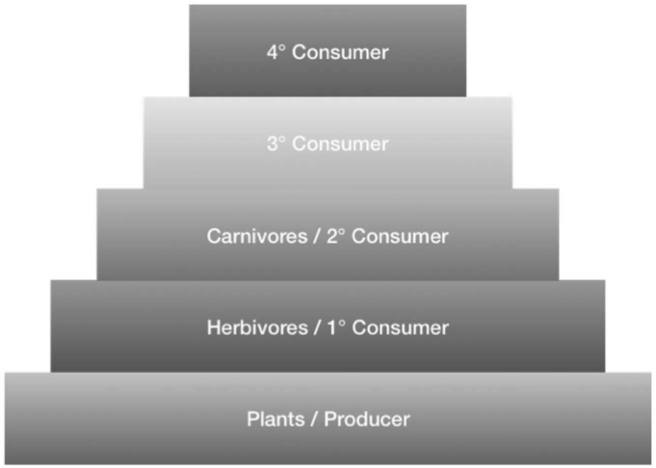


(Ankur Awadhiya, Principles of Wildlife Conservation 2021)

Kinds of pyramids

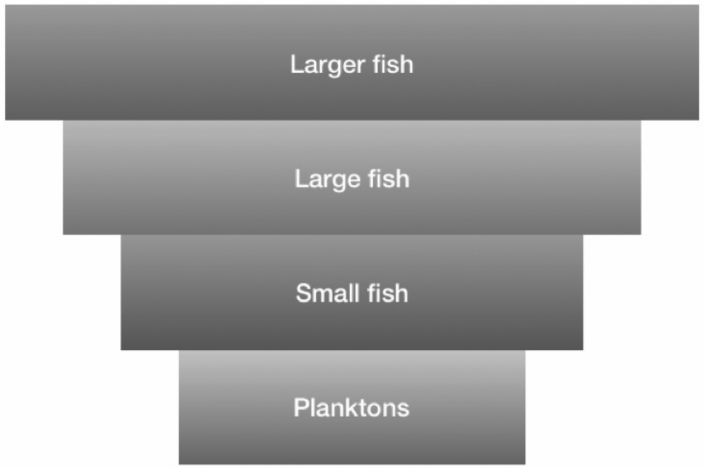
1. Pyramid of numbers: Numbers of organisms at each trophic level.
2. Pyramid of energy: Energy contained in organisms at each trophic level.
3. Pyramid of biomass: Biomass of organisms at each trophic level.

Pyramid of biomass



(Ankur Awadhiya, Principles of Wildlife Conservation 2021)

Inverted pyramid of biomass



(Ankur Awadhiya, Principles of Wildlife Conservation 2021)

Definitions I

Standing crop: A standing crop is the total dried biomass of the living organisms present at a trophic level.

Ecological efficiency: The efficiency with which energy is transferred from one trophic level to the next.

Exploitation efficiency: The amount of food ingested divided by the amount of prey production.

$$\frac{I_n}{P_{n-1}}$$

Assimilation efficiency: The amount of assimilation divided by the amount of food ingestion.

$$\frac{A_n}{I_n}$$

Definitions II

Gross production efficiency: Consumer production divided by amount of ingestion.

$$\frac{P_n}{I_n}$$

Net production efficiency: Consumer production divided by amount of assimilation

$$\frac{P_n}{A_n}$$

Ecological efficiency: Ecological efficiency is the exploitation efficiency multiplied by the assimilation efficiency multiplied by the net production efficiency, which is equivalent to the amount of consumer production divided by the amount of prey production:

Definitions III

$$EE = \frac{I_n}{P_{n-1}} \times \frac{A_n}{I_n} \times \frac{P_n}{A_n} = \frac{P_n}{P_{n-1}}$$

The 10 percent rule I

During the transfer of energy from one trophic level to the next, only about ten percent of the energy gets stored as biomass.

The remaining is

1. lost during transfer
2. lost due to incomplete digestion
3. broken down in respiration

The efficiency of plants in capturing the Sun's energy is only around 1%.

Thus, in the food chain:

Grass → Grasshopper → Frog → Snake → Hawk

if 100,000 Joules of energy from the Sun was intercepted by the grass, the amount of energy assimilated at each stage would be:

The 10 percent rule II

100,000 Joules from Sun → Grass (1000 Joules) → Grasshopper (100 Joules) → Frog (10 Joules) → Snake (1 Joule) → Hawk (0.1 Joule)

Considering the plants as level 1, we have

$$Energy\ at\ n^{th}\ level = \frac{Energy\ intercepted\ from\ the\ Sun}{10^{n+1}}$$

Trophic cascade

"An ecological phenomenon triggered by the addition or removal of top predators and involving reciprocal changes in the relative populations of predator and prey through a food chain, which often results in dramatic changes in ecosystem structure and nutrient cycling"

Engineering ecosystems - I

Wolves reintroduced in Yellowstone National Park:

1. Deer started avoiding certain locations
2. Plants regenerated in those locations
3. Average height of flora increased
4. Bird density increased
5. Beaver population increased due to abundant branches used as food
6. Beavers created dams, constructing lentic ecosystems
7. Otters, fish, reptiles, amphibian populations emerged in dammed areas
8. Wolves hunted coyotes → rabbits and mice population increased → birds of prey, weasels, and foxes numbers increased
9. Berries and carrion increased bear numbers, reinforcing wolves' impact

Engineering ecosystems - I

10. Riverine meandering and soil erosion decreased since forests stabilised banks

Thus, introduction of wolves (top predators) brought about a trophic cascade: "an ecological phenomenon triggered by the addition or removal of top predators and involving reciprocal changes in the relative populations of predator and prey through a food chain, which often results in dramatic changes in ecosystem structure and nutrient cycling"

Definitions

Primary Production: The synthesis of organic compounds from atmospheric or aqueous carbon dioxide, through the processes of photosynthesis or chemosynthesis.

Autotrophs: The organisms responsible for primary production. Also known as primary producers. Examples include trees, plants and algae.

Importance of primary production

1. Plants form 99.9% of Earth's living mantle (Whittaker 1975)
2. Conversion of the ultimate source of energy (the Sun) to bio-energy, fuelling the complete ecosystem
3. Release of oxygen as a by-product

Two processes happen in tandem

1. Photosynthesis
$$6CO_2 + 6H_2O \xrightarrow[\text{Solar energy}]{\text{Chlorophyll, enzymes}} C_6H_{12}O_6 + 6O_2$$
2. Respiration $C_6H_{12}O_6 + 6O_2 \xrightarrow{\text{Metabolic enzymes}} 6CO_2 + 6H_2O$

Definitions

Gross primary production: Energy (or carbon) fixed via photosynthesis per unit time

Net primary production: Gross primary production - Energy (or carbon) lost via respiration per unit time

Compensation point: The equilibrium point for plants where photosynthesis equals respiration

Measurements of production

$$6CO_2 + 6H_2O \xrightarrow[\text{Solar energy}]{\text{Chlorophyll, enzymes}} C_6H_{12}O_6 + 6O_2$$

can be put into energetics terms as:

$$6CO_2 + 6H_2O \xrightarrow[\text{2966 kJ}]{\text{Chlorophyll, enzymes}} C_6H_{12}O_6 + 6O_2$$

implying that for each mole of glucose produced,

1. 2966 kJ of energy is absorbed
2. 6 moles of CO_2 are utilised (134.4 litres at standard temperature and pressure[1])
3. 6 moles of O_2 are released (134.4 litres at standard temperature and pressure)

These values can easily be measured to estimate primary productivity.

[1]Since 1982, STP is defined as a temperature of 273.15 K and an absolute pressure of exactly 100 kPa (1 bar).

Another method

$$6CO_2 + 6H_2O \xrightarrow[\text{Solar energy}]{\text{Chlorophyll, enzymes}} C_6H_{12}O_6 + 6O_2$$

In this process, we may replace CO_2 with labelled, radioactive $^{14}CO_2$.

After some time, the complete plant is harvested and the quantity of ^{14}C is measured to estimate the amount of CO_2 absorbed by the plant.

Issue: Some amount of ^{14}C may also get lost during respiration.

Yet another method: Harvest method

The amount of plant material produced may be measured as:

$$\Delta B = B_2 - B_1$$

where

- ΔB = change in biomass between times t_2 and t_1, an estimate of biomass produced (or lost)
- B_2 = biomass at time t_2
- B_1 = biomass at time t_1

Efficiency

Efficiency of gross primary production

$$\eta = \frac{Energy\ fixed\ by\ gross\ primary\ production}{Energy\ in\ incident\ sunlight}$$

Efficiency of net primary production

$$\eta = \frac{Energy\ fixed\ by\ net\ primary\ production}{Energy\ in\ incident\ sunlight}$$

Definitions

Productivity

$$Productivity = \frac{Production}{Time}$$

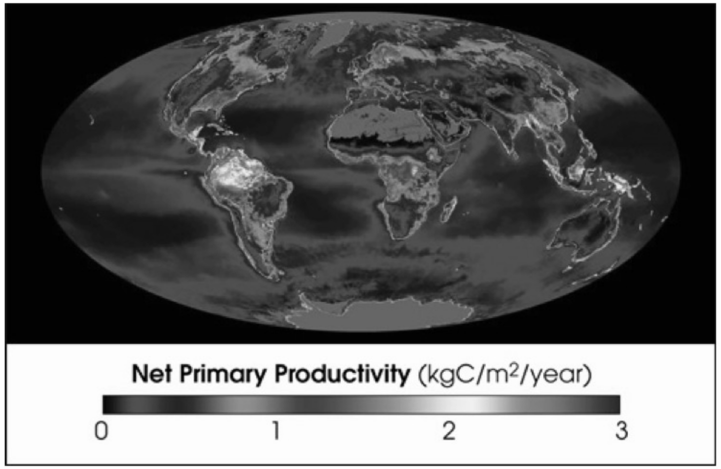
Net primary productivity

$Net\ primary\ productivity = APAR \times LUE$

where

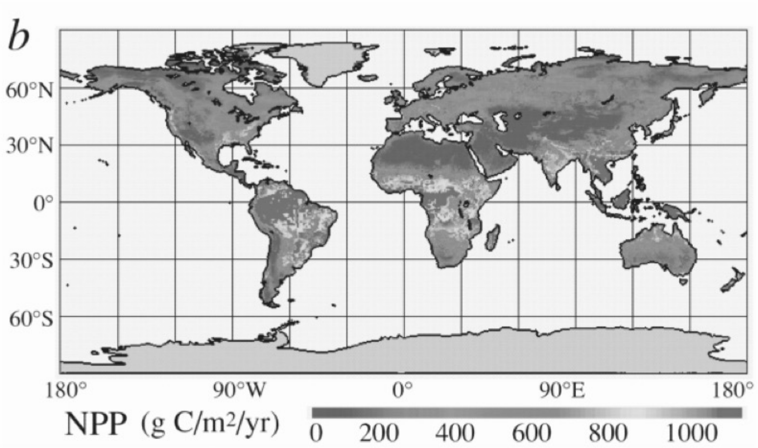
- APAR = Absorbed photosynthetically active radiation (MJ / m^2 / time)
- LUE = Light use efficiency (grams carbon per MJ energy)

NPP from satellite data



(https://science.nasa.gov)

NPP estimates through modelling



(Ito & Oikawa, 2004)

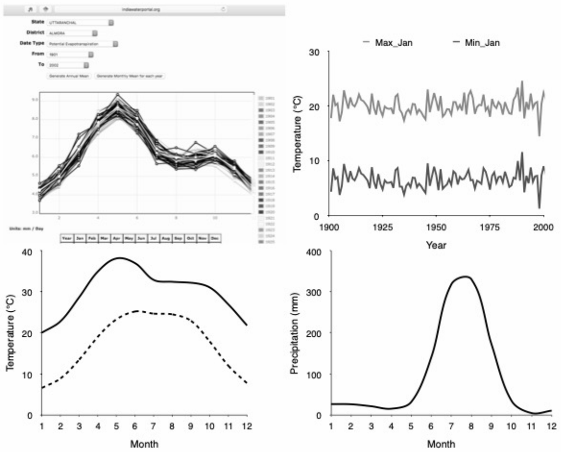
What does productivity depend upon?

Productivity is a function of seven variables[2]:

1. solar constant: the rate at which energy reaches the earth's surface from the sun, usually taken to be 1,388 watts per square metre
2. latitude
3. cloudiness
4. dust and water in the atmosphere
5. leaf arrangement
6. leaf area
7. concentration of CO_2

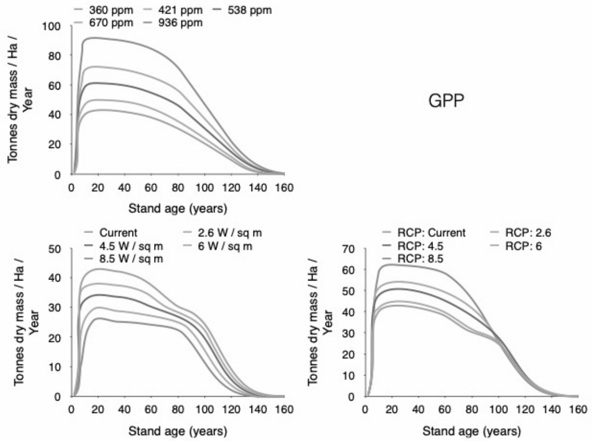
[2]Monteith, J. L. (1972). Solar radiation and productivity in tropical ecosystems. Journal of applied ecology, 9(3), 747-766. Chicago

Modelling through parameters



(Ankur Awadhiya, Impact of Global Warming on the Carbon Sequestration Potential and Stand Dynamics of Chir Pine Forests, Indian Forester 143, no. 9 (2017): 907-914.)

GPP estimates through modelling



(Ankur Awadhiya, Impact of Global Warming on the Carbon Sequestration Potential and Stand Dynamics of Chir Pine Forests, Indian Forester 143, no. 9 (2017): 907-914.)

Definitions

Oligotrophic lake: A lake with low primary productivity as a result of low nutrient content. These are characterised by low algal production, and often have very clear waters, with high drinking-water quality.

Mesotrophic lake: A lake with an intermediate level of productivity. These lakes are often clear water lakes and ponds with beds of submerged aquatic plants and medium levels of nutrients.

Eutrophic lake: A lake with high biological productivity due to excessive concentrations of nutrients, especially nitrogen and phosphorus.

Hypereutrophic lake: An extremely nutrient-rich lake characterised by frequent and severe nuisance algal blooms, low transparency and low oxygen levels, often creating dead zones beneath the surface.

Trophic classifications

Table 5: Trophic classification of lakes

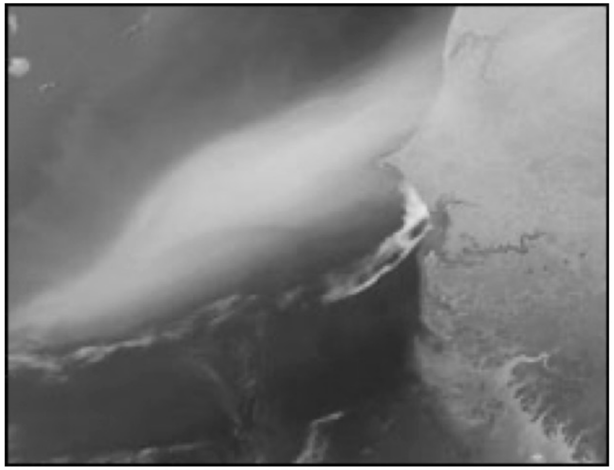
Trophic Class	Trophic Index	Chlorophyll (μg / litre)	Phosphorus (μg / litre)	Secchi depth (m)
OligoT	$0 - 40$	$0 - 2.6$	$0 - 12$	$> 8 - 4$
MesoT	$40 - 50$	$2.6 - 20$	$12 - 24$	$4 - 2$
EuT	$50 - 70$	$20 - 56$	$24 - 96$	$2 - 0.5$
Hyper-euT	$70 - 100+$	$56 - 155+$	$96 - 384+$	$0.5 - < 0.25$

Secchi depth is a measure of transparency or turbidity in a water body. The more the depth, the clearer is the water. The less the depth, the more turbid is the water in the water body.

Sources of nutrients

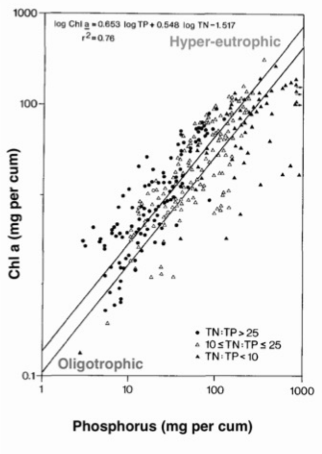
1. rivers bringing sediments
2. bird droppings
3. upwelling in oceans
4. dust clouds, etc.

Sources of nutrients



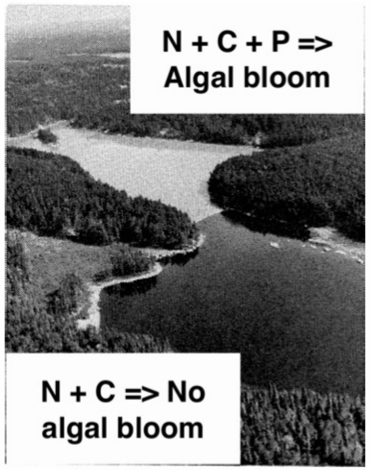
(Jacques Descloitres, MODIS Rapid Response Team, NASA/GSFC.)

The role of limiting nutrients



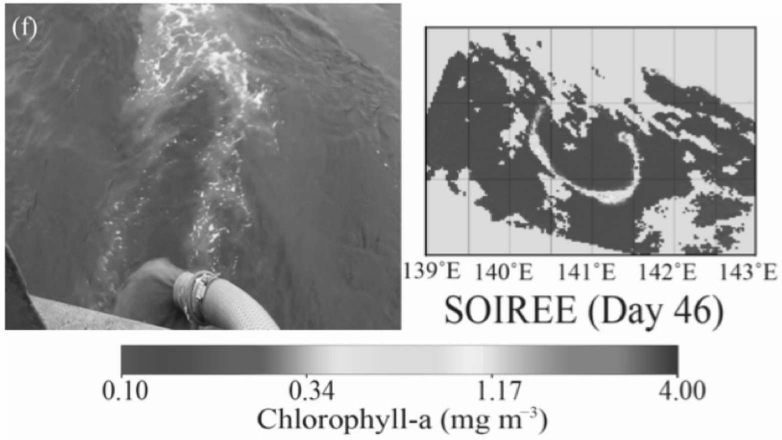
(Ahlgren, I., Frisk, T. and Kamp-Nielsen, L., 1988. Phosphorus in Freshwater Ecosystems (pp. 285-303). Springer, Dordrecht.)

Engineering ecosystems - II



(Schindler 1974 Science)

Engineering ecosystems - III



(SOIREE = Southern Ocean Iron RElease Experiment; Yoon et al. 2016 Biogeosciences Discussions)

Thank you

7. Ecological Energetics – Biogeochemical cycles

Nutrient

"A substance used by an organism to survive, grow and reproduce."

Kinds of nutrients

Macronutrients: Nutrients needed in large amounts.

Include primary nutrients (N, P, K) and secondary nutrients (Ca, Mg, S).

Micronutrients or trace elements: Nutrients needed in small or trace amounts.

Include boron, copper, iron, chlorine, manganese, zinc, and molybdenum.

Essential elements: Criteria for plants

1. In the absence of the element the plants should be unable to complete their life cycle.
2. The deficiency of an essential element cannot be met by supplying some other element.
3. The element must be directly involved in the metabolism of the plant.

Roles of some essential elements

1. Nitrogen: constituent of proteins, nucleic acids, vitamins, hormones
2. Phosphorus: constituent of nucleic acids, ATP, cell membrane, certain proteins
3. Potassium: cation-anion balance needed for maintaining cell turgidity, opening and closing of stomata, activation of certain enzymes
4. Calcium: calcium pectate in cell wall, activation of certain enzymes, calcium channels in cell membranes
5. Magnesium: constituent of chlorophyll, activation of respiration enzymes
6. Sulphur: constituent of amino acids cysteine and methionine, several vitamins and coenzymes

List of macronutrients

1. Macronutrients derived from air and water
   a. Carbon
   b. Hydrogen
   c. Oxygen
2. Primary macronutrients
   a. Nitrogen
   b. Phosphorus
   c. Potassium
3. Secondary and tertiary macronutrients
   a. Sulphur
   b. Calcium
   c. Magnesium

List of micronutrients

1. Iron
2. Molybdenum
3. Boron
4. Copper
5. Manganese
6. Sodium
7. Zinc
8. Nickel
9. Chlorine
10. Cobalt
11. Aluminium
12. Silicon
13. Vanadium
14. Selenium

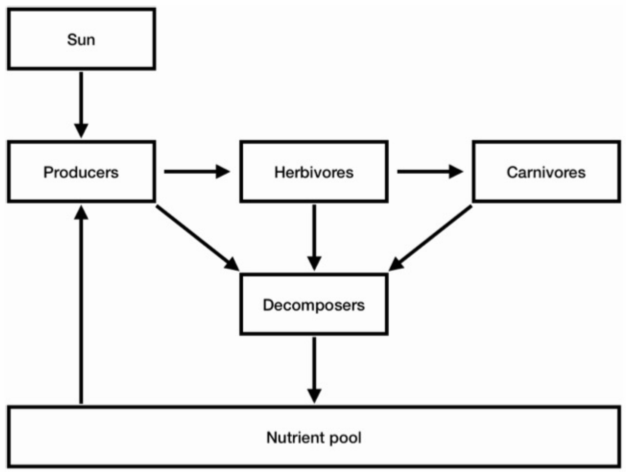
The Earth does not have an infinite supply of these elements

So we have biogeochemical cycles

Biogeochemical cycle

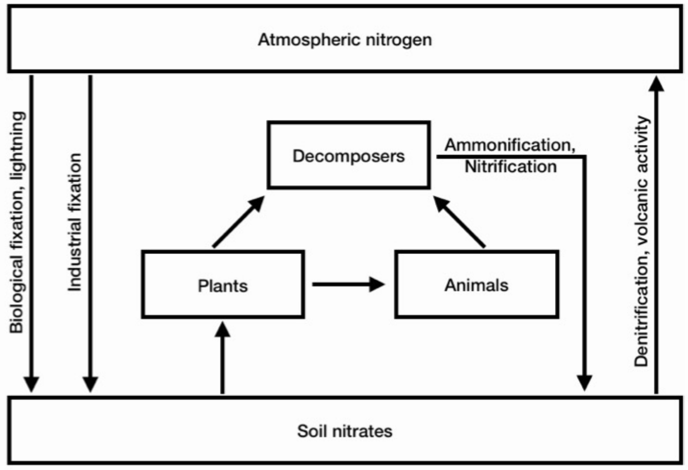
"A pathway by which a chemical substance moves through biotic (biosphere) and abiotic (lithosphere, atmosphere, and hydrosphere) compartments of Earth"

The Generalised nutrient cycle



(Ankur Awadhiya, Principles of Wildlife Conservation 2021)

The Nitrogen cycle



(Ankur Awadhiya, Principles of Wildlife Conservation 2021)

Nitrogen fixation

The conversion of atmospheric nitrogen into ammonia or other nitrogenous compounds is called nitrogen fixation.

Occurs by

1. biological fixation
2. lightning
3. industrial fixation

Biological nitrogen fixation

The conversion of atmospheric nitrogen into ammonia or other nitrogenous compounds is called nitrogen fixation.

$$N \equiv N \xrightarrow{\text{Nitrogenase}} NH_3$$

Done by

1. *Rhizobium*: symbiotic bacteria
2. *Azotobacter*: free-living bacteria
3. *Nostoc*: cyanobacteria
4. *Anabaena*: cyanobacteria

Ammonification

Production of ammonia through decomposition of organic nitrogen in dead plants and animals is called ammonification.

$$\text{Dead plants and animals} \xrightarrow{\text{Ammonification}} NH_3$$

Nitrification

Biological oxidation of ammonia to nitrites and nitrates is called nitrification.

$$2NH_3 + 3O_2 \xrightarrow{\text{Nitrosomonas or Nitrococcus}} 2NO_2^- + 2H^+ + 2H_2O$$

$$2NO_2^- + O_2 \xrightarrow{\text{Nitrobacter}} 2NO_3^-$$

These nitrifying bacteria are chemoautotrophs.

Industrial nitrogen fixation: Haber process

$$N_2 + 3H_2 \xrightarrow[\text{High temperature and pressure}]{\text{Catalyst}} 2NH_3$$

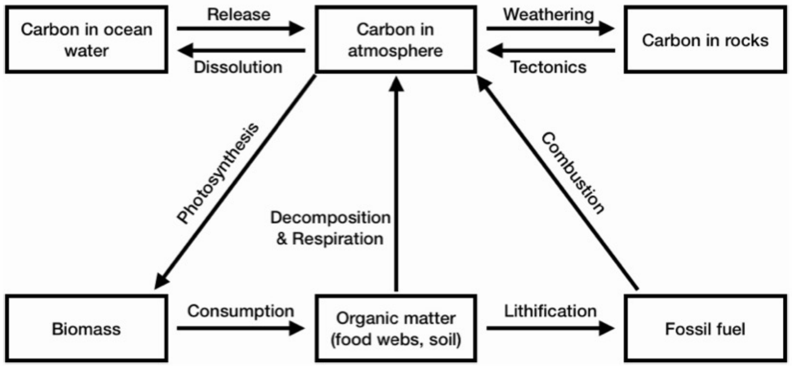
Industrial nitrogen fixation: Ostwald process

$$4NH_3 + 5O_2 \xrightarrow{\text{Catalyst}} 4NO + 6H_2O$$

$$2NO + O_2 \xrightarrow{\text{Catalyst}} 2NO_2$$

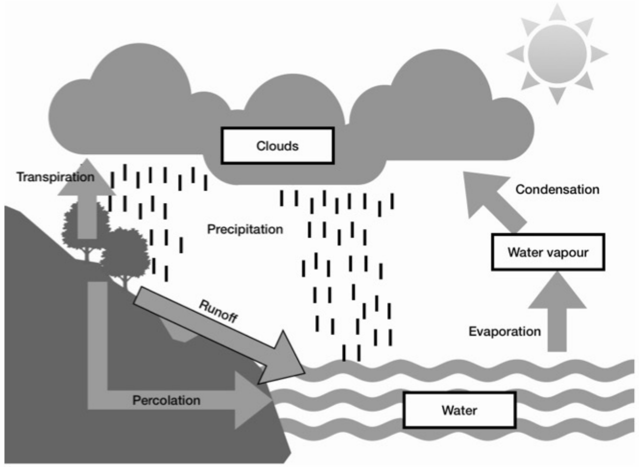
$$4NO_2 + O_2 + 2H_2O \xrightarrow{\text{Catalyst}} 4HNO_3$$

The Carbon cycle



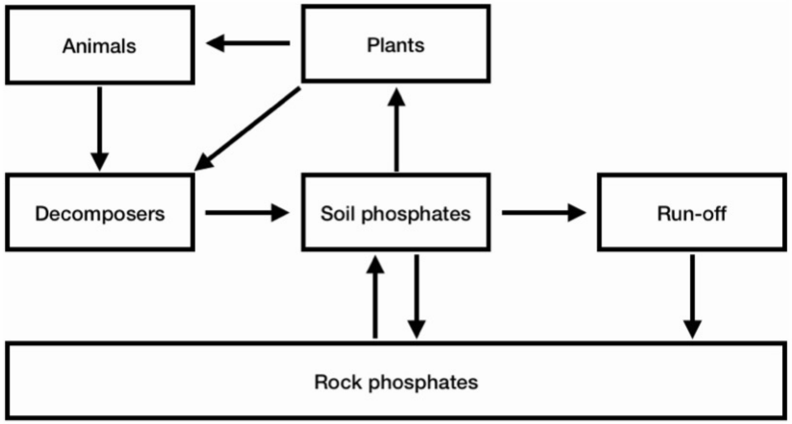
(Ankur Awadhiya, Principles of Wildlife Conservation 2021)

The Water cycle



(Ankur Awadhiya, Principles of Wildlife Conservation 2021)

The Phosphorus cycle



(Ankur Awadhiya, Principles of Wildlife Conservation 2021)

The Sulphur cycle

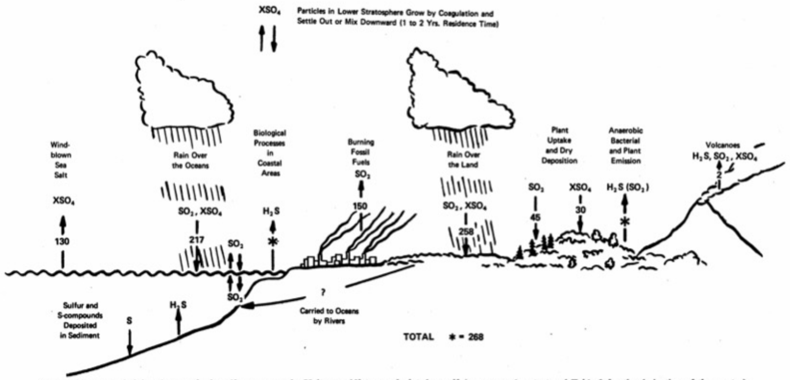
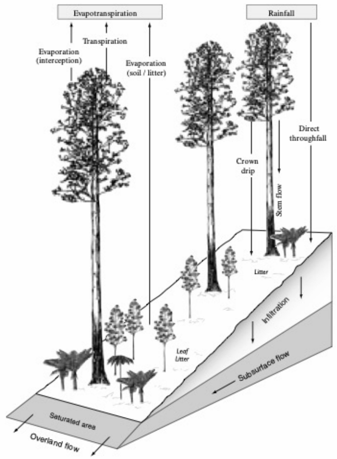


Fig. 2. Sources and sinks of atmospheric sulfur compounds. Units are 10^6 tons calculated as sulfate per year (see text and Table 3 for the derivation of these rates).

(Kellogg et al. 1972. The sulfur cycle. Science, 175(4022), pp.587-596.)

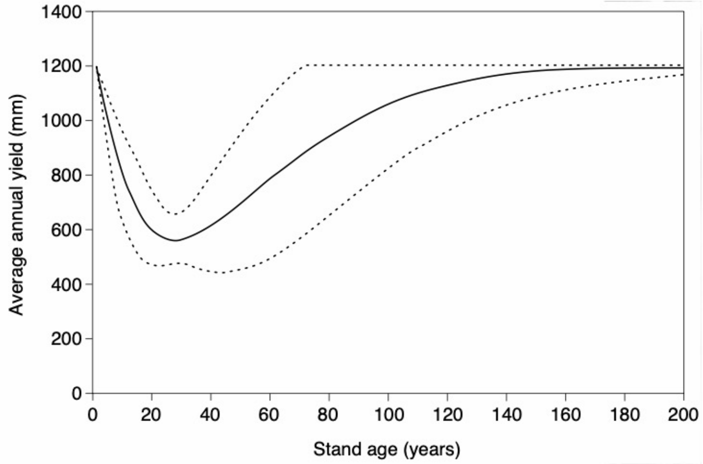
Impacts of human interventions

Rainfall in the forest



(Vertessy et al. 1998. Predicting water yield from mountain ash forest catchments. Industry report, 98/4)

Kuczera curve: changes in streamflow



(Vertessy et al. 1998. Predicting water yield from mountain ash forest catchments. Industry report, 98/4)

Changes in pH post deforestation

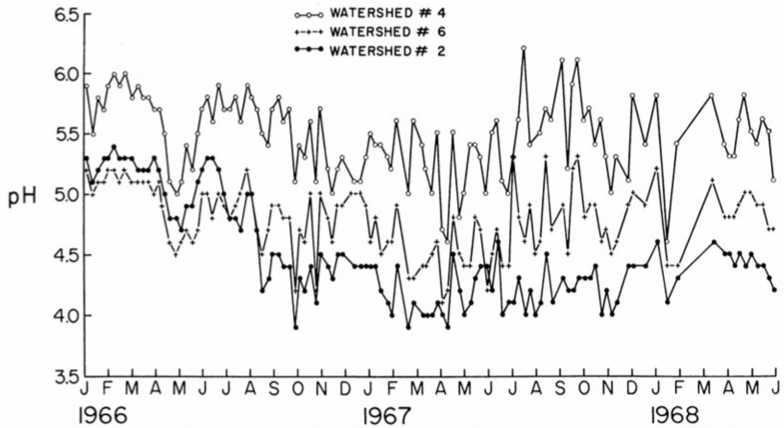


FIG. 6. pH values for stream water from Watersheds 2 (deforested), 4 and 6 during 1966–1968.

(Likens et al. 1970. Effects of forest cutting and herbicide treatment on nutrient budgets... Ecological monographs, 40(1), pp.23-47.)

Changes in ion concentration post deforestation

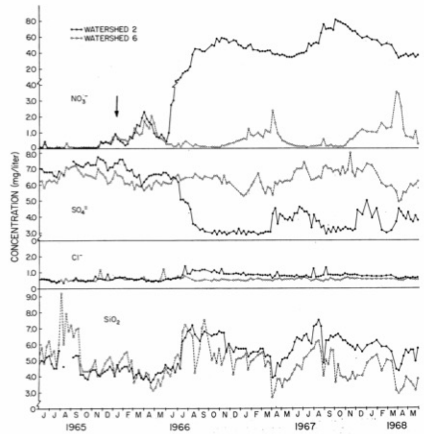


FIG. 7. Measured streamwater concentrations for nitrate, sulfate, chloride and dissolved silica in Watersheds 2 (deforested) and 6. Note the change in scale for the nitrate concentration. The arrow indicates the completion of cutting in W2.

(Likens et al. 1970. Effects of forest cutting and herbicide treatment on nutrient budgets... Ecological monographs, 40(1), pp.23-47.)

Changes in ion concentration post deforestation

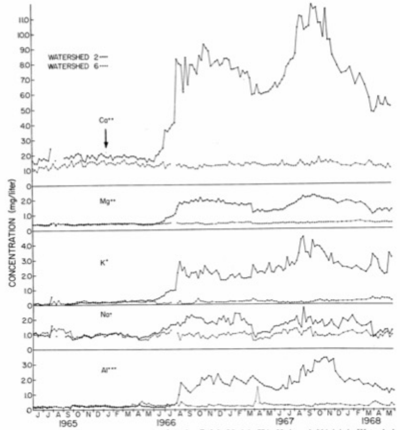


FIG. 9. Measured streamwater concentrations for Ca^{++}, Mg^{++}, K^{+}, Na^{+}, and Al^{+++} in Watersheds 2 (deforested) and 6. The points were not connected during periods when the stream discharge was negligible. The arrow indicates the completion of cutting in W2.

(Likens et al. 1970. Effects of forest cutting and herbicide treatment on nutrient budgets... Ecological monographs, 40(1), pp.23-47.)

Thank you

8. Population Ecology – Growth and regulation of populations

Population

"All the organisms of the same group or species, which live in a particular geographical area, and have the capability of interbreeding"

Impala population

(Ankur Awadhiya 2018 Kruger NP)

To manage the population, we need to understand its dynamics

$$P_{n+1} = P_n + Natality + Immigration - Mortality - Emigration$$

Importance of assessment I

1. **Numbers are essential at every stage of management.** Management follows the Deming cycle:

Plan → Do → Check → Act

And numbers are critically required at all of these stages. We need to know numbers at the planning stage to decide if interventions are required, depending on the management objectives (*Plan*).

The management interventions when deployed (*Do*) will affect the number of wildlife, and the efficiency and efficacy of these interventions can easily be evaluated (*Check*) by observing their effects on the numbers of different wildlife.

This would further help us in optimising our interventions for the future (*Act*).

Importance of assessment II

A management adage highlights the importance of these numbers by stating: "What cannot be measured cannot be managed!"

2. **Numbers are crucial inputs for decision support.** Depending on existing numbers of wildlife, we may need to:
   a. increase their numbers, if the numbers are getting low
   b. reduce their numbers, if the numbers are very high, or when there are situations of conflict
   c. maintain status-quo, if the numbers are adequate

However, we remain ignorant of the actions required of us till we actually know the numbers. Hence, it is necessary to assess wildlife numbers.

3. **Numbers help assess the risk of a population decline / crash.** When the number of individuals is very low, the population might crash due to reasons of:

Importance of assessment III

a. demographic stochasticity, such as:
   - chance variations in births and deaths leading to more deaths and less births
   - chance variations in sex ratio resulting in a population with all males or all females

b. environmental stochasticity, such as drought, flood, famine or diseases

c. genetic problems, such as:
   - inbreeding depression due to mating of close relatives
   - genetic drift of small populations
   - loss of heterozygosity

d. behavioural problems and Allee effect, such as:
   - in the case of pack hunting animals, where individuals are less efficient and may not be able to hunt alone
   - when animals are highly dispersed, and so unable to find a mate.

Importance of assessment IV

4. **Numbers help us plan scenarios and take steps.** The steps could be:
   a. adaptation, where the population is made supple enough to respond to changes, or
   b. mitigation, where the causes of change are analysed and addressed

Do we need numbers or trends? I

Actually, we need both.

Trends are helpful when we need to analyse and address the gross movement of population numbers: whether the population is increasing, decreasing or remaining constant. This is especially important for, say, prey species like chital or sambar, where exact numbers are hard to compute due to their large population sizes.

On the other hand, numbers are of crucial importance in cases where the populations have reached critical limits, or when the animal is a priority species. Thus, we need to have census for tigers, Great Indian bustards and dugongs. Mere trends will not suffice!

Do we need numbers or trends? II

It is also important to note that numbers are finer data than trends. With exact numbers, we can easily compute trends. But the information on trends is not sufficient to deduce the exact number of individuals.

What demographic information are we trying to get?

As managers and scientists, we are interested in several demographic parameters describing the population, such as:

1. **population size**: the number of individuals in the population.
2. **population density**: the number of individuals in the population per unit area (generally per hectare or per square kilometre).

Some common population densities

Organism	Density in conventional units	Density in number per cubic metres or square metres
Diatoms	5,000,000 per cum	5,000,000
Soil arthropods	500,000 per sq. m	500,000
Adult barnacles	20 per 100 sq. cm	2,000
Trees	200 per acre	0.0494
Woodland mice	5 per acre	0.00124
Deer	10 per sq. mile	0.0000039
People in Macau	20,027 per sq. km	0.020027
People in India	382 per sq. km	0.000382
People in Greenland	0.03 per sq. km	0.00000003

(Krebs, C.J., 1972. The experimental analysis of distribution and abundance. Ecology. New York: Harper and Row.)

Kinds of population density

1. Absolute density: Numbers per unit area
2. Relative density: Whether area x has more organisms than area y, or vice-versa?

Measurement of absolute population density

1. Total counts, e.g. Census of India
2. Sampling methods
   a. quadrats
   b. capture-recapture method
3. Removal method

Quadrats

1. square
2. rectangular
3. circular
4. irregular

Objective of sampling

"to secure a sample which will represent the population and reproduce the important characteristics of the population under study as closely as possible[3]."

[3] http://www.fao.org/docrep/003/x6831e/X6831E12.htm

Capture-recapture method

Steps at time 1:

1. capture
2. mark
3. release

Steps at time 2:

1. capture
2. check for marks

Capture-recapture method

$$\frac{\text{No. of marked animals in sample}}{\text{No. of animals caught in sample}} = \frac{\text{No. of marked animals in populatior}}{\text{Total population size}}$$

Capture-recapture method: Assumptions

1. Marked and unmarked animals are captured randomly
2. Mortality rate in marked and unmarked animals is the same
3. Marks are not lost or overlooked

Removal method: Assumptions

1. there is no immigration or emigration of animals
2. the death rate and birth rate are negligible during the entire 'experiment'
3. the trapped animals are permanently removed from the region
4. a trap can be occupied by only one animal at a time
5. there is no interference from animals of a wrong species
6. the probability p that a specified free animal will be caught in a trapping period remains constant, the same for all animals and periods

(Good, I.J., Lewis, B.C., Gaskins, R.A. and Howell, L.W., 1979. Population estimation by the removal method assuming proportional trapping. Biometrika, 66(3), pp.485-494.)

Removal method

If

$$\frac{dN}{dt} = -aN$$

then we have

$$N = N_0 e^{-at}$$

a and N_0 can be estimated using regression.

Measurement of relative population density

1. traps
2. number of faecal pellets
3. frequency of vocalisation
4. pelt counts: number of animals captured by trappers
5. catch per unit fishing effort
6. number of artefacts, e.g. nests
7. questionnaires to field staff
8. percentage of plant cover
9. frequency of quadrats where the species is found
10. feeding capacity: the amount of bait taken by animals

What demographic information are we trying to get? I

As managers and scientists, we are interested in several demographic parameters describing the population, such as:

1. **population size**: the number of individuals in the population.
2. **population density**: the number of individuals in the population per unit area (generally per hectare or per square kilometre).
3. **age pyramid**: the distribution of various age groups in the population.
4. **crude birth rate**: the annual number of live births per 1000 individuals.
5. **crude death rate**: the annual number of deaths per 1000 individuals.
6. **general fertility rate**: the annual number of live births per 1000 females of reproductive age.

What demographic information are we trying to get? II

7. **age-specific fertility rate**: the annual number of live births per 1000 females of specific age classes in the reproductive age.
8. **total fertility rate**: the average number of live births per female individual completing her reproductive age, if she followed the current age-specific fertility rate of the population.
9. **replacement level fertility**: the average number of offsprings that a female individual must produce such that the population is completely replaced for the next generation. The replacement level of fertility ≥ 2.
10. **juvenile mortality rate**: the annual number of deaths of juveniles per 1000 live births.
11. **life expectancy**: the number of years that an average individual in the population at a given age could expect to live, at the present age-specific mortality levels.

What demographic information are we trying to get? III

Difference between physiological and ecological longevity

a. **Physiological longevity**: the average longevity of individuals of a population living under optimum conditions, where organisms die of senescence.
b. **Ecological longevity**: the empirical average longevity of the individuals of a population under given conditions.

12. **immigration**: the number of individuals coming into the population from outside populations.
13. **emigration**: the number of individuals in the population that are going out to outside populations.
14. **net migration**: immigration - emigration.
15. **natural increase**: births - deaths.
16. **population growth**: births + immigration - deaths - emigration.

What demographic information are we trying to get? IV

17. **population growth rate**: the growth of population expressed as a fraction of the population size over a fixed time. Generally expressed as % per annum.

What is the difference between precision and accuracy? I

We need results that are both precise and accurate.

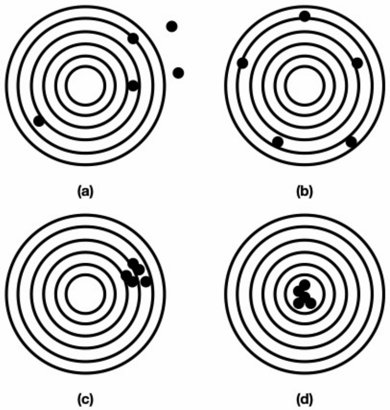
Precision is how close the measured values are to each other. Suppose we took five readings of animal density, and the values were: 101, 103, 102.5, 101 and 102 animals per square kilometre. Since these values are close to each other, we'll call the measurements precise. On the other hand, if the values were: 101, 130, 210, 94 and 50 animals per square kilometre, the values would have been less precise.

What is the difference between precision and accuracy? II

Accuracy is how close the measured values are to the correct value. Suppose the correct density of animals was 103 animals per square kilometre. If our obtained values were: 101, 103, 102.5, 101 and 102 animals per square kilometre, we'd call our readings accurate, since they hover around the correct value of 103. On the other hand, if the values were: 151, 153, 152.5, 151 and 152, then although the values are close to each other (precise), they are not close to the correct value (103). Thus, in this case, the readings will not be called accurate.

To elucidate the point, we could refer to the figure.

What is the difference between precision and accuracy?



(Ankur Awadhiya, Principles of Wildlife Conservation 2021)

What is the difference between precision and accuracy?

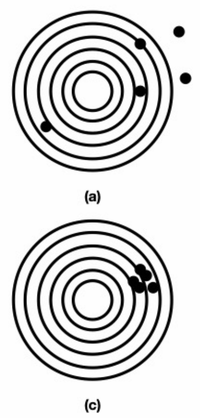
It shows the results of four shooters who aimed at the bull's eye. The shooter (a) had shots that were neither close to each other, nor close to the bull's eye. Thus, her results are neither precise, nor accurate. The shooter (b) shot all around the target. Thus, her shots are not precise. However, since their mid-point tends towards the bull's eye, we'd say that her result is more accurate than that of shooter a. Shooter (c)'s shots are grouped together, so we call her precise. However, since the grouping is far from the actual bull's eye, her result is not accurate. In the case of shooter (d), the shots are grouped together near the bull's eye. Thus, shooter (d) is both precise and accurate.

What is bias?

Bias is the difference between the mean of the measured values, and the reference value. If the reference value is the true value, then bias would indicate the error in measurement.

To elucidate the point, we refer back to the figure, representing the shooter (c).

What is bias?

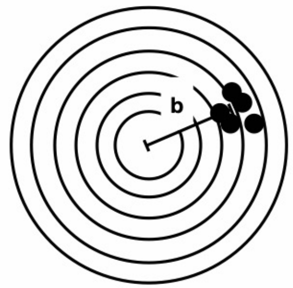


(Ankur Awadhiya, Principles of Wildlife Conservation 2021)

What is bias?

If we measure the distance from the centre of the grouped shots (mean of measured values) to the centre of the bull's eye (the reference value), we get an indication of the bias of the shooter, or her gun.

What is bias?



(Ankur Awadhiya, Principles of Wildlife Conservation 2021)

What is bias?

To remove bias, we need to *calibrate* the instrument or the method of measurement. Thus, in our example, the gun of shooter (c) may have a bend towards the right and upwards. If this bend is corrected for, the shots will start falling on the bull's eye.

Computation of animal density

A park manager conducts a population estimation exercise within a protected area. He samples 18 quadrats with line transects and obtains the following density estimates for Sambar:

Table 6: Sambar densities in different beats

Beat number	Sambar Density (number per sq. km)
1	8
2	5
3	6
4	5
5	8
6	3
7	7
8	7
9	6

Computation of animal density

Table 7: Sambar densities in different beats (contd.)

Beat number	Sambar Density (number per sq. km)
10	2
11	8
12	9
13	4
14	7
15	8
16	2
17	1
18	5

Computation of animal density

Compute the average density of sambar.

Average density will be calculated as:

$$Average\ density = \frac{\Sigma(Density\ in\ the\ beat)}{Total\ number\ of\ beats}$$

$$\implies Average\ density = \frac{8+5+6+...+5}{18}$$

$$\implies Average\ density = \frac{101}{18}$$

$$\implies Average\ density = 5.61\ animals\ per\ square\ kilometre$$

Computation of animal density

The groups sizes of chital in the core and buffer zones of Corbett Tiger Reserve, Uttarakhand were recorded during winter 2009 (Data given below). Estimate mean group size, standard deviation, standard error, range and coefficient of variation. Comment on the results obtained.

Computation of animal density

Table 8: Data for group sizes of chital in core and buffer of Corbett Tiger Reserve in Winter 2009

Core zone	Buffer zone
26	26
24	11
25	07
27	03
23	15
25	19
27	22
26	30
24	34
25	40

Computation of animal density

Mean group size: Core zone

$$Mean\ group\ size = \frac{\Sigma(Group\ sizes\ in\ core)}{Total\ number\ of\ groups}$$

$$\implies Mean\ group\ size = \frac{26 + 24 + 25 + ... + 24 + 25}{10}$$

$$\implies Mean\ group\ size = \frac{252}{10}$$

$$\implies Mean\ group\ size = 25.2\ animals\ per\ group$$

Computation of animal density

Mean group size: Buffer zone

$$Mean\ group\ size = \frac{\Sigma(Group\ sizes\ in\ buffer)}{Total\ number\ of\ groups}$$

$$\implies Mean\ group\ size = \frac{26 + 11 + 7 + ... + 34 + 40}{10}$$

$$\implies Mean\ group\ size = \frac{207}{10}$$

$$\implies Mean\ group\ size = 20.7\ animals\ per\ group$$

Computation of animal density

Standard deviation: Core zone

$$Standard\ Deviation\ (Population) = \sqrt{\frac{\Sigma(x-\mu)^2}{N}}$$

$$\implies Standard\ Deviation\ (Population) =$$

$$\sqrt{\frac{\Sigma[(26-25.2)^2+(24-25.2)^2+...+(25-25.2)^2]}{10}}$$

$$\implies Standard\ Deviation\ (Population) = \sqrt{\frac{15.6}{10}}$$

$$\implies Standard\ Deviation\ (Population) = \sqrt{1.56}$$

Computation of animal density

Standard deviation: Buffer zone

$$Standard\ Deviation\ (Population) = \sqrt{\frac{\Sigma(x-\mu)^2}{N}}$$

$$\implies Standard\ Deviation\ (Population) =$$

$$\sqrt{\frac{\Sigma[(26-20.7)^2+(11-20.7)^2+...+(7-20.7)^2]}{10}}$$

$$\implies Standard\ Deviation\ (Population) = \sqrt{\frac{1296.1}{10}}$$

$$\implies Standard\ Deviation\ (Population) = \sqrt{129.61}$$

Computation of animal density

Standard error: Core zone

$$Standard\ Error = \frac{\sigma}{\sqrt{n}}$$

$$\implies Standard\ Error = \frac{1.249}{\sqrt{10}}$$

$$\implies Standard\ Error = 0.395\ animals\ per\ group$$

Computation of animal density

Standard error: Buffer zone

$$Standard\ Error = \frac{\sigma}{\sqrt{n}}$$

$$\implies Standard\ Error = \frac{11.385}{\sqrt{10}}$$

$$\implies Standard\ Error = 3.600\ animals\ per\ group$$

Computation of animal density

Range: Core zone

$$Range = Highest\ value\ - lowest\ value$$

$$\implies Range = 27 - 23$$

$$\implies Range = 4\ animals\ per\ group$$

Computation of animal density

Range: Buffer zone

$$Range = Highest\ value\ - lowest\ value$$

$$\implies Range = 40 - 3$$

$$\implies Range = 37\ animals\ per\ group$$

Computation of animal density

Coefficient of variation: Core zone

$$CV = \frac{\sigma}{\mu} \times 100\%$$

$$\implies CV = \frac{1.249}{25.2} \times 100\%$$

$$\implies CV = 4.956\%$$

Computation of animal density

Coefficient of variation: Buffer zone

$$CV = \frac{\sigma}{\mu} \times 100\%$$

$$\implies CV = \frac{11.385}{20.7} \times 100\%$$

$$\implies CV = 54.998\%$$

Computation of animal density

Comment on the results obtained

The group sizes of chital in the core zone are more or less similar, as shown by a small range value of 4 and a coefficient of variation of 4.956%. However, the group sizes of chital in the buffer zone are extremely variable, as shown by a larger range value of 37 and a coefficient of variation of 54.998%. The coefficients of variation also hint that the standard deviation is very far from the mean value in the case of the chital groups in the buffer zone, while the standard deviation is close to the mean in the case of the chital groups in the core zone.

Computation of animal density

These numbers also provide an indication of the habitats in the core and buffer zones. Since core zones are mostly unfragmented and uniform, the group sizes of chital groups show little variation from one group to the next. On the other hand, since the buffer zones are relatively fragmented and non-uniform, showing also high anthropogenic influences, each chital group in the buffer zone will show a difference from the other groups, depending on the patch of habitat that was available to it.

In this way, we may utilise statistical information to make sense of, or even to predict, the ecological information.

Rate of population growth

$$N_{t+1} = R_0 \times N_t$$

where

N_t = Population size at generation t

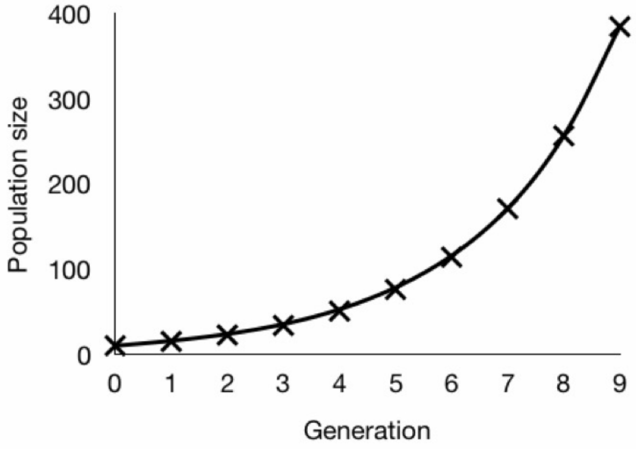
N_{t+1} = Population size at generation t + 1

R_0 = Net reproductive rate = Number of female offsprings produced per female per generation

Condition of constant $R_0 = 1.5$

Generation	Population size
0	10
1	15
2	22.5
3	33.75
4	50.625
5	75.9375
6	113.90625
7	170.859375
8	256.2890625
9	384.43359375

Condition of constant $R_0 = 1.5$



(Ankur Awadhiya, Principles of Wildlife Conservation 2021)

But R_0 is not constant. It varies with population size.

The logistic growth equation

$$\frac{dN}{dt} = rN \times \left(\frac{K-N}{K}\right)$$

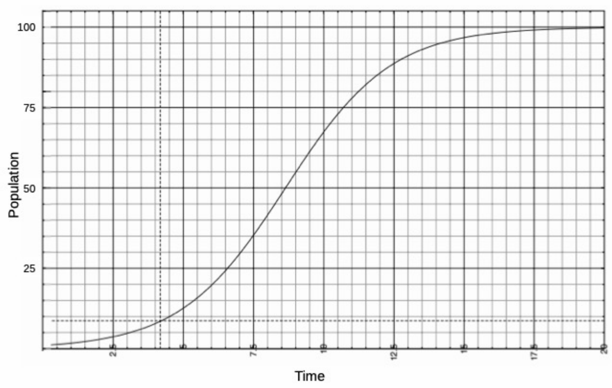
where

N = Population size at time t

K = Carrying capacity of the environment

r = intrinsic growth rate

The logistic growth equation



(Ankur Awadhiya, Principles of Wildlife Conservation 2021)

The logistic growth equation

A population follows the equation for logistic population growth:

$$\frac{dN}{dt} = rN \times (\frac{K-N}{K})$$

If the carrying capacity K = 100, initial population N = 25 and maximum addition of animals per unit time is 10, what is the value for intrinsic growth rate?

The logistic growth equation

We are given:

$$(\frac{dN}{dt})_{max} = 10$$

$$\implies rN \times (\frac{K-N}{K}) \leq 10$$

Putting the values of N and K, we have

$$r \times 25 \times (\frac{100-25}{100}) \leq 10$$

$$\implies r \times 25 \times (\frac{75}{100}) \leq 10$$

$$\implies r \leq \frac{10 \times 100}{25 \times 75}$$

The logistic growth equation

$$\implies r \leq 0.533$$

Thus, maximum $r = 0.533$ per year.

Answer:

The value of the intrinsic growth rate, r is given by: $r = 0.533$ per year.

Predator-prey relations: Lotka-Volterra equations

$$\frac{dV}{dt} = rV - \alpha VP$$

$$\frac{dP}{dt} = \beta VP - qP$$

where

V = prey population at time t

P = predator population at time t

α, β, r, q = constants

Predator-prey relations: Lotka-Volterra equations

Suppose that tiger and chital populations are governed by Lotka-Volterra dynamics, with the following coefficients:

r = 0.008

q = 0.8

$\alpha = \beta = 0.001$

If the initial population sizes are:

Tigers, P = 14, and

Chital, V = 1000,

what are the short-term population dynamics predicted by the model?

Predator-prey relations: Lotka-Volterra equations

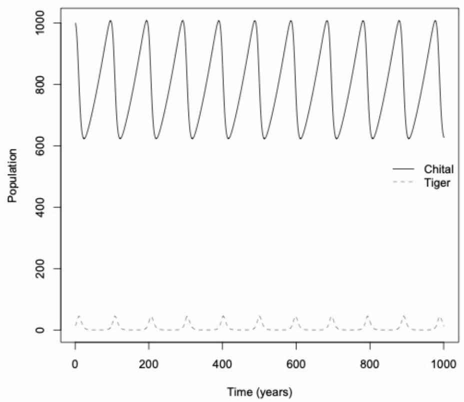
The Lotka-Volterra equations are given by:

$$\frac{dV}{dt} = rV - \alpha VP$$

$$\frac{dP}{dt} = \beta VP - qP$$

Under the given conditions, the graph is shown in figure.

Plot of chital and tiger populations with the given initial conditions.



(Ankur Awadhiya, Principles of Wildlife Conservation 2021)

Predator-prey relations: Lotka-Volterra equations

In the short-term, the model predicts that the chital population shall decline, while the tiger population shall increase. This would then be continued with a cyclical steady state, where the populations of chital and tiger go through ups and downs, with the tiger population at a lag with respect to the chital population. This is because the tiger population will utilise chital population as prey to increase their numbers while decreasing the chital numbers. After some time, the chital population will not be sufficient to support the large tiger population, and the tiger population will start decreasing. With less number of predators, the chital population will start increasing and re-establish itself. Thus we reach the same starting conditions of large chital population and low tiger population. And this cycle will continue.

Population studies

1. Problems of dynamics: How does the population change with time?
2. Problems of statics: What determines the equilibrium conditions and average values?

Problems of dynamics

1. Does the change occur in a particular time of the year?
2. Does the change occur in a particular stage in the life cycle of the organism?
3. What are the agents that operate at these times or stages?

Some common agents

1. Extrinsic agents
    a. weather
    b. predators
    c. parasites
    d. diseases
    e. quantity and quality of food available
    f. shelter
2. Intrinsic agents
    a. physiological
    b. behavioural

Problems of statics

1. The population size does not change, so dynamic factors need not be considered.
2. Experimentally manipulate habitat variables to look for responsible factors.

Thank you