Ecological Principles and Biodiversity for Sustainability

Dr. Ankur Awadhiya, IFS

1. Introduction to Ecology, Biodiversity, and Sustainability

What is Ecology?

Greek *oikos* = household

Greek *logos* = study

Literal definition: The study of "life at home."

Definition of Ecology

1. "Ecology is the scientific study of interactions among organisms and their environment."
2. "Ecology is the scientific study of interactions that determine the distribution and abundance of organisms."

What do we study in Ecology? Habitats

(Ankur Awadhiya 2015 Indian Wild Ass sanctuary)

What do we study in Ecology? Biodiversity

(Ankur Awadhiya 2015 Bharatpur Sanctuary)

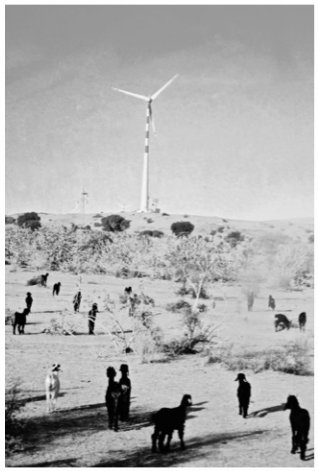
What do we study in Ecology? Population interactions

(Ankur Awadhiya 2015 Sariska TR)

What do we study in Ecology? Community interactions

(Ankur Awadhiya 2016 Kaziranga TR)

What do we study in Ecology? Effects of changes



(Ankur Awadhiya 2015 Gujarat)

Approaches to Ecology

1. The Theoretical approach: Using *equations and models* in an *ab initio* manner.
2. The Laboratory approach: Using the Scientific Method of formulating hypotheses and testing them through *experiments*.
3. The Field approach: Through *observations* in the field.

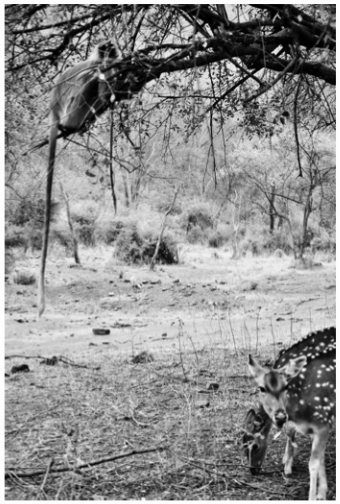
Biodiversity: What is a forest?

(Ankur Awadhiya 2023 Kanha TR)

What is in a forest?

(Ankur Awadhiya 2023 Gir NP)

What is in a forest?



(Ankur Awadhiya 2017 Sariska TR)

What is in a forest?

(Ankur Awadhiya 2023 Velavadar NP)

What is in a forest?

(Ankur Awadhiya 2023 Gir NP)

What is in a forest?

(Ankur Awadhiya 2023 Velavadar NP)

What is in a forest?

(Ankur Awadhiya 2023 Kanha TR)

What is in a forest?

(Ankur Awadhiya 2018 Manas TR)

What is in a forest?

(Ankur Awadhiya 2015 Jodhpur)

What is in a forest?

(Ankur Awadhiya 2017 Sariska TR)

What is in a forest?

(Ankur Awadhiya 2015 Timli)

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(Ankur Awadhiya 2023 Gir NP)

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(Ankur Awadhiya 2018 Mudumalai TR)

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(Ankur Awadhiya 2017 Sariska TR)

What is in a forest?

(Ankur Awadhiya 2018 Gir NP)

What is in a forest?

(Ankur Awadhiya 2014 Mussoorie)

What is in a forest?

(Ankur Awadhiya 2015 Timli)

What is in a forest?

(Ankur Awadhiya 2015 Timli)

What is in a forest?

(Ankur Awadhiya 2016 Kaziranga)

What is in a forest?

(Ankur Awadhiya 2018 Manas TR)

All of these are signs of biodiversity!

What is biodiversity?

"Biodiversity is the variety of life in *all its forms* and at *all levels of organisation*."

all its forms: plants, vertebrates, invertebrates, fungi, bacteria, and other microorganisms

all levels of organisation: genes, species, ecosystems, etc.

Biodiversity is covered in detail in the next lecture.

What is sustainability?

Gandhiji: "The world has enough for everyone's needs, but not everyone's greed"

"Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs. It contains within it two key concepts:

1. The concept of 'needs', in particular, the essential needs of the world's poor, to which overriding priority should be given; and
2. The idea of limitations imposed by the state of technology and social organisation on the environment's ability to meet present and future needs.[1]"

[1]Brundtland, G., 1987. Our common future: Report of the 1987 World Commission on Environment and Development. United Nations, Oslo, 1, p.59.

3 pillars of sustainability

1. environmental sustainability
2. economic sustainability
3. social sustainability

Environmental sustainability

1. ecosystem services
2. green engineering and chemistry
3. air quality
4. water quality
5. reducing effects of stressors like pollution, greenhouse gas emissions, etc.
6. resource integrity by minimising waste generation to prevent accidental release in the future

Social sustainability

1. environmental justice and empowerment of communities burdened by pollution
2. protection, sustenance and improvement of human health
3. increasing participation of stakeholders
4. education about sustainability
5. protection, maintenance and access to resources
6. promotion of sustainable living

Economic sustainability

1. job security
2. incentivisation of sustainable practices
3. market practices for sustainability
4. natural resource accounting
5. lifecycle cost assessment
6. cost structures to reduce risk and promote new technologies

Triple bottom line

"An accounting framework with three parts: social, environmental (or ecological) and financial"

Organisation of this course I

1. Introduction to Ecology, Biodiversity, and Sustainability
2. Biodiversity Organisation of the living world
3. Biodiversity – Economic valuation
4. Ecological interactions
5. Introduction to Behavioural Ecology
6. Ecological Energetics – Introduction, food chains, food webs, and trophic levels
7. Ecological Energetics – Biogeochemical cycles
8. Population Ecology – Growth and regulation of populations
9. Community changes and ecological succession
10. Biogeography and geographical distributions
11. Biogeography – Push and pull factors
12. Human Ecology – Introduction and impacts in anthropocene

Organisation of this course II

13. Human population growth and requirements
14. Threats to biodiversity and ecology
15. Case studies – Impacts of oil spills
16. Case study – Impact of plastics on Ecology and Biodiversity
17. Climate change and its impacts on Ecology and Biodiversity
18. Conservation of biodiversity – In situ conservation
19. Conservation of biodiversity – Ex situ conservation
20. Employing Ecology and Biodiversity for sustainable development

Administrative details

Course webpage at home.iitk.ac.in/~ankura

Email: ankura@iitk.ac.in

Cut-off based grading

Thank you

2. Biodiversity – Organisation of the living world

The parable of two watchmakers I

From The Architecture of Complexity[2]

There once were two watchmakers, named Hora and Tempus, who manufactured very fine watches. Both of them were highly regarded, and the phones in their workshops rang frequently — new customers were constantly calling them. However, Hora prospered, while Tempus became poorer and poorer and finally lost his shop. What was the reason?

The watches the men made consisted of about 1,000 parts each. Tempus had so constructed his that if he had one partly assembled and had to put it down-to answer the phone say-it immediately fell to pieces and had to be reassembled from the elements. The better the customers liked his watches, the more they phoned him, the more difficult it became for him to find enough uninterrupted time to finish a watch.

The parable of two watchmakers II

The watches that Hora made were no less complex than those of Tempus. But he had designed them so that he could put together subassemblies of about ten elements each. Ten of these subassemblies, again, could be put together into a larger sub-assembly; and a system of ten of the latter sub-assemblies constituted the whole watch. Hence, when Hora had to put down a partly assembled watch in order to answer the phone, he lost only a small part of his work, and he assembled his watches in only a fraction of the man-hours it took Tempus.

[2]Herbert A. Simon Proceedings of the American Philosophical Society, Vol. 106, No. 6. (Dec. 12, 1962)

Simon's hierarchical principle

Hierarchy "emerges almost inevitably through a wide variety of evolutionary processes, for the simple reason that hierarchical structures are stable[3]".

[3]Yin, H., Yao, X., Tino, P., Corchado, E. and Byrne, W. eds., 2007. Intelligent Data Engineering and Automated Learning-IDEAL 2007: 8th International Conference, Birmingham, UK, December 16-19, 2007, Proceedings (Vol. 4881). Springer.

Simon's hierarchical principle in centipede

(Ankur Awadhiya 2018 Kruger NP)

The emergent principle

"The whole is greater than the sum of the parts."

"The whole has properties its parts do not have."

Emergent properties in termite mounds

(Ankur Awadhiya 2015 Timli forest)

Levels of organisation in the biological world

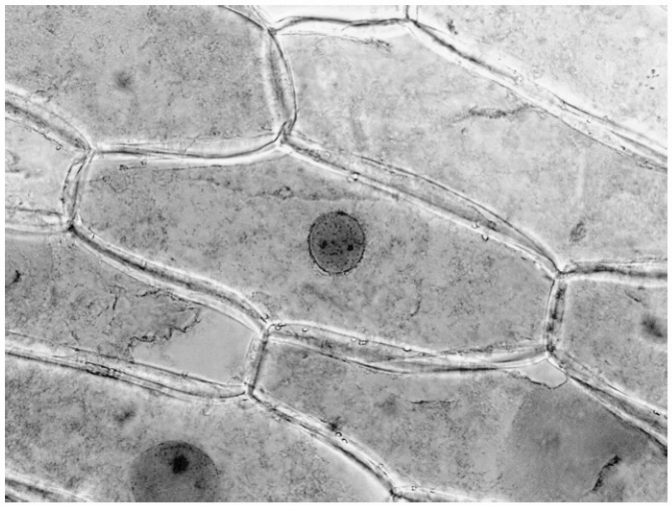
Sub-cellular organelle → Cell → Tissue → Organ → Organ system → Organism → Population → Community → Ecosystem → Biome → Biosphere

Sub-cellular organelle

"A specialized subunit within a cell that has a specific function"

e.g. mitochondrion, chloroplast, nucleus, vacuole

The nucleus in a cell

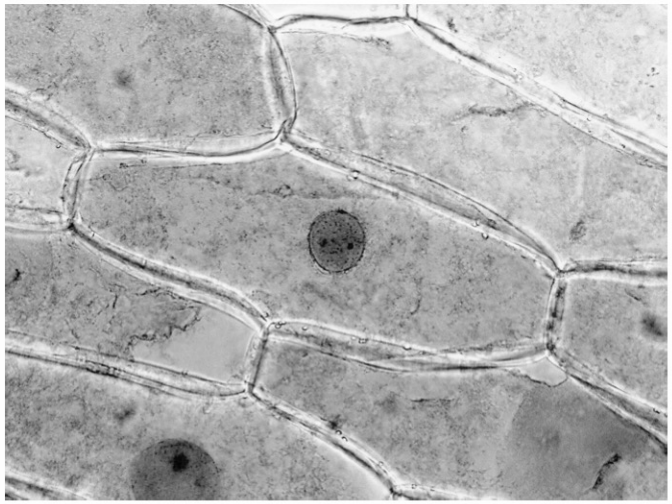


(Ankur Awadhiya 2011 IIT Kanpur)

Cell

"The basic structural, functional, and biological unit of all known living organisms, the smallest unit of life"

The nucleus in a cell

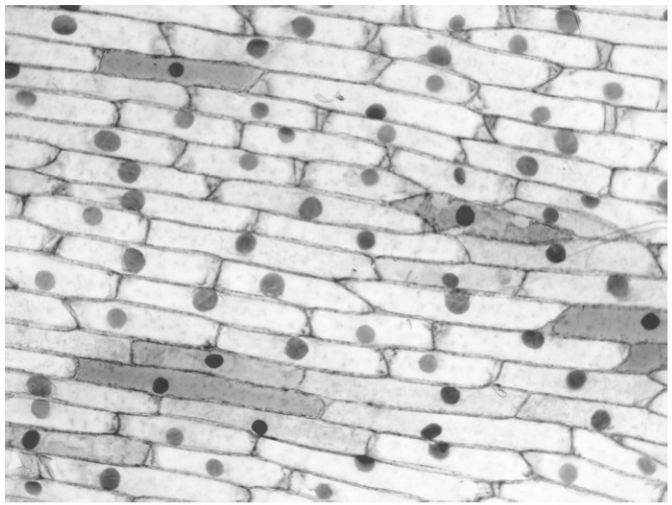


(Ankur Awadhiya 2011 IIT Kanpur)

Tissue

"An ensemble of similar cells and their extracellular matrix from the same origin that together carry out a specific function"

Epidermis Tissue



(Ankur Awadhiya 2011 IIT Kanpur)

Organ

"Collections of tissues with similar functions"

Intestines in the digestive system

(Ankur Awadhiya 2011 IIT Kanpur)

Organ system

"A group of organs that work together to perform one or more functions"

Intestines in the digestive system

(Ankur Awadhiya 2011 IIT Kanpur)

Organism

"An individual entity that exhibits the properties of life"

Hyena

(Ankur Awadhiya 2018 Kruger NP)

Population

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

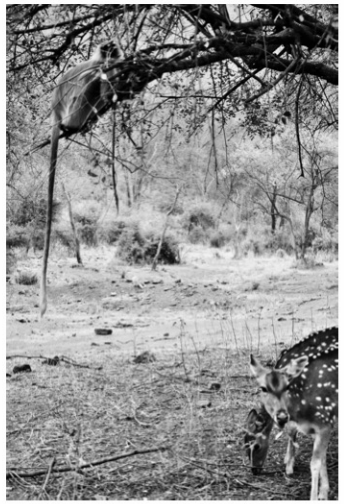
Cheetah population

(Ankur Awadhiya 2018 Kruger NP)

Community

"A group or association of populations of two or more different species occupying the same geographical area and in a particular time"

Langur-Chital association



(Ankur Awadhiya 2017 Sariska Tiger Reserve)

Ecosystem

"A community made up of living organisms and nonliving components such as air, water, and mineral soil"

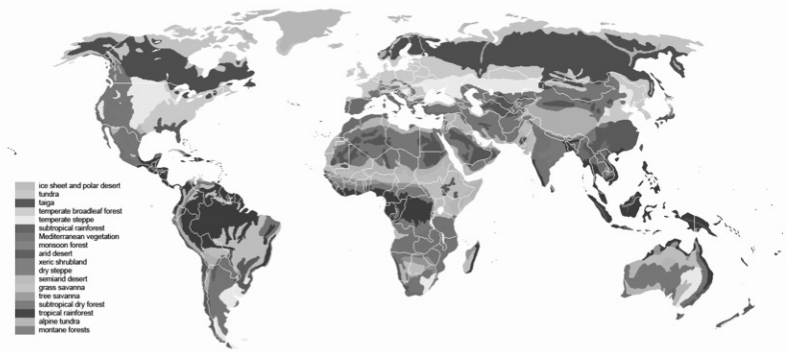
Ecosystem

(Ankur Awadhiya 2017 Sariska Tiger Reserve)

Biome

"A community of plants and animals that have common characteristics for the environment they exist in"

Biomes of the world



(Ville Koistinen Wikimedia curid=1700408)

Biosphere

"The worldwide sum of all ecosystems"

The Blue Marble

(NASA/Apollo 17 crew)

Levels of organisation in the biological world

Sub-cellular organelle → Cell → Tissue → Organ → Organ system → Organism → Population → Community → Ecosystem → Biome → Biosphere

What is biodiversity?

"Biodiversity is the variety of life in *all its forms* and at *all levels of organisation*."

all its forms: plants, vertebrates, invertebrates, fungi, bacteria, and other microorganisms

all levels of organisation: genes, species, ecosystems, etc.

Species biodiversity

"Species are groups of actually or potentially interbreeding natural populations, which are reproductively isolated from other such groups[4]"

Species biodiversity: How many species are there, and how are they distributed?

[4] Mayr 1942

Genetic biodiversity

Gene: A unit of heredity that is transmitted from parents to offsprings.

Genetic biodiversity: Diversity of genetic information present at the levels of phyla, families, species, populations and individuals.

Examples of genetic biodiversity

1. Polymorphism, P: "the proportion or percentage of genes that are polymorphic"

A gene is considered polymorphic if the frequency of the most common allele is less than some arbitrary threshold (otherwise it is monomorphic, i.e. lacking in variation). This threshold is usually 95% [5].

2. Heterozygosity, H: "the proportion or percentage of genes at which the average individual is heterozygous"

[5] Hartl and Clark 1997

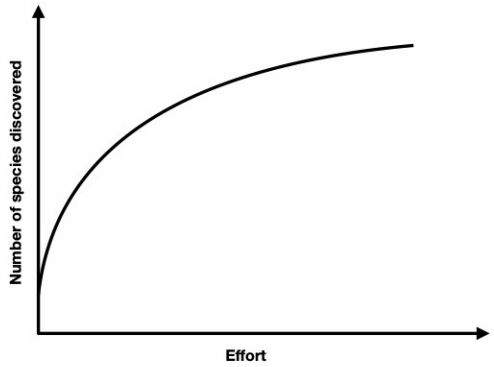
Ecosystem biodiversity

How many ecosystems are there, and how are they distributed?

Measures of biodiversity

1. Species richness: number of species present
2. Species evenness: the distribution of individuals of different species

Species accumulation curve



Measures of biodiversity

Simpson's diversity index

$$D = \frac{1}{\Sigma_{i=1}^{S} P_i^2}$$

where

D is the Simpson's diversity index

S is the number of species in the area

P_i is the proportion of the i^{th} species

Measures of biodiversity

Equitability or evenness

$$E = \frac{D}{D_{max}}$$

where

E is the index of equitability or evenness

D is the Simpson's diversity index

D_{max} is the maximum possible value of Simpson's diversity index, given by S (D is maximum when each species is represented by 1 and only 1 individual)

Measures of biodiversity

Shannon's diversity index

$$H = -\Sigma_{i=1}^{S} P_i ln P_i$$

where

H is the Shannon's diversity index

S is the number of species in the area

P_i is the proportion of the i^{th} species

Measures of biodiversity

Equitability or evenness

$$J = \frac{H}{H_{max}}$$

where

J is the index of equitability or evenness

H is the Shannon's diversity index

H_{max} is the maximum possible value of Shannon's diversity index, given by ln S

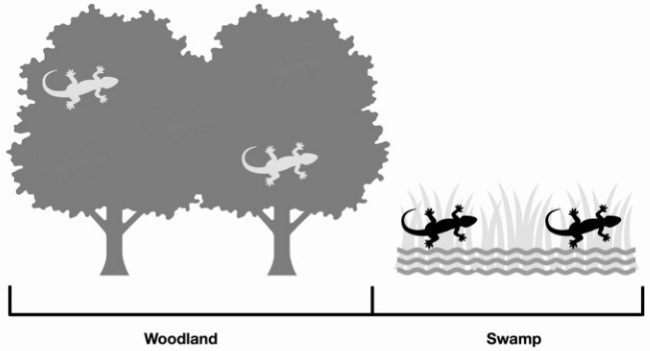
Measures of biodiversity

α biodiversity: the diversity that exists within an ecosystem

β biodiversity: the diversity that exists among different ecosystems

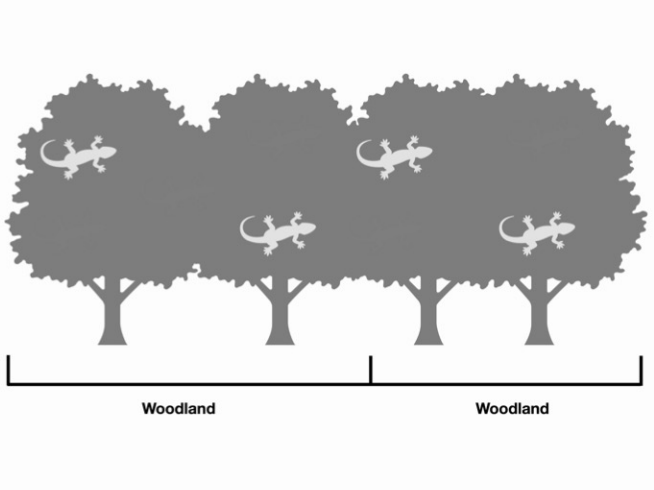
γ biodiversity: the diversity that exists among different geographies

Measures of biodiversity: Importance



(Ankur Awadhiya, Principles of Wildlife Conservation 2021)

Measures of biodiversity: Importance



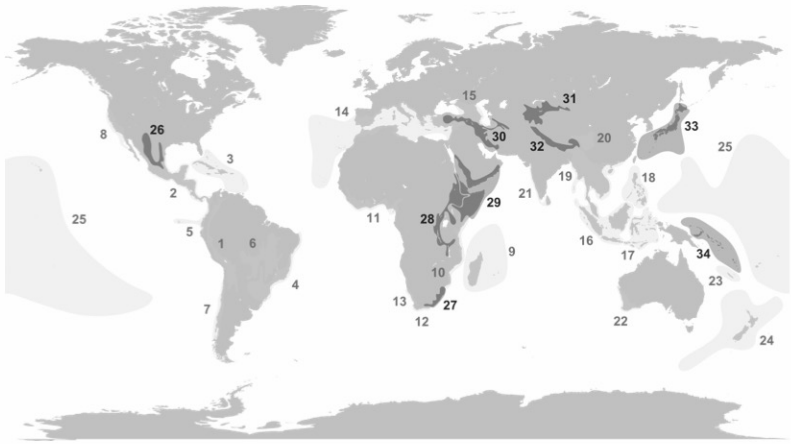
(Ankur Awadhiya, Principles of Wildlife Conservation 2021)

Biodiversity and spatial scale: Hotspots

Biodiversity hotspots are areas with

1. high species richness
2. high degree of endemism
3. high degrees of threat

Biodiversity hotspots of the world



(Wikimedia curid=10956104)

Thank you

3. Biodiversity – Economic valuation

Biodiversity has economic ramifications

We get several benefits from biodiversity.

Different areas have different amounts of biodiversity; making separate areas economically disparate.

Why do some areas have more biodiversity, and some have less? I

1. Evolutionary speed hypothesis: There is more biodiversity in areas with

- more time to evolve
- more rapid evolution: shorter generation times, higher mutation rates, natural selection acting more quickly

2. Geographical area hypothesis: There is more biodiversity in areas with

- larger spatial extent
- physically or biologically complex habitats

for these support more niches (roles) for organisms.

Why do some areas have more biodiversity, and some have less? II

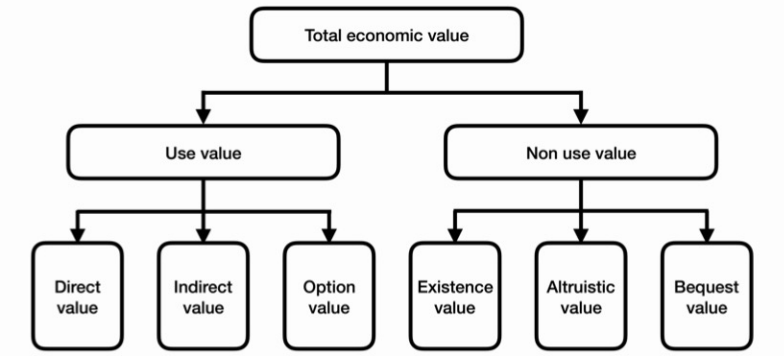
3. Interspecific interactions hypothesis: There is more biodiversity in areas with

- competition: affects niche partitioning
- predation: retards competitive exclusion

4. Ambient energy hypothesis: There is more biodiversity in areas with more energy, for fewer species can tolerate climatically unfavourable conditions
5. Intermediate disturbance hypothesis: There is less biodiversity in areas with

- very high / frequent disturbances: leads to extinction of species
- very low / infrequent disturbances: leads to competitive equilibrium and loss of species of low competitive ability

Total economic value of biodiversity



Use value

Value arising out of use of the resource

Non-use value

Value arising even though the resource is not being used

Direct value

Direct value comprises of:

1. consumptive and productive values such as

- timber
- firewood
- medicines
- grazing
- NTFPs
- water, etc.

2. non-consumptive values such as

- recreation / ecotourism
- education and research
- human and wildlife habitat, etc.

Indirect value

These include

1. watershed benefits, including

- agricultural productivity
- soil conservation
- ground water recharge
- regulation of stream flows

2. ecosystem services, such as

- nitrogen fixation
- waste assimilation
- carbon sequestration and storage
- microclimatic functions

3. evolutionary processes, including

- global life support
- biodiversity

Option value

An option for the future direct and indirect use of biodiversity.

Existence value

Value deriving from the knowledge that the resources continue to exist.

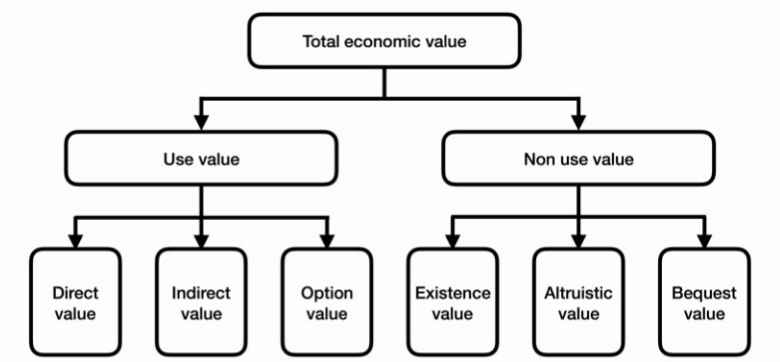
Altruistic value

Value derived from the knowledge of use of resources by others in the current generation.

Bequest value

Value of leaving use and non-use values for offspring's or future generations.

Total economic value of biodiversity



Methods of valuation

There are three accepted approaches for valuation:

1. market prices / revealed willingness to pay, including

- market price method
- hedonic pricing method
- travel cost method

2. circumstantial evidence / imputed willingness to pay, such as

- replacement / substitute cost
- damage cost avoided

3. surveys / expressed willingness to pay, such as

- contingent valuation method

Ecosystem Services

"the benefits people obtain from ecosystems"

Classification of Ecosystem Services I

1. Provisioning services

- food: honey, spices, wild fruits, etc.
- raw materials: timber, fuel wood, fodder, organic matter, etc.
- genetic resources: crop improvement genes
- purified water
- medicinal resources: medicinal plants, assay organisms, etc.
- energy: hydropower, biological fuels, etc.
- ornamental resources: feathers, shells, flowers, fur, butterflies, etc.

2. Regulating services

- carbon sequestration
- climate regulation
- biological control of pest population through predation

Classification of Ecosystem Services II

- waste decomposition and detoxification
- bioremediation
- purification of air and water
- protection against floods
- groundwater recharge
- protection against disasters such as hurricanes and tsunamis

3. Supporting services

- soil formation and humus formation
- nutrient cycling
- primary production and oxygen generation
- provisioning of habitat for biodiversity
- biologically mediated habitats such as corals and mangroves
- pollination

Classification of Ecosystem Services III

4. Cultural services

- recreational (e.g. ecotourism, outdoor sports, etc.)
- scientific and educational (e.g. for scientific studies and discovery, excursions)
- religious and spiritual
- cultural (e.g. use as a motif for books, films, paintings, etc.)
- therapeutic (e.g. ecotherapy)
- inspirational

The InVEST model

InVEST = Integrated Valuation of Ecosystem Services and Tradeoffs

This is a GIS (Geographic Information System) based suite of open-source software models for mapping and doing valuation of ecosystem services.

It performs computations using spatially explicit data and models. The final results can be in the form of

1. biophysical information (e.g. tonnes of carbon sequestered), or
2. economic information (e.g. value of that amount of sequestered carbon)

Some ecosystem services and their valuation I

1. employment generation, computed as

$$\Sigma(\text{man days} \times \text{wage rate})$$

2. fishing benefits, computed as

$$\Sigma(\text{production} \times \text{market prices})$$

3. fuelwood benefits, computed as

$$\Sigma(\text{production} \times \text{market prices})$$

4. fodder benefits, computed as

$$\Sigma(\text{production} \times \text{market prices})$$

Some ecosystem services and their valuation II

5. timber benefits, computed as

$$\Sigma(\text{production} \times \text{market prices})$$

6. bamboo benefits, computed as

$$\Sigma(\text{production} \times \text{market prices})$$

7. NTFP benefits, computed as

$$\Sigma(\text{production} \times \text{market prices})$$

8. genepool benefits such as resilience of ecosystems and avenues for future use of biological compounds and other products, computed using benefits transfer method

Some ecosystem services and their valuation III

Benefits transfer method: "a method to estimate economic values for ecosystem services by transferring available information from studies already completed in another location and / or context"

9. carbon sequestration benefits, computed as

   Σ(sequestration$\times$market prices (or using social cost of carbon))

10. carbon storage benefits, computed as

    $$\Sigma(\text{total storage} \times \text{social cost of carbon})$$

Social cost of carbon: "the cost of impacts caused by emission of carbon dioxide"

Some ecosystem services and their valuation IV

11. water provisioning benefits, computed as

    $$\Sigma(\text{water provisioned} \times \text{market prices})$$

12. water purification benefits, computed as

    Σ(water purified$\times$average cost of treating water (replacement))

13. soil conservation and sediment retention benefits, computed as

    $$\Sigma(\text{erosion avoided} \times \text{cost of damage avoided})$$

14. nutrient retention benefits, computed as

    $$\Sigma(\text{nutrients retained} \times \text{cost of artificial fertilisers})$$

15. biological control of pests, computed using benefits transfer method

Some ecosystem services and their valuation V

16. moderation of extreme events benefits, computed using benefits transfer method
17. pollination benefits, computed using benefits transfer method
18. nursery for various species benefits, computed using benefits transfer method
19. habitat for various species benefits, computed using benefits transfer method
20. cultural heritage benefits, computed using contingent valuation method
21. recreation benefits, computed using travel cost method
22. air quality benefits, computed as

    $$\Sigma(\text{air purified} \times \text{average cost of treating air (replacement)})$$

Some ecosystem services and their valuation VI

23. waste assimilation benefits, computed using benefits transfer method
24. climate regulation benefits, computed using benefits transfer method

Example: Panna Tiger Reserve I

1. Flow benefits: ₹69.55 billion per year

- Annual direct benefits: ₹0.78 billion
- Annual indirect benefits: ₹53.11 billion
- Option benefits: ₹15.65 billion

2. Stock benefits: ₹137.46 billion per year
3. Critical ecosystem services:

- Water provisioning: ₹25.82 billion per year
- Climate regulation: ₹20.21 billion per year
- Waste assimilation: ₹1.66 billion per year
- Benefits to human health: ₹144.55 billion per year

4. Kinds of services:

Example: Panna Tiger Reserve II

- Provisioning services: ₹0.67 billion per year
- Supporting services: ₹0.38 billion per year
- Regulating services: ₹68.48 billion per year
- Cultural services: ₹18.40 million per year

5. **Investment multiplier: 1939.36**

Data source: IIFM: Economic valuation of tiger reserves in India

Often ecosystem services are about choices

1. tsunami protection wall or mangrove forests, e.g. Odisha
2. water purification plants or wetlands, e.g. Catskill mountains
3. artificial pollination or honeybees, e.g. Israel
4. sewage treatment facilities or forests, e.g. Kakreta

Kakreta facility

(Ankur Awadhiya 2015 Agra)

Thank you

4. Ecological interactions

What are interactions?

Effects that the organisms in a community have on each other are called interactions.

Intraspecific and interspecific interactions

Intraspecific interactions: Effects that the organisms in a community have on members of their own species.

Interspecific interactions: Effects that the organisms in a community have on members of species other than their own.

Harmonious and inharmonious interactions

Harmonious interactions: Positive ecological interactions where none of the participating organisms is harmed.

Inharmonious interactions: Negative ecological interactions where at least one of the participating organisms is harmed.

Main intraspecific ecological interactions

1. Harmonious interactions

- colonies
- societies

2. Inharmonious interactions -intraspecific competition

- cannibalism

Main interspecific ecological interactions

1. Harmonious interactions

- protocooperation
- mutualism
- commensalism

2. Inharmonious interactions

- interspecific competition
- parasitism
- predatism
- ammensalism

A table of ecological interactions

Table 1: Table of ecological interactions

Interaction	Impact on 1st organism	Impact on 2nd organism
Competition	-	-
Amensalism	-	0
Exploitation	-	+
Neutralism	0	0
Commensalism	0	+
Mutualism	+	+

Harmonious interactions

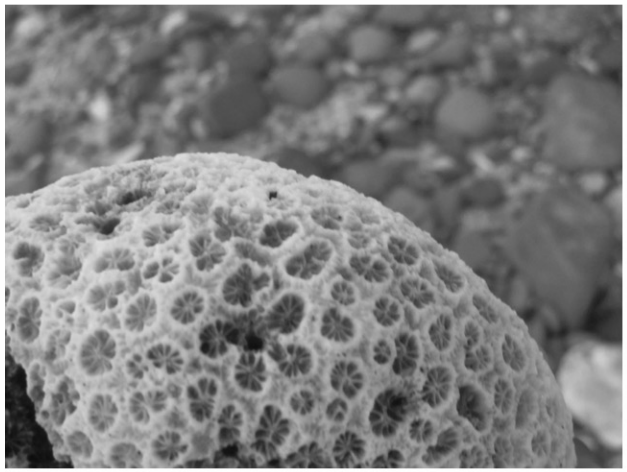
Colonies

Definition: "functional integrated aggregates formed by individuals of the same species"

Example:

1. coral reefs
2. filamentous algae
3. microbial colonies

Corals



(Ankur Awadhiya 2016 Andamans)

Microbial colonies

(Ankur Awadhiya 2010 IIT Kanpur)

Societies

Definition: "interactions for labor division and collaboration among individuals of the same species"

Example:

1. bee hives
2. termite mounds
3. wolf packs

Termite mound

(Ankur Awadhiya 2015 Timli)

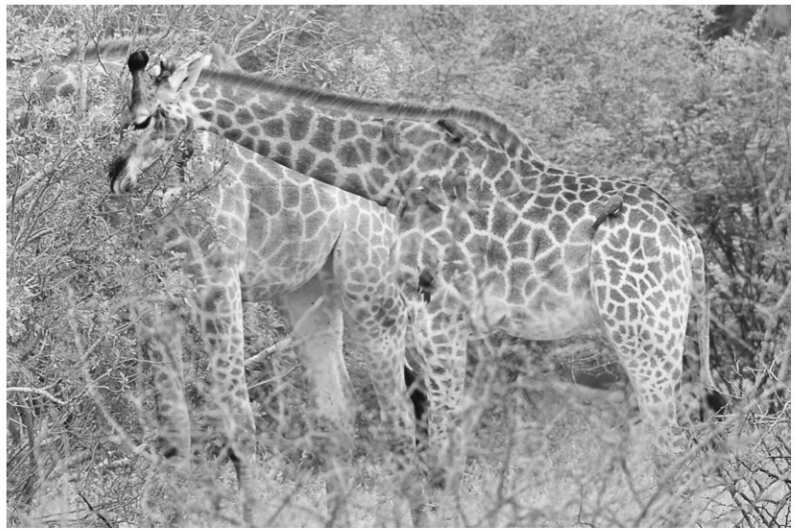
Protocooperation

Definition: "an ecological interaction in which both participants benefit but which is not obligatory for their survival"

Example:

1. birds eating ectoparasites on the bodies of animals
2. cleaner fishes
3. hermit crabs and sea anemones

Birds on giraffe



(Ankur Awadhiya 2018 Kruger NP)

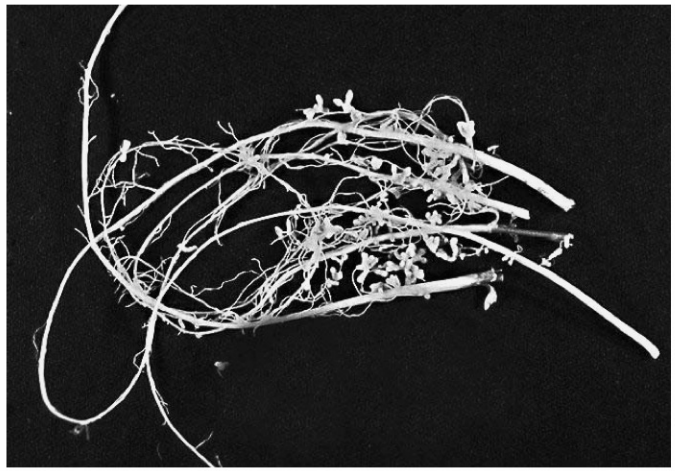
Mutualism

Definition: "an ecological interaction in which both participants benefit and which is obligatory for their survival"

Example:

1. microbes digesting cellulose in the stomach of ruminants
2. *Rhizobium* in the root nodules of leguminous plants

Root nodules in Soyabean roots



(Wikimedia curid-52367)

Commensalism

Definition: "an ecological interaction in which one individual benefits while the other is neither benefits nor is harmed"

Example:

1. bacteria and other micro organisms living on the skin without being pathogenic or beneficial
2. Egrets feeding with buffaloes

Egret with buffaloes

(Ankur Awadhiya 2018 Bhopal)

Egret with buffaloes

(Ankur Awadhiya 2018 Bhopal)

Inharmonious interactions

Main inharmonious ecological interactions

1. Intraspecific interactions

- intraspecific competition
- cannibalism

2. Interspecific interactions

- interspecific competition
- parasitism
- predatism
- ammensalism

Competition

Definition: "Competition is the ecological interaction in which individuals explore the same ecological niche or their ecological niches partially coincide and, therefore, competition for the same environmental resources takes place."

Cannibalism

Definition: "Cannibalism is the act of one individual of a species consuming all or part of another individual of the same species as food."

Examples:

1. Sexual cannibalism in black widow
2. Sexual cannibalism in praying mantis

Parasitism

Definition: "An ecological interaction in which an organism lives at the expense of another."

Types:

1. ectoparasites, e.g. leech
2. endoparasites, e.g. *Plasmodium vivax*

Predation

Definition: "An ecological interaction in which one individual mutilates or kills another to get food"

Predation

(Ankur Awadhiya 2018 Kruger NP)

Predation

(Ankur Awadhiya 2018 Mudumalai NP)

Amensalism

Definition: "An interaction where an organism inflicts harm to another organism without any costs or benefits received by itself"

e.g. trampling of grass due to movement of animals

Blackbucks grazing

(Ankur Awadhiya 2018 Velavadar NP)

Thank you