NATIONAL OPEN UNIVERSITY OF NIGERIA

FACULTY OF SCIENCES

COURSE CODE: BIO 313

COURSE TITLE: ANIMAL ECOLOGY

BIO 313: ANIMAL ECOLOGY

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COURSE GUIDE

Introduction

Animal Ecology (BIO 313) is a 2 credit-hours course for undergraduate students of Biology that deals with the historical concept of ecology, ecology of local and aquatic animals. The other contents are growth rate, age structure of animal population, Natality and Mortality, Survivorship Curves, Life Tables and K-Factor Analysis, Competition, The Natural Regulation of Animal Numbers, Population Cycles, Dynamics of Predator-Prey Systems, Ecology of African Bats and Behavioural Ecology.

Course Competencies

This course aims to provide the basic knowledge in Ecology to enable the sudent know/understand the relationship between animals in their ecosystem and with the environment

Course Objectives

The Comprehensive Objectives of the Course are to;

1. Explain the historical background of animal ecology,
2. Explain the basic fundamentals of ecology and its components,
3. Explain the various relationships influencing the ecological community,
4. State and explain the different types of ecosystem components to include the levels of energy flow in ecosystem and ways by which population can be changed

Working Through this Course

To successfully complete this course, you are required to read each study unit, read the textbooks and other materials provided by the National Open University.

Reading the reference materials can also be of great assistance. Each unit has self – assessment exercise which you are advised to do.

There will be a final examination at the end of the course. The course should take you about 8 weeks to complete.

This course guide provides you with all the components of the course, how to go about studying and how you should allocate your time to each unit so as to finish on time and successfully

Study Units

The course is divided into 3 modules and study units in this course are given below:

BIO 313 ANIMAL ECOLOGY (2UNITS)

Module 1: Introduction to Animal Ecology
Unit 1: Historical Background of Animal Ecology
Unit 2: Fundamentals of Ecology
Unit 3: Interactions in Animals
Unit 4: Ecology of Aquatic Animals
Unit 5: Ecology of Terrestrial Animals

Module 2: Ecology of Animal Population
Unit 1: Growth rate and Age structure of animal population
Unit 2: Factors affecting Animal Population
Unit 3: Measurement of Population dynamics
Unit 4: Life tables and K-values
Unit 5: Key-Factor Analysis

Module 3: Population Cycle in Animal Ecology
Unit 1 Competition in Animal Ecology
Unit 2: Population Cycle
Unit 3: Population Cycles in a Predator-Prey System
Unit 4: Ecology of African Bat
Unit 5: Behavioural Ecology

References and Further Readings

You would be required to read the recommended references and textbooks in each unit of the course materials.

Presentation Schedule

There is a time-table prepared for the early and timely completion and submissions of your TMAs as well as attending the tutorial classes. You are required to submit all your assignments at the stipulated date and time.

Assessment

There are three aspects to the assessment of this course. The first one is the in-text questions and the second is self-assessment exercises, while the third is the written examination or the examination to be taken at the end of the course. Review the exercises or activities in the unit by applying the information and knowledge you acquired during the course. The work submitted to your tutor for assessment will account for 30% of your total work. At the end of this course you will have to sit for a final or end of course examination of about a two hour duration and this will account for 70% of your total course mark.

How to get the Most from the Course

In this course, you have the course units and a course guide. The course guide will tell you briefly what the course is all about. It is a general overview of the course materials you will be using and how to use those materials. It also helps you to allocate the appropriate time to each unit so that you can successfully complete the course within the stipulated time limit.

The course guide also helps you to know how to go about your in-text questions and Self-assessment questions which will form part of your overall assessment at the end of the course. Also, there will be tutorial classes that are related to this course, where you can interact with your facilitators and other students. Please I encourage you to attend these tutorial classes.

This course exposes you to Animal Ecology, a sub-discipline and very interesting field of Biological Science.

Online Facilitation

Eight weeks are provided for tutorials for this course. You will be notified of the dates, times and location for these tutorial classes.

As soon as you are allocated a tutorial group, the name and phone number of your facilitator will be given to you.

The duties of your facilitator is to monitor your progress and provide any necessary assistance you need.

Do not delay to contact your facilitator by telephone or e-mail for necessary assistance if

- You do not understand any part of the study in the course material.
- You have difficulty with the self-assessment activities.
- You have a problem or question with an assignment or with the grading of the assignment.

It is important and necessary you attend the tutorial classes because this is the only chance to have face to face contact with your facilitator and to ask questions which will be answered instantly. It is also a period where you can point out any problem encountered in the course of your study.

Course Information

Course Code: BIO 313
Course Title: ANIMAL ECOLOGY
Credit Unit: 2

Course Status: ELECTIVE
Course Blub: This course provides students with the basic knowledge in Ecology to enable them understand the relationship between animals in their ecosystem and with the environment
Semester: FIRST SEMESTER
Course Duration: 13 WEEKS
Required Hours for Study : 65 hours

Ice Breaker

Dr**.** Esenowo, Imeh Kokoete is a Senior Lecturer of Ecology and Environmental Biology in the Department of Animal and Environmental Biology, University of Uyo. Dr. Esenowo moderate and facilitate courses in the National Open University. He has supervised student projects and seminar review in the Department of Biology, Faculty of Science.
Dr. Esenowo research interests are physico-chemical aspects of freshwater and terrestrial ecosystem, fish biology and environmental toxicology.

Module 1: Introduction to Animal Ecology

Module Introduction

In Module One, unit one deals with the history and current understanding of Animal Ecology and how organisms and its environment relate and influence one another in their various ecosystems. You are taught about the fundamentals of ecology; interaction in animals and ecology of aquatic and terrestrial animals.

Unit 1: Historical Background of Animal Ecology
Unit 2: Fundamentals of Ecology
Unit 3: Interactions in Animals
Unit 4: Ecology of Aquatic animal
Unit 5: Ecology of Terrestrial animal
Glossary

Unit 1: Historical Background of Animal Ecology

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1.1 Introduction
1.2 Intended Learning Outcomes (ILOs)
1.3 Historical background of Ecology
1.4 Summary
1.5 References/Further Readings/Web Sources
1.6 Possible Answers to Self-Assessment Exercises

1.1 Introduction

Ecology (from Greek: οἶκος,"house"; -λογία, "study of") is the study of living organisms relating with each other and their surroundings. Ecosystems can be defined as a web, community, or network of individuals that arrange into a self-organized and complex hierarchy of pattern and process. Ecosystems create a biophysical feedback between living (biotic) and non-living (abiotic) components of an environment that generates and regulates the biogeochemical cycles of the planet. Ecosystems provide goods and services that sustain human societies and general well-being. Ecosystems are sustained by biodiversity within them Biodiversity is the full-scale of life and its processes, including genes, species and ecosystems forming lineages that integrate into a complex and regenerative spatial arrangement of types, forms, and interactions.

Ecology is a sub-discipline of biology, the study of life. The word "ecology" ("oekologie") was coined in 1866 by the German scientist Ernst Haeckel (1834–1919). Haeckel was a zoologist, artist, writer, and later in life a professor of comparative anatomy. Ancient philosophers of Greece, including Hippocrates and Aristotle, were among the earliest to record notes and observations on the natural history of plants and animals; the early rudiments of modern ecology. Modern ecology mostly branched out of natural history, science that flourished in the late 19th century. Charles Darwin's evolutionary treatise and the concept of adaptation as it was introduced in 1859 is a pivotal cornerstone in modern ecological theory.

Ecology is not synonymous with environment, environmentalism, natural history or environmental science. Ecology is closely related to the biological disciplines of physiology, evolution, genetics and behaviour. An understanding of how biodiversity affects ecological function is an important focus area in ecological studies. Ecosystems sustain every life supporting function on the planet, including climate regulation, water filtration, soil formation (pedogenesis), food, fibers, medicines, erosion control, and many other natural features of historical, spiritual or scientific value. Ecologists seek to explain:

1. life processes and adaptations
2. distribution and abundance of organisms
3. the movement of materials and energy through living communities
4. the successional development of ecosystems. and
5. the abundance and distribution of biodiversity in context of the environment.

There are many practical applications of ecology in conservation biology, wetland management, natural resource management (agriculture, forestry, fisheries), city planning (urban ecology), community health, economics, basic and applied science, and it provides a conceptual framework for understanding and researching human social interaction (human ecology).

1.2 Intended Learning Outcomes (ILOs)

At the end of this unit, the student should be able to explain the historical background of animal ecology and the various contributions of scientists to the development of animal ecology

1.3 Historical Background of Ecology

Studies of animal distribution began in the nineteenth century, but the formal development of animal ecology did not occur until the 1920s. British zoologist Charles Elton, whose field research emphasized the study of populations in the wild, was perhaps the most influential figure. Elton's work, often involving northern fur-bearing animals of commercial value, made a number of concepts part of the naturalist's vocabulary, including the ecological niche, the food chain, and the pyramid of numbers, that is, the decrease in numbers of individual organisms, or total quantity (weight) of organisms, at each successive stage in a food chain, from plants and plant-eating animals at the bottom to large carnivores at the top. Just as with plant ecology, diverse schools of animal ecology emerged in Europe and the United States during the first half of the twentieth century. Some schools, like Elton's, focused on empirical studies of predator-prey interactions and population fluctuations, others focused on animal community organization, still others on broader patterns of distribution and abundance.

Although some of the early work in animal ecology, particularly in the United States, attempted to model itself on plant ecology, by the 1930s animal ecology had emerged as an independent field. There was little overlap or interaction between the work of animal and plant ecologists. Effective impetus for an integrated perspective in ecology came from work in aquatic biology, best exemplified in the late nineteenth century by Karl Möbius's studies of the depleted oyster bank off Germany's north coast and the pioneering limnological (freshwater) studies of François Alphonse Forel on Swiss lakes. This work was continued and refined in the early twentieth century by many researchers, including August Thienemann in Germany and Einar Naumann in Sweden. Möbius's concept of the “biocenosis,” the integrated community consisting of all living beings associated with a given habitat or a particular set of environmental conditions, was adopted widely by German and Russian ecologists in the 1920s and 1930s. An integrative perspective also emerged in soil science, as in Sergei Winogradsky's turn-of-the-century studies of soil microbiology, and in studies of biogeochemical cycles, as in the work of Russian geochemist Vladímir Vernadsky, who introduced the term “biosphere” in 1914. However, the integrative concept that had the broadest appeal and played a central role in bringing together the many different strands of ecological science was that of the “ecosystem,” introduced by British botanist Arthur G. Tansley in 1935 but first used effectively in an aquatic setting.

Tansley was Britain's foremost plant ecologist and the founder in 1913 of the British Ecological Society, the first such national organization, formed two years earlier than its American counterpart. A pioneer in vegetation surveys, a critic of Clements's idea of the climax community, a passionate conservationist, and a student of Sigmund Freud, Tansley brought his broad experience and erudition to bear on the problem of identifying the ideal ecological unit of study. He suggested that the term “ecosystem” captured this concept best without implying any mysterious vital properties. The new term received its fullest early treatment in a seminal paper published in 1942 by a young American limnologist, Raymond Lindeman. Making use of the concept of ecological succession, Elton's pyramid of numbers and food chains, earlier studies of energy flow in aquatic systems, and Clements's notion of the stable climax community, Lindeman traced the flow of energy through the different trophic (feeding) levels (producers, primary consumers, secondary consumers) in a small Minnesota pond as a way to mapping its structure as an ecosystem and to demonstrate its progress in development toward a stable, equilibrium state.

World War II proved to be a watershed for ecology. Although earlier preoccupations with community classification and structure, population dynamics, and patterns of distribution continued in the post-war years, newer methodologies, practices, and conceptual schemes took hold, and ecology as a science and a profession grew in size, status, and organization. In the post-war period, Lindeman's ground breaking work on ecosystem ecology found a home among biologists funded by the U.S. Atomic Energy Commission, who used radionuclides to trace the flow of materials and energy through natural ecosystems. Ecosystem research soon expanded from its base in the Atomic Energy Commission. It also prospered among a small group of Tansley's followers at the new Nature Conservancy in Britain. It became an essential feature of modern ecological science, a message conveyed to several generations of students worldwide through the successive editions of Eugene P. Odum's *Introduction to Ecology*, first published in 1953. Meanwhile, the pre-war synthesis of Darwinian natural selection theory with Mendelian genetics resulted in the gradual post-war emergence of a more strongly Darwinian perspective in population and community ecology.

The post-war years also saw a shift toward quantitative aspects of ecology. Mathematical techniques developed in the United States, Europe, and the Soviet Union during the interwar period joined with war-born techniques involving information systems and cybernetics to produce a movement toward mathematical modelling and computer simulation of populations, communities, and ecosystems. Much of this modelling and its techniques came under attack during the last decades of the twentieth century. Some ecologists abandoned model building for empirical studies, others worked on refining and improving the models, and many called into question the underlying notions of stability and equilibrium upon which most of the models were based.

The devastation brought by World War II also contributed to greater post-war interest in the conservation of natural resources, protection of wildlife, and preservation of natural environments, a trend that, when linked in the 1960s with social criticism, blossomed into an international environmental movement that drew heavily upon concepts and theories of ecology. As had occurred before the war in a more limited way among a few visionaries, ecology now came to be widely viewed not only as the source of remedies for environmental ills but also as the scientific underpinning for a new social order. This proved to be a mixed blessing for ecologists. On the one hand, funding for ecological research increased considerably, and many more people were drawn into the field. On the other hand, the theoretical framework of ecological science, being neither unified nor consistent, could not provide easy, unambiguous solutions to environmental problems, let alone unified and consistent social visions. Toward the end of the twentieth century, this disagreement and uncertainty among ecologists was used as fuel in legislative and legal debates arguing against the protection of endangered species and the maintenance of pristine nature reserves. This situation encouraged the further refinement and integration of ecological science toward the incorporation of human disturbance and the notion of managed ecosystems.The Studies of animal distribution began in which century?
Who is the founder of British Ecological Society?

Self-Assessment Exercises 1

Attempt these exercises to measure what you have learnt so far. This should not take you more than 5 minutes.

1. The British zoologist Charles Elton works involves many concepts which include what type of animal?
2. How has post-World War II impacted on the ecosystem?

1.4 Summary

You have been introduced to the field of animal ecology including some of its most fundamentals; early history, and current understanding of its development. Animal Ecology asks questions about how organisms and its environment relate and influence one another in their various ecosystems.

1.5 References/Further Readings/Web Sources

Donald Worster, *Nature's Economy: A History of Ecological Ideas*, 2d ed. (1994).

Eugene Cittadino, *Nature as the Laboratory: Darwinian Plant Ecology in the German Empire, 1880–1900* (1990).

Leslie A. Real and James H. Brown, eds., *Foundations of Ecology* (1991).

Gregg Mitman, *The State of Nature: Ecology, Community, and American Social Thought, 1900–1950* (1992).

Michael Shortland, ed., *Science and Nature: Essays in the History of the Environmental Sciences* (1993).

Robert P. McIntosh,The Background of Ecology (1985).

Sharon Kingsland, Modeling Nature: Episodes in the History of Population Ecology, 2d ed. (1995).

Stephen Bocking, Ecologists and Environmental Politics: *A History of Contemporary Ecology* (1997).

Pascal Acoted., The European Origins of Scientific Ecology *(1800–1901)*, 2 vols. (1998).

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https%3A//www.ncbi.nlm.nih.gov/pmc/articles/PMC5424069,-%E2%80%9CHistorical%20ecology%20can

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https://www.bing.com/videos/search?q=Historical+Background+of+Animal+Ecology+&&view=detail&mid=F5F48568B4DD988C3E0EF5F48568B4DD988C3E0E&&FORM=VRDGAR&ru=%2Fvideos%2Fsearch%3Fq%3DHistorical%2BBackground%2Bof%2BAnimal%2BEcology%2B%26FORM%3DHDRSC3

1.6 Possible Answers to SAEs

Answers to SAEs 1

1. Elton's work, often involving northern fur-bearing animals of commercial value, made a number of concepts part of the naturalist's vocabulary, including the ecological niche, the food chain, and the pyramid of numbers, that is, the decrease in numbers of individual organisms, or total quantity (weight) of organisms, at each successive stage in a food chain, from plants and plant-eating animals at the bottom to large carnivores at the top.

2. The devastation brought by World War II also contributed to greater post-war interest in the conservation of natural resources, protection of wildlife, and preservation of natural environments, a trend that, when linked in the 1960s with social criticism, blossomed into an international environmental movement that drew heavily upon concepts and theories of ecology.

Unit 2: Fundamentals of Ecology

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2.1 Introduction
2.2 Intended Learning Outcomes (ILOs)
2.3 Ecological Community
  2.3.1 Composition and Diversity
  2.3.2 Habitat and Ecological Niche
2.4 Summary
2.5 References/Further Readings/Web Sources
2.6 Possible Answers to Self-Assessment Exercises

2.1 Introduction

Fundamentally, ecology is like a society, while ecologists are like economists that investigate the economy of nature instead of human. We will be talking about ecology in three basic scales after the introductory section: population, community, and ecosystem. They are stacked and connected one by one, each acts as the building block of the superior system, until finally we arrive at the global level, with the most dynamic, diversified, and ultimate living things system on the planet, the biosphere

2.2 Intended Learning Outcomes (ILOs)

At the end of this unit, the student should be able to;

- Explain the basic fundamentals of ecology and its components
- Explain the various relationships influencing the ecological community

2.3 Ecological Community

A *community* is *comprised of all the various populations interacting in an area*. An example of a community is a coral reef where numerous populations of fishes, crustacea and corals exist and interact. Ecologists try to know at this level how different relationships like predation and competition are influencing the organization and evolution of a community.

In-Text Question(s)

What is Community?
Answer: A community is comprised of all the various populations interacting in an area.

2.3.1 **Composition and Diversity**

Communities distinguish from each other by two characteristics: composition and diversity. The *composition* of a community is simply a listing of the various species in the community. The diversity digs deeper than mere composition in that it involves both species richness (the number of species) as well as evenness (the relative abundance of different species).

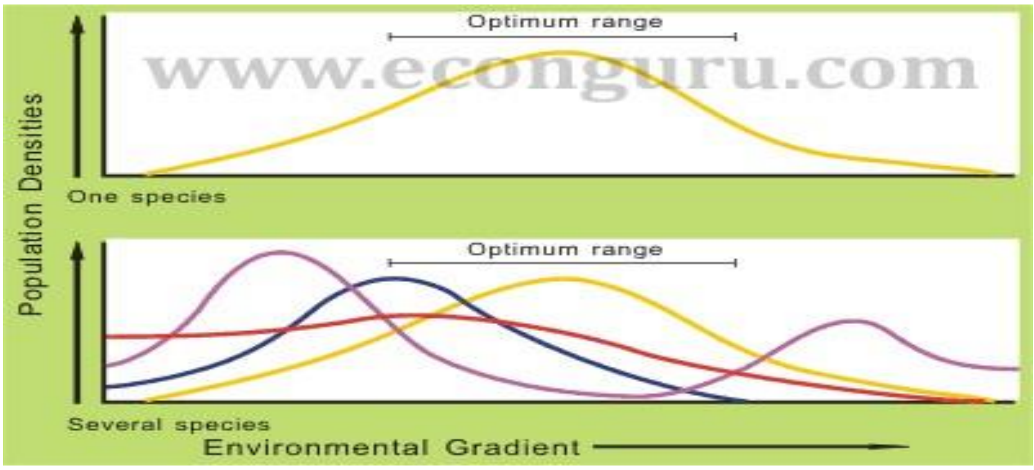

Figure 1: Community Individualistic Model (www. econguru.com)

A species' spreading range is based on its tolerance for such abiotic factors in the environment as temperature, light, water availability, salinity, and so forth. To determine a species' tolerance range, we plot the species' ability to survive and reproduce under a particular gradient of environmental conditions, resulting a bell-shaped curve. If we put together several species' range in one graph, a community is formed because their tolerance ranges simply overlap.

However, other models exist such as *interactive model* to explain community and most ecologists supported it for many years, because it bases its hypothesis not only on species' responses to abiotic factors but also biotic factors. Search the web if you want to learn more about it.How can communities be distinguish from each other?

Self-Assessment Exercises 1

Attempt this exercises to measure what you have learnt so far. This should not take you more than 5 minutes. 1. Differentiate between habitat and Niche?

2. 3. 2 Habitat and Ecological Niche

Just as Elton John sings the Circle of Life, each species plays its role in a community, eats or be eaten, lives or let live. They occupy particular positions both in a spatial sense (where to live) and a functional sense (what is the part). A *habitat* is *an environment wherein an organism lives and reproduces*, while the *ecological niche* is *the functional role the organism plays in its community, including its habitat as well as the interactions with other organisms.* Niche includes everything e.g. resources an organism needs to meet its energy, nutrient, and survival demands) and every aspects of the way(e.g. the environmental features it needs to hunt and to escape successfully) an organism live with the environment, since it's difficult to delve into one niche completely, most observations concentrate on certain aspects of it.

Since an organism's niche is affected by abiotic factors (such as climate and habitat) and biotic factors (such as competitors, parasites, and predators) simultaneously, usually two types of niches are looked at separately by ecologist, the fundamental niches and the realized niches. The *fundamental niche* of an organism comprises all conditions where under, it can potentially survive and reproduce; the *realized niche* is the set of conditions where under, it exists in nature.What is a Habitat?

Self-Assessment Exercises 2

Attempt this exercise to measure what you have learnt so far. This should not take you more than 5 minutes What is Diversity?

2.4 Summary

You are taught about the fundamentals of ecology; Composition and diversity, habitat and ecological niche.

2.5 References/Further Readings/Web Sources

Begon, M., J. L. Harper and C. R. Townsend, 1990. Ecology - Individuals, Populations and Communities, Blackwell Scientific Publ., London, UK, 2nd edition. Chapter 4.

Chapman, J. L. and Reiss, M. J. (2010), Ecology, Principles and Applications, 2nd ed. Cambridge University Press.

Fundamental of ecology, author: EconGuru, introduction to ecosystems and community. Ecological population; Chapter 1 to chapter 3.

Miller, G. T. and Spoolman, S. E. (2009), Essentials of Ecology, 5th ed. Brooks/Cole, Cengage Learning.

Miller, G. T. Jr. (1988), Environmental Science, 2nd ed. Wadsworth, Belmont.

Odum, E. P. and Barrett, G. W. (2004), Fundamentals of Ecology, 5th ed. Cengage Learning

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2.6 Possible Answers to SAEs

Answers to SAEs 1

1. A *habitat* is *an environment wherein an organism lives and reproduces*, while the *ecological niche* is *the functional role the organism plays in its community, including its habitat as well as the interactions with other organisms.* Niche includes everything e.g. resources an organism needs to meet its energy, nutrient, and survival demands) and every aspects of the way(e.g. the environmental features it needs to hunt and to escape successfully) an organism live with the environment, since it's difficult to delve into one niche completely, most observations concentrate on certain aspects of it.

Answers to SAEs 2

1. Diversity involves both species richness (the number of species) as well as evenness (the relative abundance of different species).

Unit 3: Interactions in Animals

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- 3.3.4 Symbiotic Relationships

3.4 Summary
3.5 References/Further Readings/Web Sources
3.6 Possible Answers to Self-Assessment Exercises

3.1 Introduction

Animals interact with each other in numerous, complex ways. Of the various types of interactions between species, most involve resources and consumers. We shall be considering the different types of interaction that exist in nature.

3.2 Intended Learning Outcomes (ILOs)

At the end of this unit, the student should be able to;

- Explain the various relationships influencing the ecological community
- Explain the different types of interaction in animals

3.3 Interactions

A resource, in ecological terms, is something (such as food, water, habitat, sunlight, or prey) that is required by an organism to perform a vital function such as growth or reproduction. A consumer is an organism that consumes a resource (such as predators, herbivores, or detritivores). Most interactions between animals involve one or more competitor species vying for a resource.

Competition for resources, predator-prey, parasite-host, and other types of interactions integrate species into a system of dynamic interacting populations.

Table 1: Showing the different types of Interaction among animals

Species Interactions	
Type of Interaction	**Expected Outcome**
Competition	- - Decrease in both species
Predation	+ - Predator increases, prey decreases
Symbiotic Relationships	
Parasitism	+ - Parasite increases, host decreases
Commensalism	+ 0 One increases, the other not affected
Mutualism	+ + Increase in both species

Source: (www. econguru.com)

As indicated in the above table, *competition* for limited resources between two species has a negative effect on the population abundances of both species. In *predation* and *parasitism*, the abundances of predator and parasite are expected to increase at the expense of that of prey and host, since predators feed on prey and the parasites obtain nutrients from the host. In *commensalism* one species is benefited whereas the other is not harmed. In *mutualism*, two species help one another and both species are benefited. List the different types of interaction in nature

3.3.1 **Competition among Populations**

Interspecific competition occurs when members of different species try to utilize the same resource like light, space, or nutrients that is in limited supply, or when their niches overlap. If it is unlimited, no competition would have been triggered. Competition leads to several possible outcomes and one of them, is the extinction of one of the competitors.

Competition can cause species to evolve differences in traits. This occurs because the individuals of a species with traits similar to competing species always experience strong interspecific competition. These individuals have less reproduction and survival than individuals with traits that differ from their competitors. Consequently, they will not contribute many offspring to future generations. For example, the finches previously discussed can be found alone or together on the Galapagos Islands. Both species' populations actually have more individuals with intermediate-sized beaks when they live on islands without the other species present. However, when both species are

present on the same island, competition is intense between individuals that have intermediate-sized beaks of both species because they all require intermediate sized seeds. Consequently, individuals with small and large beaks have greater survival and reproduction on these islands than individuals with intermediate-sized beaks.
Studies show that when *G. fortis* and *G. fuliginosa* are present on the same island, *G. fuliginosa* tends to evolve a small beak and *G. fortis* tends to evolve a large beak. The observation that competing species' traits are more different when they live in the same area than when competing species live in different areas is called character displacement. For the two finch species, beak size was displaced: Beaks became smaller in one species and larger in the other species. Studies of character displacement are important because they provide evidence that competition plays a very important role in determining ecological and evolutionary patterns in nature.
What is interspecific competition?

Self-Assemeement Exercises 1

Attempt this exercises to measure what you have learnt so far. This should not take you more than 5 minutes.

1. Can competition cause species to evolve differences in traits?

3.3.2 The Competition Exclusive Principle

To explain how species coexist, in 1934 G. F. Gause proposed the competitive exclusion principle: species cannot coexist if they have the same niche. The word "niche" refers to a species' requirements for survival and reproduction. These requirements include both resources (like food) and proper habitat conditions (like temperature, **pH**). Gause reasoned that if two species had identical niches (required identical resources and habitats) they would attempt to live in the exact same area and would compete for the exact same resources. If this happened, the species that was the best competitor would always exclude its competitors from that area. Therefore, species must at least have slightly different niches in order to coexist.

Peter Grant and colleagues tested Gause's principle by studying seed-eating finches (birds) that live on the Galapagos Islands in the Pacific Ocean. They found that different finch species can coexist if they have traits that allow them to specialize on particular resources. For example, two finch species, *Geospiza fuliginosa* and *Geospiza fortis,* vary in a key trait: beak size. Beak size is a critical trait because it determines the size of a seed that a finch can eat: Individuals with small beaks eat small seeds, individuals with intermediate sized beaks can eat intermediate size seeds and individuals with large beaks can eat large seeds. *G. fuliginosa* and *G. fortis* do compete for intermediate sized seeds because each species has some individuals with intermediate sized beaks. However, *G. fuliginosa* specializes upon smaller seeds because it has more individuals with small beaks. Conversely, *G. fortis* specializes upon larger seeds because it has more individuals with large beaks. Thus, these species niches differ slightly because a specific trait, beak size, allows them to specialize upon a particular seed size.

Joe Connell also tested Gause's principle by studying barnacles (shelled marine organisms) that live on rocks along European coastlines. In 1961, Connell found that two barnacle species, *Balanus* and *Chthamalus,* can coexist because they differ in two traits: growth rate and vulnerability to **desiccation**. *Balanus* 's growth is rapid, which allows it to smother and crush the slower-growing *Chthamalus. Balanus,* however, dies close to shore because it gets too dry during low tide. In contrast, *Chthamalus* tolerates these dry conditions. Consequently, even though *Balanus* is a better competitor for space, these barnacles coexist because *Chthamalus* can survive in areas that *Balanus* cannot survive. These and many other examples support the competitive exclusion principle: Species can only coexist if they have different niches

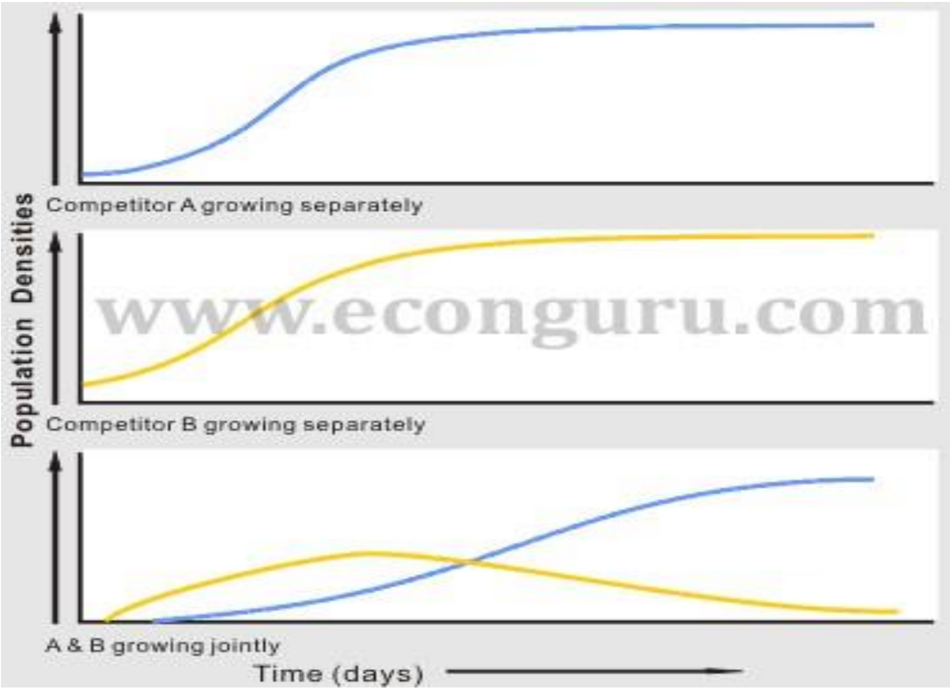

Figure 1: Competition to Extinction (Source: www.econguru.com)

When grown alone in pure culture, both A and B exhibit a somewhat logistic growth pattern, expanding their colonies rapidly till reaching the *carrying capacity* of the environment. However, when the two species come to mixed culture together, A is the better competitor who drives B out in the end.

You might wonder, now that competitions lead to extinctions, why the world is still filled with myriads of living things that share the resources. Good question, but you are partly right, and partly wrong. Extinction is not the only result of competition, two species can both survive the competition, but they have to change, or more technically, their niches have to adapt. In the light of *competitive exclusion principle* that no two species can concurrently occupy the same niche, either one of the species die out or both shift their niches. One of the embodiment of niche shift, or *niche partitioning* is *resource partitioning*. Resource partitioning decreases competition between two species, and it is more observable than other subtle forms of niche partitioning. Example of Resource Partitioning are when three species of ground finches of the Galapagos Islands occur on isolated islands, their bills tend to be the same intermediate size, enabling them to feed on a wider range of seeds. Where they co-occur, selection has favoured divergence in beak size because the size of the beak affects the kinds of seeds that can be eaten. In other words, competition has led to resource partitioning.

The tendency for characteristics to be more divergent when populations belong to the same community than when they live separately is termed *character displacement*. And it is often used as evidence for competition and how resource partitioning have taken place. Who proposed the competition exclusive principle?

Self-Assessment Exercises 2

Attempt this exercises to measure what you have learnt so far. This should not take you more than 5 minutes. 1. What was Gause reasoned on the Competition Exclusive Principle?

3.3.3 **Predator-Prey Interactions**

In *predation*, *one organism, called the predator feeds on another, called the prey*. With common sense, there should be no dispute on that the relationship between lion and zebra is that of predation. But what is the relationship that herbivorous deer feeds on trees and bushes? This might be a little bit surprising, but in a broader sense, predaceous consumers include not only animals but also herbivores that feed on plants.

By observation, we have revealed the interacting pattern between the populations of predator and prey, cycles of fluctuation that one drives the other and vice versa. Population of the prey increases as that of the predator decreases, since fewer prey are being eaten. At the *carrying capacity* of the environment, the number of prey reaches its summit and stops growing. The predators now are provided with plenty of prey to feed on, so the population increases as that of prey decreases. Again, the predators' increased number overconsume the prey, as the prey population declines, so does the prey population. See the graph below.

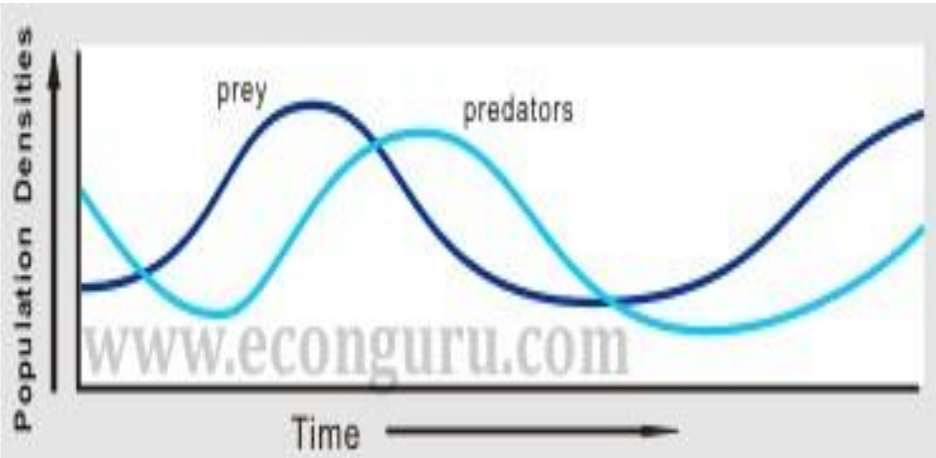

Figure 2: Predator-Prey Population Dynamics (source: www.econguru.com)

Notice that the predator population is smaller than that of prey, and that it fluctuates lagging behind the prey also.

Most predator-prey population cycles are like what we have discussed, probably with more elaboration of the dynamics and curves. However, their interactions involve more than just population cycles, other behaviours like prey defences might also interest you. If so, do check the picked links below. What is Predator- prey Interaction?

3.3.4 Symbiotic Relationships

A *symbiotic relationship*, or *symbiosis* is *one in which members of two populations interact very closely*. As indicated by the figure 3 in section 3.1.3, three types of symbiotic relationships exist and by the way at least one species benefits from such a relationship while the other is harmed or unaffected or benefited.
Parasitism resembles predation in that *an organism called a parasite derives nourishment from another called the host* (just as the predator derives nourishment from its prey), though parasites also take hosts as habitats and springboards to transmit themselves to other hosts.

Parasites appear in all kingdoms of life. Some of the frequently heard of parasites include viruses (e.g., HIV), bacteria (e.g., strep infection), protists (e.g., malaria), fungi (e.g., rusts and smuts), plants (e.g., mistletoe) and animals (e.g., leeches).

Commensalism is a symbiotic relationship wherein *one species is benefited and the other is neither benefited nor harmed*. Well known instances are those in which one species provides a habitat or a means of transportation for the other.

1. Example of Commensalism

Animalia: Barnacles attach themselves to the backs of whales and the shells of horseshoe crabs to get a free home and ticket for transportation. Remoras are fishes that attach themselves to the bellies of sharks by means of modified dorsal fin acting as a suction cup.

Plantae: Epiphytes grow in branches of tree in order to receive light, but not to take nourishment from the trees. Instead, their roots obtain nutrients and water from the air.

Mutualism is a symbiotic relationship in which *both species benefit*. In many cases, mutualistic relationships help organisms obtain food or avoid predation. As with parasitism, it is possible to find examples of mutualism in all kingdoms.

2. Example of Mutualism

Human and Bacteria: Human cannot synthesize vitamins by themselves, but can benefit from some bacteria residing in their intestinal tract that make vitamins. Meanwhile, bacteria are provided with food.

Termites and Protozoa: Termites rely on the protozoa in their intestinal tract to digest wood.

To sum up, symbiotic relationships do occur between species, but the three patterns we provided may be too simple to embrace all the natural forms of symbiosis. We were just skimming roughly. Many other derivative forms of symbiosis are developed, look for other materials if you are interested. What is Symbiosis?

Self-Assessment Exercises 3

Attempt this exercises to measure what you have learnt so far. This should not take you more than 5 minutes.

1. List examples of mutualism in animals?

3.4 Summary

You are taught about interactions, competition among populations, predator-prey. Interactions, Symbiotic Relationships

3.5 References/Further Readings/Web Sources

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3.6 Possible Answers to SAEs

Answer to SAEs 1

1. Competition can cause species to evolve differences in traits. This occurs because the individuals of a species with traits similar to competing species always experience strong interspecific competition. These individuals have less reproduction and survival than individuals with traits that differ from their competitors. Competition can cause species to evolve differences in traits. This occurs because the individuals of a species with traits similar to competing species always experience strong interspecific competition. These individuals have less reproduction and survival than individuals with traits that differ from their competitors.

Answer to SAEs 2

1. Gause reasoned that if two species had identical niches (required identical resources and habitats) they would attempt to live in the exact same area and would compete for the exact same resources. If this happened, the species that was the best competitor would always exclude its competitors from that area. Therefore, species must at least have slightly different niches in order to coexist.

Answer to SAEs 3

1. Answer: Human and Bacteria: Human cannot synthesize vitamins by themselves, but can benefit from some bacteria residing in their intestinal tract that make vitamins. Meanwhile, bacteria are provided with food.

Termites and Protozoa: Termites rely on the protozoa in their intestinal tract to digest wood

Unit 4: Ecology of Aquatic Animals

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4.1 Introduction

Animal ecology is an important area of study for scientists. It is the study of animals and how they relate to each other as well as how they relate to their environment. There are various forms of animal ecology. By studying this information, you learn more about what makes these animals prosper or what potentially holds them back. In animal ecology, there are many factors that is currently threatening the existence of these animals which are caused by human activities.

Perhaps the best examples are in the water. A look at areas like lakes, coastlines and even marine life will show you just how much human environmental damage has hurt these animals. Animal ecology has changed drastically in recent time. Here are some examples of how the environment and human interaction has changed the scope of many animals.

1. Animal habitats in many marine areas have ceased to exist. Coral reefs and other very delicate ecosystems have been harmed by human presence.
2. In the arctic regions, melting ice has limited the lifespan of polar bears, which make the ice their home. Additionally, sea lions and other marine life that use the ice to rest on have been unable to do so.
3. Dams and other waterway changes have hurt animal ecology throughout the country. Animals are no longer able to get to the source of water they need.
4. Deforestation in jungles and other habitats has caused many of the only locations for animals to live to be wiped away. Urban city development has also pushed animals farther and farther out of their natural habitats.

There are many other ways that animal ecology has changed. The goal of scientists is to find out what is happening and why it is happening that way. It is often very much a worry when animal species are dying or are unable to evolve naturally because of the drastic changes in their lifestyles and living areas. Through study of animal ecology, scientists hope to understand better what really is happening and what effect it will have both in the short and in the long term.

4.2 Intended Learning Outcomes (ILOs)

At the end of this unit, the student should be able to explain the ecology of different fish species

4.3 Ecology and Biology of Aquatic Animals

An aquatic animal is any animal whether invertebrate or vertebrate that lives in water for most or all of its lifetime. Many insects such as mosquitoes, mayflies, dragonflies and caddisflies have aquatic larvae, with winged adults. Aquatic animals may breathe air or extract oxygen from water through specialised organs called gills or directly through the skin.

The term aquatic can be applied to animals that live in either fresh water or salt water. However, the adjective marine is most commonly used for animals that live in saltwater, i.e. in oceans, seas, etc.

Aquatic animals (especially freshwater animals) are often of special concern to conservationists because of the fragility of their environments. Aquatic animals are subject to pressure from overfishing, destructive fishing, marine pollution and climate change. Many habitats are at risk which puts aquatic animals at risk as well. Aquatic animals play an important role in the world. The biodiversity of aquatic animals provide food, energy, and even jobs.

Fresh water creates a hypotonic environment for aquatic organisms. This is problematic for some organisms with pervious skins or with gill membranes, whose cell membranes may burst if excess water is not excreted. Some protists accomplish this using contractile vacuoles, while freshwater fish excrete excess water via the kidney. Although most aquatic organisms have a limited ability to regulate their osmotic balance and therefore can only live within a narrow range of salinity, diadromous fish have the ability to migrate between fresh water and saline water bodies. During these migrations they undergo changes to adapt to the surroundings of the changed salinities; these processes are hormonally controlled. The eel (*Anguilla anguilla*) uses the hormone prolactin, while in salmon (Salmo salar) the hormone cortisol plays a key role during this process.

Freshwater molluscs include freshwater snails and freshwater bivalves. Freshwater crustaceans include freshwater crabs and crayfish.

In addition to water breathing animals, e.g., fish, most mollusks etc., the term "aquatic animal" can be applied to air-breathing aquatic or sea mammals such as those in the orders Cetacea (whales) and Sirenia (sea cows), which cannot survive on land, as well as the pinnipeds (true seals, eared seals, and the walrus). The term "aquatic mammal" is also applied to four-footed mammals like the river otter (Lontra canadensis) and beavers (family Castoridae), although these are technically amphibious or semiaquatic. There are up to one million types of aquatic animals and aquatic species.

Amphibians, like frogs (the order Anura), while requiring water, are separated into their own environmental classification. The majority of amphibians (class Amphibia) have an aquatic larval stage, like a tadpole, but then live as terrestrial adults, and may return to the water to mate.

Certain fish also evolved to breathe air to survive oxygen-deprived water, such as Arapaima (family Osteoglossidae) and walking catfish.

Most mollusks have gills, while some fresh water ones have a lung instead (e.g. Planorbidae) and some amphibious ones have both (e.g. Ampullariidae). Many species of aquatic animals lack a backbone or are invertebrates.

Aquatic animals play an important role for the environment as well as human's daily usage. The importance of aquatic animals comes from the fact that they are organisms that provide humans with sources such as medicine, food, energy shelter, and raw materials that are used for daily life.

Each aquatic species plays a different role to help us make every day easier, healthier, and also more productive. They also help with the atmospheric pressure and global climate change. What is Aquatic animal?

Self-Assessment Exercises 1

Attempt this exercises to measure what you have learnt so far. This should not take you more than 5 minutes.

1. What kind of condition does freshwater create for aquatic organism?

4.3.1 Clupeidae

Most clupeid species are marine, but some are anadromous (shads) and *Ethmalosa fimbriata* (bonga) are adopted to withstand low salinities particularly in the rainy season.

a. Bonga (*Ethmalosa fimbriata*)

Bonga is the most important clupeid species in the coastal inshore waters of Nigeria. This species rarely goes below 20 m. It is more euryhaline than the flat sardinella and it is found in estuaries, the sea, lagoons and also in places that are liable to have great variations in salinity. It prefers warm and turbid waters. Because of these ecological preferences, it tends to replace the flat sardinella, and even more clearly the round sardinella, in those sectors without upwelling but with strong surface desalination. Its biology and migrations seem small in extent and limited to estuaries and the adjacent coastal areas (Longhurst, 1960).

Ethmalosa is a non-selective filter-feeder subsisting mainly on large diatoms and phytoplankton. The species migrates into and out of the estuaries following seasonal changes in salinity as well as with the abundance of plankton in the estuaries during the dry season. Ethmalosa tends to be more abundant in Nigerian estuaries during the period October-April. Its migration is possibly due to spawning and feeding. Juveniles are definitely more abundant in rivers and in estuaries, while young spawners and adults can be found both in estuaries and at sea. This pelagic fish is a target species for the artisanal gillnet and beach seine fisheries.

Fig 1: *Bonga (Ethmalosa fimbriata*)

b.Shad (*Iisha africana*)

Shad is an anadromous clupeid in habiting inshore waters, sand beaches and estuaries (in almost all fresh waters). *Ilisha africana* has a maximum length (L∞) of about 22 cm and it has a good preference for crustacea and small fishes (juveniles). It may be caught at the surface or near the bottom down to about 25 m. Hence it can be a target species for beach seine, gillnet, purse seine and inshore trawl fisheries.

c. Sardine (*Sardinella* spp)

The flat sardinella is found from Mauritania to Angola. It is coastal fish, more euryhaline, most often found to be abundant near the outlet of water courses. It prefers warmer waters with a temperature above 24°C and seems to avoid waters that are not clear. It is not very abundant in areas without upwelling where the warm and low saline superficial layer is permanently present as in the Baight of Biafra and a large portion of the Nigerian shelf.

In Nigeria Sardinella spp. are caught by canoe fishermen using ringnets, castnets, gillnets, beach seines and also by trawlers. But Sardinella is not a target species of any of the main fisheries. What is another name for Bonga fish?

Self-Assessment Exercises 2

Attempt this exercises to measure what you have learnt so far. This should not take you more than 5 minutes. 1. Write a little ecological notes on Sardine?

4.3.2 Carangidae

The following carangid species are fairly abundant in Nigerian waters: Caranx spp., Chloroscombrus chrysurus, Decapterus rhonchus amd Trachurus spp. There are mostly schooling species distributed on the continental shelf but some occur in brackish waters especially when young.

a. Various jacks (*Caranx spp.)*
Caranx spp. have wide distribution along the West African coast from Senegal to Angola. Some species inhabit inshore waters and estuaries and the others are located in deeper waters (over 100–m depth). Hence, this fish group can be vulnerable to both artisanal and industrial fleets. Caranx spp. feed mainly on fish but also on shrimps, some crabs and invertebrates. This fish species group is caught in pelagic and bottom trawls, seines, set and ring gillnets and sometimes on line gear.

Fig 2: Various jacks (*Caranx* spp.)

b. Atlantic pumber (*Chloroscombrus chrysurus*)
Chloroscombrus chrysurus occurs along the West African coast from Mauritania to Angola. This schooling pelagic species inhabits the Nigerian continental shelf at depths of 10–50 m. It also occurs in estuaries and the mangrove fringed lagoons and brackishwater areas. Its juveniles are sometimes located offshore in association with jellyfish. Atlantic bumper can be a target species of the artisanal fleet using set gillnets and seines as well as for the industrial fleets using trawls and operating in waters of 10– 50 m depth.

c. False scad (*Decapterus rhonchus*)

This is a schooling carangid species inhabiting near bottom waters, mostly between 30 m and 50 m but can be located in waters over 200 m depth. It feeds on small fish and invertebrates. This species is mostly exploited by industrial fleets using trawls, but it can also be fished by artisanal motorized canoes using gillnets.

d. Horse mackerel (*Trachurus spp.)*
Horse mackerel occurs in schools in sandy bottom localities and usually at 100–200 m depth. Since the main fishing grounds are on the continental shelf, the species is not normally caught by artisanal fishermen. It is usually a target species of the offshore trawl and purse seine fisheries and sometimes it can be caught with longlines. It appears that the Nigerian industrial fisheries can exploit *Trachurus capensis* (Cape horse mackerel) and *Trachurus trecae* (Cunene horse mackerel).
What is another name for *Trachurus spp*?

4.3.3 Polynemidae

a. Lesser African threadfin (*Galeoides decadactylus*)
Galeoides decadactylus does not appear to penetrate below the thermolcline. It occurs in inshore waters adjacent to sandy beaches. The species is known to develop female gonads by passage through a nonfunctional hermaphroditic stage arising from a normal male. Understanding its reproductive and recruitment strategy appear to be vital in the managing of this fish species.

Galeoides prefers silty and sand-silty bottoms. It is a semi-diadromous fish with spawning migration into estuaries and lower reaches of rivers. It feeds on benthic organisms such as crustacea and polychaetes. It is a target species for the artisanal fishery using gillnets and beach seines as well as the industrial fleets employing trawls in the inshore areas.

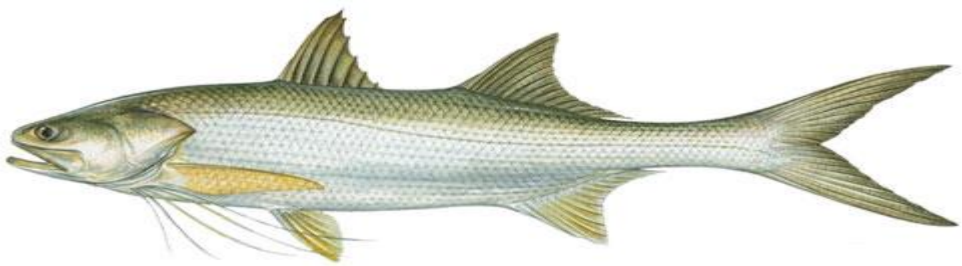

Fig 3: Lesser Africana threadfin (Galeoides decadatylus)

b. Royal threadfin (*Pentanemus quinquarius*)
Pentanemus quinquarius has a normal reproductive cycle. It occurs on sandy bottoms down to a depth of 50 m. It is caught by the artisanal gillnet fishery on nearshore sandy bottoms but the species is also harvested offshore by the industrial fleet using trawls. Additionally Pentanemus can be caught with beach seines.

c. Giant African threadfin (*Polydactylus quadrifilis*)
The giant African threadfin (*Polydactylus quadrifilis*) can grow up to lengths 150–200 cm. The species inhabits inshore and offshore sandy bottoms up to a depth of 50 m. It also occurs in estuaries and lagoons fringed by mangrove. This fish species is jointly

harvested by the artisanal fishermen and industrial fleets. Its attractive size has made it extremely vulnerable to gillnet and beach seine fisheries.

The giant African threadfin (*Polydactylus quadrifilis*) can grow up to what size?

4.3.4 Sciaenidae

The croakers and drums are the important sciaenid species in Nigeria. This fish species group is primarily marine but also occurs seasonally in brackishwater areas. Most of the species inhabit sandy and muddy bottoms in coastal areas with large river flows.

a. Bobo croaker (*Pseudotolithus elongates*)
Pseudotolithus elongatus prefers surroundings that are less saline. In fact, commercial concentrations correspond to the great estuaries in the gulf of guinea where the species can be caught in large quantities in certain seasons.

They inhabit mud bottoms in coastal waters up to 50-m depth but also enter estuaries and coastal lagoons. This species, with maximum length of about 45 cm, moves further offshore to spawn during the rainy season. P. elongatus is jointly harvested by the artisanal and industrial fleets. It can be caught with bottom trawls, setnets, beach seines and longlines.

Fig 4: Bobo croaker (*Pseudotolithus elongatus*)

b. Longneck croaker (*Pseudotolithus typus*)
Pseudotolithus typus grows to a larger size than *P. elongatus*. It attains a maximum length ($L\infty$) of 100 cm and fish of 50-cm length are common in the catch. The main fishing ground for this species is from the Gulf of Guinea to the Congo. It is the most important commercial sciaenid species in Nigeria.
It inhabits mud and sandy bottoms up to a depth of 150 m but it is more abundant in waters of less than 60 m and temperature above 18°C. It also occurs in estuaries. Hence, it is fished by artisanal and industrial fleets using bottom trawls, bottom set nets and longlines.

c. Boe drum (*Pteroscion peli*)

Pteroscion peli occurs along the west coast of Africa, from Senegal to Angola. It inhabits mud and sandy-mud bottoms in coastal waters extending to 200-m depth. But it is most common in waters of less than 50-m depth. This species is more accessible to the industrial fisheries using trawls and hook on line than to the artisanal fisheries using gillnets and beach seines. What is another name for Bobo croaker?

Self-Assessment Exercises 3

Attempt this exercises to measure what you have learnt so far. This should not take you more than 5 minutes. 1. Write a little ecological notes on Longneck croaker?

4.3.5 Sparidae

The seabreams occur in fairly deep waters of the continental shelf and off the slope. The small young individuals do occur in shallow waters but mostly at a depth greater than 15 m, forming aggregations. The adult seabreams are more solitary. The most common species are *Dentex angolensis* and *Pagellus bellottii.*

a. Angola dentex (*Dentex angolensis*)
Dentex angolensis occurs along the West African coast from Morocco 33°N to Angola. It inhabits various bottoms on the continental shelf and the slope from about 15 m to about 300-m depth. It is a protogynic hermaphrodite with most individuals beginning as females and changing to males at a length 18–23 cm.
They are known to occur in Nigerian waters but the species is not an important element of the artisanal fisheries. It is caught by the trawl fishery but separate statistics are not available. Angola dentex is a carnivorous species feeding on crustacea, small fish, molluscs and other invertebrates. It can be caught in bottom trawls, bottom setnets and longlines.

Fig 5: Angola dentex (*Dentex angolensis*)

b. Red pandora (*Pagellus bellottii*)
The geographical distribution of *P. bellottii* extends from the straits of Gibraltar to Angola and also around the Canary Islands. It is a protogynic hermaphrodite (the majority of individual are first females), then become males. Red pandora is

omnivorous with a predominantly carnivorous diet consisting of crustacea, cephalopods, small fish and worms.

This is one of the most abundant sparid species in the CECAF area but it is not a target species of artisanal fisheries in Nigeria. It is possibly caught by the trawl fishery but separate catch data are not reported. What is another name for Angola dentex?

4.3.6 Penaeid shrimps

Three commercially important penaeid shrimps occur in Nigerian waters. *Penaeus notialis* (the pink shrimp) is by far the most dominant species. It occurs in the lagoons, estuaries, creeks and open sea. *Parapenaeopsis atlantica* (Guinea shrimp) is also fairly abundant in the open sea depth 10–16 m. The estuarine white shrimp (*Palaemon hastatus*) occurring in brackish waters and open sea is mainly exploited by artisanal fishermen.

The coastal penaeid shrimps have interesting recruitment features. The first phase in the life of coastal penaeid shrimps takes place at sea between three weeks, and one month and thereafter in the coastal zones, in bays, estuaries, in mangrove swamps which are rich in food, or in submerged vegetation. As their development progresses the shrimps migrate toward greater and greater depths. When the areas of distribution of juveniles and adults are clearly separated geographically, a true migration seaward occurs after which spawning takes place.

Since the types of exploitation (and the operational zones of the various gears) are extremely diversified, there are in fact several successive recruitment phases:
when the shrimps leave the nursery edges and become accessible to artisanal fisheries; when they reach the large bays where they are accessible to small trawlers; during migration, when they are caught by fixed nets; when they reach the sea and are caught by industrial trawlers.

The entry process into the different fisheries is associated with the development stage of the shrimps. If recruitment is defined as the probability of a shrimp of a given size to be found in the fishing area this probability can be expressed for shrimps of each size as the percentage of shrimps at that size, in the total population that is present in that area. If the percentages are plotted against size a recruitment curve will be obtained. What is another name for *Penaeus notialis*?

4.4 Summary

The ecology of animals integrate the organisms (animal) and their environment dependently, animals inhabit community and interact with the biotic and abiotic factors in the environment to survive. Fish species have their favourable environmental condition at their best active. Some of these is discuss in this this unit.

4.5 References/Further Readings/Web Sources

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4.6 Possible Answers to SAEs

Answers to SAEs 1

1. Fresh water creates a hypotonic environment for aquatic organisms. This is problematic for some organisms with pervious skins or with gill membranes, whose cell membranes may burst if excess water is not excreted. Some protists accomplish this using contractile vacuoles, while freshwater fish excrete excess water via the kidney. Although most aquatic organisms have a limited ability to regulate their osmotic balance and therefore can only live within a narrow range of salinity, diadromous fish have the ability to migrate between fresh water and saline water bodies.

Answers to SAEs 2

1. The flat sardinella is found from Mauritania to Angola. It is coastal fish, more euryhaline, most often found to be abundant near the outlet of water courses. It prefers warmer waters with a temperature above 24°C and seems to avoid waters that are not clear. It is not very abundant in areas without upwelling where the warm and low saline superficial layer is permanently present as in the Baight of Biafra and a large portion of the Nigerian shelf.

Answers to SAEs 3

1. Pseudotolithus typus grows and attains a maximum length (L∞) of 100 cm and 50-cm in length. The main fishing ground for this species is from the Gulf of Guinea to the Congo. It is the most important commercial sciaenid species in Nigeria. It inhabits mud and sandy bottoms up to a depth of 150 m but it is more abundant in waters of less than 60 m and temperature above 18°C. It also occurs in estuaries. Hence, it is fished by artisanal and industrial fleets using bottom trawls, bottom set nets and longlines

Unit 5: Ecology of Terrestrial Animals

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5.1 Introduction
5.2 Intended Learning Outcomes (ILOs)
5.3 Ecology and Biology of Terrestrial species
 5.3.1 Terestrial Animals
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 5.3.4 Arboreal Animals
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5.4 Summary
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5.6 Possible Answers to Self-Assessment Exercises

5.1 Introduction

Animal ecology is an important area of study for scientists. It is the study of animals and how they relate to each other as well as how they relate to their environment.

There are various forms of animal ecology. By studying this information, you learn more about what makes these animals prosper or what potentially holds them back. In animal ecology, there are many factors that is currently threatening the existence of these animals which are caused by human activities.

5.2 Intended Learning Outcomes (ILOs)

At the end of this unit, the student should be able to explain the ecology of different terrestrial species

5.3 Ecology and Biology of Terrestrial species

The word "*Terrestrial*," which means earthly, is borrowed from the Latin word 'terra,' meaning earth, land, or ground, with the suffix -al. The terrestrial animals are the animals that live predominantly or entirely on land, and they also grow and reproduce on land. Having successfully adapted to dry environments, animals belonging to this habitat have completely abandoned their need for an aquatic phase in their lifespan.

Sometimes it's hard to differentiate or judge whether an animal is "terrestrial" or "aquatic" since there are no universally accepted criteria to decide. Many animals considered terrestrial have a lifecycle, which is partly dependent on being in the water, just like in the case of penguins, seals, and walruses who sleep on land, but feed on the ocean and are yet considered terrestrial. Even some species of crabs are also considered terrestrial species. What are Terrestrial animal?

5.3.1 Terrestrial Animals

i.) Lions (Panthera leo)

The lion (Panthera leo) is a large cat of the genus Panthera native to Africa and India. Deep-chested build, tiny round ears, a fuller mane, and a heavy furry tuft at the ledge are the main physical characteristics of a lion. The fur of lions varies in color from light buff to silver-gray, yellowish red, and dark brown.

The males have a prominent mane, typically brownish and tinged with yellow, rust, and black hair that grows downward and backward, covering most of the head, neck, shoulders, and muscular chest. The average head to body length of a male lion is about 190-210 cm, whereas the female ones have a length of 160-189 cm.
Lions are deadly predators who have a short and powerful attack, and they catch their prey with a fast rush and final leap. Lions usually hunt zebra, giraffe, African buffalo, and blue wildebeest.

They are mostly active at night, and they prefer habitat consisting of grassland, savanna, dense scrub, open woodland. Lions are found in sub-Saharan Africa, and a small population of Asiatic lions is found in India's Gir forest.

Fig 1: Lions *(Panthera leo)*

The lion (*Panthera leo*) are native to which locality?

ii.) Dogs (Canis sp.)

The dog or domestic dog (*Canis familiaris* or *Canis lupus familiaris*) is a domesticated descendant of the wolf which is characterized by an upturning tail. The dog is derived from an ancient extinct wolf, and the modern wolf is the dog's nearest living relative. These adorable fuzzballs are one of the most ubiquitous domestic animals in the world. The anatomy of dogs differs from breed to breed; they have powerful muscles, a cardiovascular system supporting sprinting and endurance, and teeth to capture, hold and tear.

They regulate their body temperature through panting and sweating via their paws. They have an incredible hearing ability – the frequency range of dog hearing is between 16-40 Hz and up to 45-60 Hz. The amazing part is the number of smell-sensitive receptors is forty times more than humans.

How do dog regulate their body temperature?

iii.) Monkeys

Monkey is a common name that may refer to most mammals of the infraorder Simiiformes, also known as the simians. Monkeys are mammals; some monkeys live on the ground, and some inhabit the trees. Many small monkeys are kept as exotic pets for their adorable look, a common example being pygmy marmosets.

Their bodies are designed to provide them both strength and agility, which makes them flexible and fast. Monkeys are extremely intelligent and social creatures since socialization is important for them to survive in their environment. There are more than 350 species of primates found all over from the habitats in Asia, Africa, and South America. What is the function of their body?

iv.) Giraffes (Giraffa sp.)

Giraffes are regarded as the tallest living terrestrial animals, with long necks, legs, and a unique coat pattern that serves as camouflage.

The interesting feature in their body is the ossicones that are usually mistaken as horns. Their diet consists of leaves, fruits, and flowers of woody plants like acacia. They have a long purple colored Prehensile tongue of about 45cm in length. The average height of a Giraffe is around 5m; they are mostly found in the sub-Saharan region of Africa. What is an interesting feature in body of Giraffes?

v.) Hippopotamus (*Hippopotamus amphibious*)

Deriving their name from the Greek word, translating to 'river horse' hippos are one of the heaviest terrestrial animals on earth. These creatures are the heaviest animals on the land, next to elephants. Although they are also termed as 'semi-aquatic,' they are generally leagued into the terrestrial category.

These mammals are mostly herbivorous with a lifespan of 40-50 years, and although they are exaggeratingly heavy and fleshy, they can run at a speed of 48 km/hour on the land. Seemingly serene and calm, these 8000 pounds creatures shouldn't be messed with because they are just as dangerous as a wild elephant that's gone frenzy What is another common name for Hippos?

vi.) Bears (Ursus sp.)

Bears are the large solitary, stocky mammals equipped with nonretractable claws, shaggy fur and are about 8 feet long and weigh about 60-1600 pounds. They are extensively found in America, Europe, and Asia.

They can hibernate, which is an effective survival solution. Bears are great swimmers, which allows them to survive in near the coldest of oceans. Despite the bulky build that bears possess, they are incredible climbers and adept runners.
Where are bears found?

vii.) Snakes

Snakes are limbless reptiles with long, cylindrical bodies, scaly skin, lidless eyes, and a forked tongue. Most species are not poisonous, some are mildly poisonous, and others produce a deadly poison. The term venom is commonly used to describe the poison produced by a snake. Although controversial, snakes that have adapted to both land and water are majorly considered terrestrial animals. These infamous reptiles known for their toxic venoms or constrictions around their prey's body are found all over the world except for a few parts like New Zealand, Antarctic, and Ireland, etc.

All snakes are carnivores (meat-eaters) and cold blooded, meaning their body temperature is determined by the environment rather than being internally regulated. For this reason, snakes are found mainly in tropical and temperate regions, and are absent in cold climate zones. The 2,700 species of snakes fall into four superfamilies: Boidae (boas, anacondas, and pythons), Elapidae (cobras, coral snakes, mambas, and kraits), Colubridae (king snakes, water snakes, garter snakes, black snakes, and adders, to name only a few) and Viperidae (true vipers and pit vipers).

Snakes have extremely poor sight and hearing. They detect their prey primarily by means of vibrations, heat, and chemical signals they detect with their other senses. For example, a snake's flicking, forked tongue acts as a chemical collector, drawing chemical "smells" into the mouth. Those smells are then analyzed by two chemical sensors known as Jacobson's organs on the roof of its mouth. This mechanism also allows male snakes to detect females in the reproductive state. The legless carnivorous reptiles that come in absolutely mesmerizing patterns and colours from jet black to light green are ectothermic creatures. What is the feeding habits of snake?

Self-Assessment Exercises 1

Attempt this exercises to measure what you have learnt so far. This should not take you more than 5 minutes.

1. List some characteristics features of snake?

5.3.2 Terrestrial Birds

Terrestrial birds are those that forage, roost, and predominantly spend a significant portion of their lives on the ground. When these types of birds are threatened, then they don't fly away; rather, they freeze, walk or run. Some of these birds have a unique cumbersome flight style, which is less suited for long flights, and when flying, they generally stay low above the ground while the others are flightless. Examples of terrestrial birds are; The Barred Buttonquail, Female Black Francolin, The Cheer Pheasant, The Chestnut-bellied Sandgrouse, The Eurasian Thick-knee, The Ferruginous Partridge, The Grey Francolin, The Indian Courser, The Kalij Pheasant, The Masai Ostrich. What are terrestrial birds?

5.3.3 Aerial Animals

Animals that thrive when airborne, accomplishing other activities like feeding, drinking, and bathing, spending much of their life in flight are called Aerial Animals. There are several adaptations that were adapted by these animals to fly swiftly in the air.

These adaptations include their lightweight skeletons and slender, streamlined bodies, which increase the flight efficiency and make lengthy flights easier for them, the long and pointed wings serve to aid their flight agility, and their long tail helps them to steer while flying in the air easily.

Since these animals have an amazing flight style, aeronautics and mechanical engineers are studying their flying patterns and developing myriad flying vehicles and machines from commercial aircraft to remote-controlled drones. Examples are; Albatross, Vultures, Butterflies, Moth, Sugar Gliders, Hummingbird, Geese, Bats, Gliding lizard, Eagles. What are Aerial birds?

5.3.4 Arboreal Animals

The arboreal animals are the tree-living animals who spend most part of their life cycle on trees and branches, mainly in the rainforest. These animals have amazing adaptations that not only help them to live and move about in trees but also help them to survive and hide in the environment.

To deal with the mechanical challenges of moving through their habitats, the arboreal animals have elongated limbs, which help them to cross gaps, testing the firmness of support ahead, and to reach food and other resources.

They use their prehensile tails to grasp the branches of trees. Animals like spider monkeys and crested geckos have an adhesive pad at the tip of the tail to provide increased friction.

Their small body size provides them with advantages like increased stability, lower mass, controlled gliding, and gives them the ability to move through more cluttered habitat amidst branches, stems, leaves, etc. the following are example; Sloths, Koalas, Beckos, Tree Snakes, Possums, Orangutans, Parrots, Woodpeckers, Chameleons, Red Pandas. What are Arboreal Animals?

Self-Assessment Exercises 2

Attempt this exercises to measure what you have learnt so far. This should not take you more than 5 minutes.

1. Give examples of arboreal animals.

5.3.5 Amphibious Animals

To live a double life – that succinctly describes Amphibians, in a nutshell. The amphibious animals are cold-blooded vertebrate animals who are born in water and breathe through gills in their larva stage, and as they grow adult, their lungs develop the ability to breathe air, allowing them to live on both land and water.

They have skin glands that help to transport water, oxygen, and carbon dioxide into or out of them, producing useful proteins. They are also frequently used as a defense to fight against bacteria or fungal infections.

The toxic amphibians are mostly bright coloured to warn the potential predators from coming in close vicinity. Their skin needs special environmental conditions in order to allow them to survive, and too much exposure to the sun can damage their skin cells.

Wind can also dry their skin and dehydrate them, which is why most amphibians are nocturnal, surfacing, and preying only in the dark. The amphibians inhabit a variety of habitats, including terrestrial, fossorial, freshwater ecosystems. Examples are; American Bullfrogs, Geckos, Salamanders, Toads, Newts, Tortoise, Alligator Newts, Worms, Axolotls, Green Tea Frogs. What are amphibious animals?

Self-Assessment Exercises 3

Attempt this exercises to measure what you have learnt so far. This should not take you more than 5 minutes.

1. Where are amphibious animals found and list examples

5.4 Summary

The ecology of animals integrate the organisms (animal) and their environment dependently, animals inhabit community and interact with the biotic and abiotic factors in the environment to survive. Terrestrial species have their favourable environmental condition at their best active. Some of these is discuss in this this unit.

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5.6 Possible Answers to SAEs

Answer to SAEs 1

1. Snakes are limbless reptiles with long, cylindrical bodies, scaly skin, lidless eyes, and a forked tongue. Most species are not poisonous, some are mildly poisonous, and others produce a deadly poison. The term venom is commonly used to describe the poison produced by a snake.

Answer to SAEs 2

2. Sloths, Koalas, Beckos, Tree Snakes, Possums, Orangutans, Parrots, Woodpeckers, Chameleons, Red Pandas.

Answer to SAEs 3

3. The amphibians inhabit a variety of habitats, including terrestrial, fossorial, freshwater ecosystems. Examples are; American Bullfrogs, Geckos, Salamanders, Toads, Newts, Tortoise, Alligator Newts, Worms, Axolotls, Green Tea Frogs.

Glossary

°C= degrees Celsius
cm = centimeters
CO_2 = Carbondioxide
CECAF= Fishery Committee for the Eastern Central Atlantic
CH_4 = methane (CH_4)
ft = feets
°F = degree Fahrenheit
Hz = Hertz
in = inches
Ib = pounds
Kgs = kilograms.
km = kilometers
m = meters
mm = millimeters
NaCl= Sodium Chloride
O_2 = Oxygen
oz = ounce
pH = Hydrogen ion concentration
TEDs = turtle exclusion devices
L = length
HIV = Human immunodeficiency virus
% = percentage
g = grams
spp = species

End of the Module Questions

1. Who is Charles Elton?
2. Diferentiate between Habitat and Niche
3. What is Mutualism?
4. What is Aquatic animal?
5. What is Terrestrial animal?

Module 2: Ecology in Animal Population

Module Introduction

Module Two is concerned with the growth and regulation of population size, as well as the factors influencing them. Populations are not stable and always exhibit up and down variations in response to changes in environmental or intrinsic factors. The measurement of population dynamics is very important in ecological study of animals. Life table and K- factor analysis has been applied to a variety of animal species.

Unit 1: Growth rate and Age structure of animal population
Unit 2: Factors affecting Animal Population
Unit 3: Measurement of Population dynamics
Unit 4: Life tables and K-values
Unit 5: Key-Factor Analysis
Glossary

Unit 1: Example 1

Contents
1.1 Introduction
1.2 Intended Learning Outcomes (ILOs)
1.3 Animal Population
  1.3.1 Growth Patterns
  1.3.2 Age Structure of Animals
  1.3.3 Population Growth Curve
1.4 Summary
1.5 References/Further Readings/ Web Sources
1.6 Possible Answers to Self-Assessment Exercises

1.1 Introduction

A population is a collection of individuals of the same species that live together in a region. *Population ecology* is the study of populations (especially population abundance) and how they change over time. Crucial to this study are the various interactions between a population and its resources. A population can decline because it lacks resources or it can decline because it is prey to another species that is increasing in numbers. Populations are limited by their resources in their capacity to grow; the maximum population abundance (for a given species) an environment can sustain is called the *carrying capacity*. As a population approaches its carrying capacity, this has led to overcrowding which means that there are fewer resources for the individuals in the population and leading to reduction in the birth rate. A population with these features is said to be *density dependent*. Of course most populations are density dependent to some extent, but some grow (almost) exponentially and these are, in effect, density independent.

1.2 Intended Learning Outcomes (ILOs)

At the end of this unit, a student should be able to:

Explain the term population growth, age distribution and population size
Describe the growth pattern in animal population
Estimate the size of a population using two different techniques.

1.3 Animal Population

Population density is *the number of individuals of a certain species per unit area or volume*, and *population distribution* is *the pattern of dispersal of individuals within that area*. They are indispensable variables for ecologists to analyse and discover the spreading pattern of a certain species within a certain area and time. Consider calculating the average density of people in Nigeria, but we know very well that most people live in cities where the number of people per unit area is dramatically higher than that in the country. Therefore, basing ecological population models solely on density can be misleading.

The density and distribution of a population changes with time, due to abiotic factors (inorganic factors) as well as biotic factors (organic factors). Abiotic factors that could have an influence on a population include temperature, rainfall, type of soil and so forth, while biotic factors are those that are related to other living things. For example, a particular kind of plant pervading only in a particular area is very likely to affect the density and distribution of a population of an animal that feeds only on it. In these situations, *limiting factors* are those that *particularly determine whether an organism lives in an area*.

An example of a limiting factor is found in mountainous regions and high latitudes where timberline is the limit of tree growth. Trees cannot grow above the high timberline because water remains frozen at the low temperature for most of the year. In this case, timberline, or more specifically, temperature is the limiting factor for tree density and distribution.

Population size is *the number of individuals in a population*. Technically, genetic relationship is used to distinguish whether an individual belongs to a population or not. Instead of simply counting, it is necessary to estimate the present population size, using methods which vary with the kind of species in question.
Just as density and distribution, population size fluctuates with time. There are generally four sources of contribution to the fluctuation of a population size, natality (rate of birth), mortality (rate of death), immigration and emigration. How they each changes the population size is indicated below.

Immigration

$\downarrow +$

Natality $\xrightarrow{+}$ **Population Size** $\xrightarrow{-}$ **Mortality**

$\downarrow -$

Emigration

Fig 1: Factors that Affect Population Size

Usually it is acceptable to assume that immigration and emigration are about equal and therefore only necessary to consider natality and mortality. What population density? What is Population size?

Self-Assessment Exercises 1

Attempt this exercises to measure what you have learnt so far. This should not take you more than 5 minutes. 1. What are limiting factors?

1.3.1 Growth Patterns

Theoretically, there exist two distinct and simple growth patterns, or mathematical models for population growth. In the first one, *only one* reproductive chance is given to members of the population during their entire lifespan. Once mission accomplishes, they die. Many insects and annual plants reproduce in this manner. In the other model, members experience *many* reproductive events throughout their lifetime. Most vertebrates and trees have this pattern of reproduction.

Expressed in mathematical equations and graphs, the two growth patterns can be referred to as the *exponential growth pattern* and the *logistic growth pattern* respectively. We are not going to resort to number and equation here, but a glance at the graphs below will be enough for this introductory course.

Fig 2: Population Exponential Growth (Source: www.econguru.com)

Two major features of the curve are:

Lag phase: in which growth is slow because population base is small and Exponential growth phase: in which growth is accelerating, that is, the rate of growth itself grows.

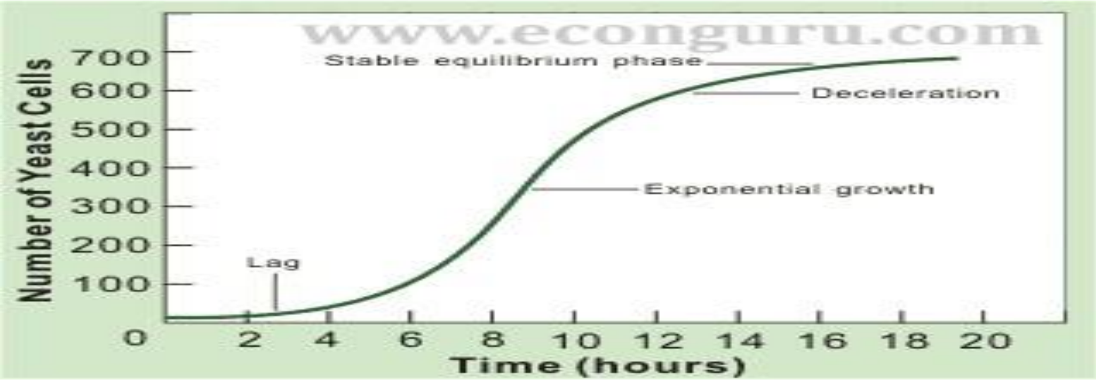

Fig 3: Population Logistic Growth (Source: www.econguru.com)

Four major features of the curve are:

A. Lag phase: *in which Growth is slow because the population base is small*
B. Exponential growth phase: *in which Growth is accelerating, that is, the rate of growth itself* grows.
C. Deceleration phase: in which the rate of population growth slows down.
D. *Stable equilibrium phase:* in which little growth because births and death are about equal.

Population growth patterns require an assumption that members of a population are all identical individuals. However, individuals are in their different stages of lifespan. In a given period of time, some are born and some die. See if you can figure out the data in this table:

Table 1: Showing A Life table for a *Poa annua* (a grass) Cohort

Age (Month)	Number Observed Alive	Proportion Surviving	Number Dying	Mortality Rate Per Capita	Avg. Number of seeds/individual
0-3	843	1,000	121	0.143	0
3-6	722	857	195	0.271	300
6-9	527	625	211	0.400	620
9-12	316	375	172	0.544	430
12-15	144	171	95	0.626	210

15-18	54	64	39	0.722	60
18-21	15	17.8	12	0.800	30
21-24	3	3.6	3	1.000	10
24	0	-	-	-	-

(Source: www.econguru.com)

A *cohort* of a population, is the total number of new births of it at the same time. As you can see in table 1, the number of grass observed alive at the beginning is 843, and data are noted down every 3 months. The grass are gradually dying out, and the life stages at which they perish vary. From another perspective, let's look at the number that survives instead of focusing on the number dying in each period. After the first observational period, 722 survive the first 3 months. *Survivorship* is *the probability of new born individuals of a cohort surviving to particular ages*. Plotting the number surviving against percent of life span, we get survivorship curves that show the number of individuals of a cohort still living over time.

For the sake of discussion, we will establish three types of representative survivorship curves hypothetically, displayed in the graph of the following image. Curve I is characteristic of a population in which most individuals survive will pass the midpoint. On the contrary, Curve III typifies populations wherein most individuals die young. In the type II curve, survivorship decreases at a constant rate throughout the lifespan.

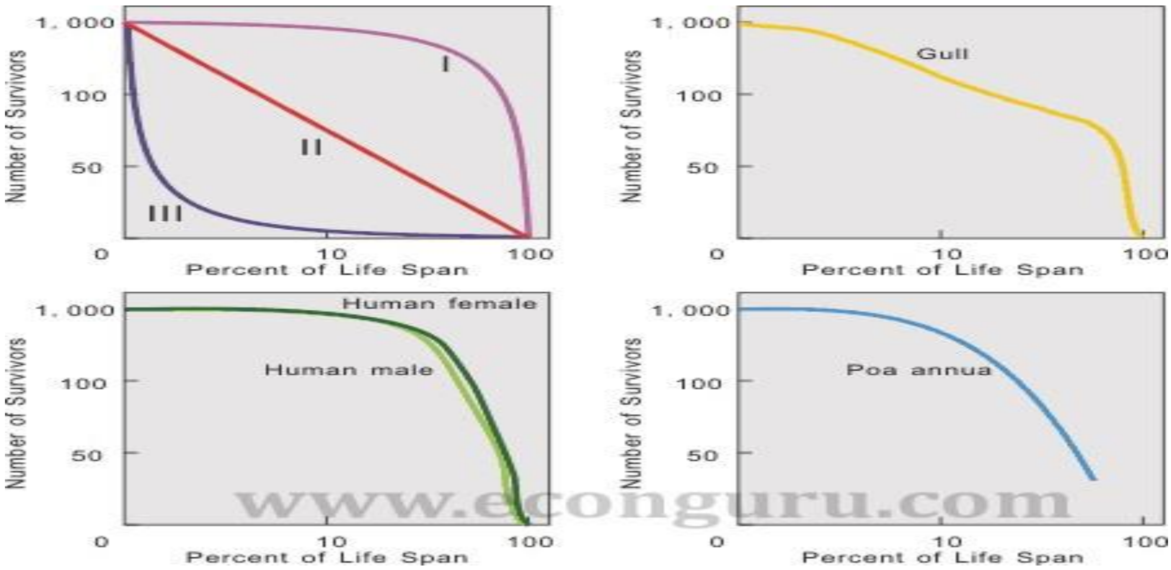

Fig 4: The different types of **Survivorship curve (Source: www.econguru.com)**

As shown by the other three graphs, the survivorship curves of natural populations do not fit these three idealized curves congruously. However, similarities exist to help understanding. Survivorship curve for *gulls* fits the type II curve somewhat. The survivorship curves of *human males and females* differ slightly but both resemble the type I curve fairly well. The survivorship curve for *Poa annua* seems to be a combination of the type I and type II curves.

Survivorship curves denote mortality patterns of a certain population over a certain period of time. It may vary in abnormal conditions, but in most cases the pattern stay predictable. Mention the two growth patterns? What is Survivorship?
Self-Assessment Exercises 2

Attempt this exercises to measure what you have learnt so far. This should not take you more than 5 minutes. 1. What are the major features of the logistic growth curve?

This is the number of individuals in different age classes; pre-reproductive, reproductive, and post-reproductive. Short-lived organisms increase rapidly, with short span between generations long-lived organisms, increase slowly, and have long span between generations.

Determining individual ages of animals with the following;

A. Marking of young individuals through time
B. Examining a representative sample of carcasses of individuals wear
C. Replacement of teeth in deer and other ungulates.
D. Annual growth rings in the horns of sheep
E. Plumage changes and wear in birds and
F. Growth rings in scales of fishes

Age Pyramids is comparing of the percentages population in different age groups. The pyramids with a broad base of young suggest growing populations. Pyramids with a narrow base of young and even ratios, suggest a declining or aging population and depict changing dynamics of a population.

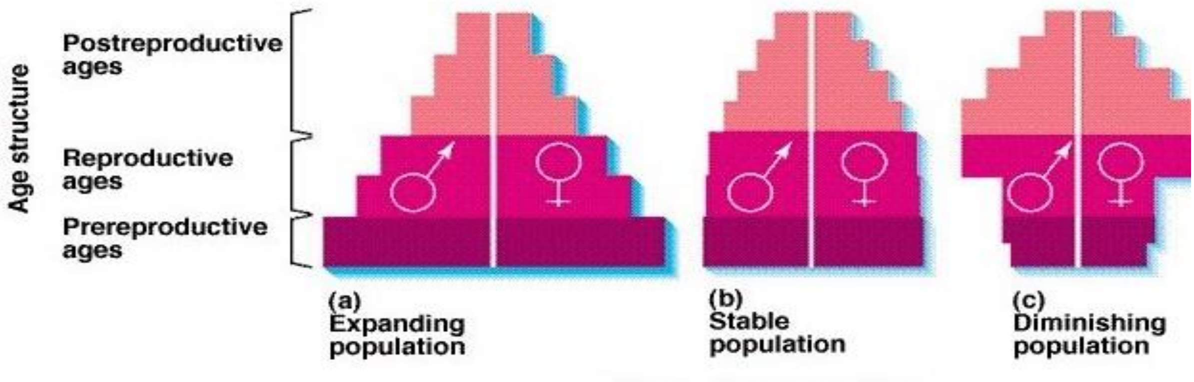

Fig 5: Showing the different age structure (Source: www.econguru.com)

In-Text Question(s)

The age structure of animals is divided into how many parts or groups?
Answer: The age structure of animals is divided into three groups, pre-reproductive, reproductive, and post-reproductive

1.3.3 Population Growth Curve

This shows the net result of births, deaths, and dispersion. It usually shows three to five phases. Most organisms show 3 phases: lag phase, exponential growth phase, and equilibrium phase

i) Lag phase - slow growth because the process of growth and reproduction of offspring takes time
ii) Exponential growth phase - characterized by more organisms undergoing reproduction, so that the population begins to increase at very fast rate; birth rate exceeds the death rate
iii) Equilibrium phase - characterized by the birth rate and death rate that are equal to one another; population will stop growing and reach a relatively stable population.

The net result of births, deaths, and dispersion can take a number of forms:

i) J-shaped or exponential growth form – density occurs when there is Increases in a geometric fashion until the population runs out of some resource or encounters some other limitation (Fig 5).

ii) S-shaped or Sigmoid growth - limiting factors resulting from crowding provide negative feedback that reduces the rate of growth more and more as density increases. If the limitation is linearly proportional to density, the growth form will be a symmetrical sigmoid curve with density levelling off as to reach the carrying capacity; the carrying capacity represents the maximum sustainable density (Fig 6).

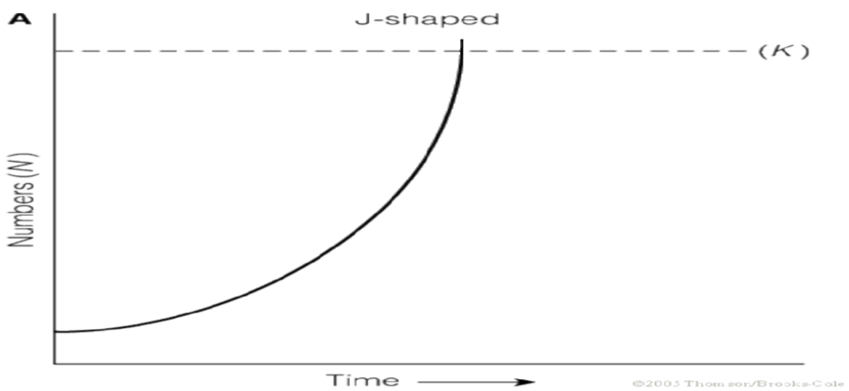

Fig 5: Showing the J-shaped growth form (Source: www.econguru.com)

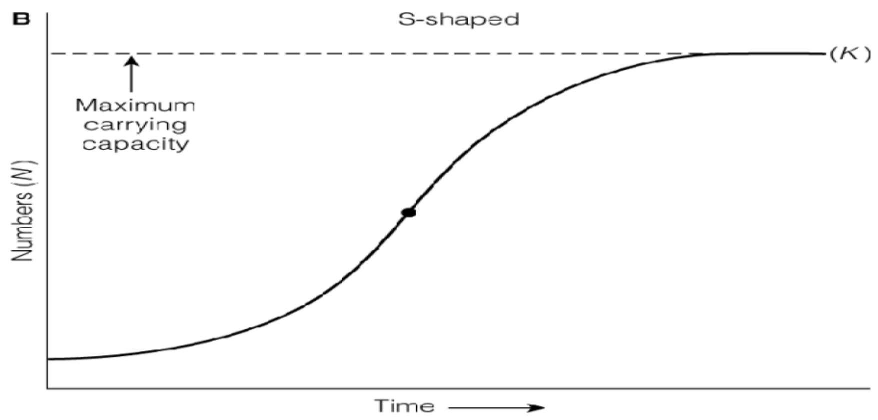

Fig 6: Showing the S-shaped or Sigmoid growth (Source: www.econguru.com)

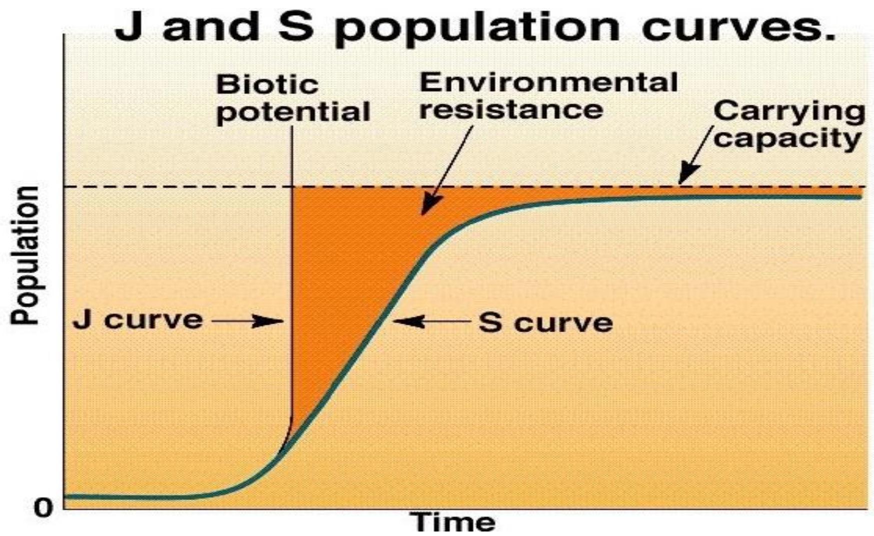

Fig 7: showing the J and S population curve (Source: www.econguru.com)

The Basic Concepts of Rate are shown below:

i) Population dynamics - the study of changes in the relative number of organisms in populations and the factor explaining these changes.

ii) Rate – obtained by dividing the change in some quantity by the period of time elapsed during the change

iii) Equation $\Delta N/\Delta t$ = average rate of change in the number of organisms per time.

iv) Instantaneous rate: rate at a particular time (rate of change when Δ t approaches 0,

v) d= derivative dN/dt = i.e rate of change in the number of organisms per time at a particular instant).

vi) Point of inflection – point where growth rate is maximum

What is Exponential growth phase?

1.4 Summary

A population *is defined as* the organism belonging to the same species located in the same place at the same time and ecology is the study of those organisms in relation to their environments*. At this* ecological level, the interest is in the growth and regulation of population size, as well as the factors behind them.

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1.6 Possible Answers to SAEs

Answers to SAEs 1

1. Limiting factors are those that particularly determine whether an organism lives in an area. An example of a limiting factor is found in mountainous regions and high latitudes where timberline is the limit of tree growth. Trees cannot grow above the high timberline because water remains frozen at the low temperature for most of the year. In this case, timberline, or more specifically, temperature is the limiting factor for tree density and distribution.

2. The Four major features of the curve are:
    A. Lag phase: *in which Growth is slow because the population base is small*
    B. Exponential growth phase: *in which Growth is accelerating, that is, the rate of growth itself* grows.
    C. Deceleration phase: in which the rate of population growth slows down.
    D. *Stable equilibrium phase:* in which little growth because births and deaths are about equal.

Unit 2: Factors Affecting Animal Population

Contents

2.1 Introduction
2.2 Intended Learning Outcomes (ILOs)
2.3 Factors affecting animal population
  2.3.1 Birth rate or Natality rate
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  2.3.3 Migration
  2.3.4 Age distribution (Age composition)
  2.3.5 Abiotic and Biotic Factors
2.4 Summary
2.5 References/Further Readings/Web Sources
2.6 Possible Answers to Self-Assessment Exercises

2.1 Introduction

There are various factors affecting population size: natality, mortality, immigration, and emigration etc. Natality refers to the birth rate. Mortality refers to the death rate. Immigration occurs when individuals from one population of a species join another population of the same species. Emigration occurs when individuals leave a population. The intrinsic population growth rate (r) = (births + immigration) – (deaths + emigration). Zero population growth occurs when the birth rate and immigration are balanced over the long term by the death rate and emigration.

2.2 Intended Learning Outcomes (ILOs)

At the end of this unit, the student should be able to state and explain the different factors affecting animal population

2.3 Factors Affecting Animal Population

All species of organisms have a great capacity to reproduce. A theoretical growth curve reflects population growth at its maximum rate of increase, per individual, under ideal conditions. Without restraints, the size of any population would increase at an exponential rate. The result is a J-shaped curve. As long as birth rates remain even slightly higher than death rates, a population will grow exponentially. The size and density of a population are affected by various factors. Some of the important ones are discuss below.

2.3.1 **Birth rate or Natality rate**

Natality rate is the rate at which new individuals are added to a particular population by reproduction (birth of young ones or hatching of eggs or germination of seeds/spores).
It is generally expressed as number of births per 1,000 individuals of a population per year.

'Absolute', 'physiological or maximum natality', refers to the theoretical maximum production of new individuals under ideal conditions. But it is never realised because of environmental resistance (factors like inter and intra specific competitions, availability of food, space etc.)

'Actual birth rate' being achieved under existing conditions, which is much lesser than 'absolute natality is called realized natality. Higher realized natality rate increases the population size and population density. What is Birth rate?
Natality rate is the rate at which new individuals are added to a particular population by reproduction (birth of young ones or hatching of eggs or germination of seeds/spores)

2.3.2 **Death or Mortality rate**

Mortality rate is the rate at which the individuals die or get killed. It is the opposite of natality rate.

Mortality rate is generally expressed as number of deaths per 1,000 individuals of a population per year.

Lowest death rate for a given species in most favourable conditions is called potential mortality while the actual death rate being observed in existing conditions is called realized mortality.
Realized mortality decreases the population size and population density.

The percentage ratio of natality over mortality expressed in percentage is called Vital index.

$$\text{Vital Index} = \frac{\text{Natality rate}}{\text{Mortality rate}} \times 100$$

Vital index determines the normal rate of growth of a population.

Table 1: Showing the Differences between Natality rate and Mortality rate

Character	Natality rate	Mortality rate
1. Definition	Number of births per 1,000 individuals of a population per year	Number of deaths per 1,000 individuals of a population per year
2.Poulation density	Increases population size and population density	Decreases population size and population density

What is death rate?

2.3.3 Migration

The movement of organisms in large numbers from one place to another place is termed as migration. There are many reasons for migration. The term migration is mainly used to define regular and periodic movements of the population away from or back to their place of origin. These migrations are of various types. Some may span for an entire lifetime and it happens to be a single migration of an individual. This is in the case for the Pacific salmon. On another hand, an individual may migrate frequently, like many of the migratory birds and other mammals. Animals usually travel in groups along well-known routes or may travel in separate gathering for breeding.

Immigration is the permanent entry of new individuals of same species into a population from outside. It increases the size of local population.

Emmigration is the permanent movement/departure of individuals of same species out of the local population due to several reasons such as lack of food, scarcity of space (overcrowding), etc. Emmigration decreases the size of local population, but the species spread to new areas.

If more individuals are added than lost, then the population will show positive growth. If more individuals are lost than added, then the population will show negative growth. But if the two rates are equal, then the population will become stationary and is called zero growth.

Population growth = (Birth + Immigration) - (Death + Emmigration)

Many factors play their role in the initiation of migration. External factors like climate, natural disasters, drought, shelter, food shortage, etc may cause animals to migrate to seek better conditions.

Seasonally, the timing of migration is influenced by internal “clocks” that are influenced by day length and perhaps also weather. For example – Consider a species of the deer that live in a certain park. They would migrate to warmer places during winter if the park they reside is harsh for them to survive. But, if they are living near a place, where they can graze throughout the year, then there is no need for their migration.

Over shorter time scales, the exact timing of migratory movements is greatly influenced by the weather. Birds tend to move when conditions favour flying in the direction they need to go (e.g., when they have a tailwind, when air turbulence is low, when it is not raining).

It is noted that many birds migrate at night and there are possible reasons for this action.

1. The atmosphere is more stable at night than during the day because there are fewer thermals (“updrafts” caused by warming of the Earth’s surface).
2. The air temperature is lower, which may make thermoregulation easier; remember that flight generates a lot of heat that birds need to offload.
3. Predation risk may be lower than during the day.

But some species do migrate by day. In particular, large soaring birds such as hawks, storks and pelicans move during the daytime. These birds use thermals to help them travel.

In birds, the migratory instinct is closely linked to the cycle of enlargement of the reproductive system in spring. There are several species of birds that migrate to long ranges, flying to the north in the springtime to breed in the warm conditions and migrate back to their origin.

Bird migration is the natural seasonal movement, often south and north along a flyway, in between the breeding grounds and wintering grounds. Migratory birds fly several kilometres in search of the best environmental specifications and habitats for food, breeding and raising their young ones. Migration is motivated primarily by the unavailability of food and nesting locations. It occurs mainly in the northern hemisphere, where birds travel in search of warmer places such as the Caribbean Sea or the Mediterranean Sea. What is Migration? What do you understand as positive growth?

Self-Assessment Exercises 1

Attempt this exercises to measure what you have learnt so far. This should not take you more than 5 minutes.

1. Write on the timing of migration influenced by internal clocks.

2.3.4 Age distribution (Age composition)

The relative abundance of the organisms of various age groups in the population is called age distribution of population.

With regard to age distribution, there are three kinds of populations.

1. Rapidly growing population is a population, which has high birth rate and low death rate, so there are more number of young individuals in the population.
2. Stationary population is a population, which has equal birth and death rates, so population shows zero population growth.
3. Declining population is a population, which has higher death rate than birth rate, so the population has more numbers of older individuals.

What is stationary population?

2.3.5 Biotic and Abiotic factors

Biotic and abiotic are the two essential factors responsible for shaping the ecosystem. The biotic factors refer to all the living organisms present in an ecosystem from animals and humans, to plants, fungi, and bacteria, and the abiotic factors refer to all the non-living components like physical conditions (temperature, pH, wind, humidity, salinity, sunlight, etc.) and chemical agents (different gases and mineral nutrients present in the air, water, soil, etc.) in an ecosystem. Therefore, both the abiotic and biotic resources affect survival and reproduction process.

Biotic factors like organisms of other species living in the same area affect the population, as they involve in different types of food relationships. For e.g., if the population happens to increase in size, it is brought down by an increase in its predators number or decrease in the amount of available food. Different populations have different ability to tolerate changes in weather, physico-chemical and biotic factors. This is called resilience. In nature, factors like predators, diseases, food scarcity etc. prevent a population to sour towards infinity. The sum of all these factors, which prevent a population from growing at its maximum rate, is called environmental resistance or population regulation.

The following are examples of Abiotic factors that affect population.

1. **Water**

Wetland conditions such as shallow water, high plant productivity, and anaerobic substrates provide a suitable environment for important physical, biological, and chemical processes. Because of these processes, wetlands play a vital role in global nutrient and element cycles.

The rate of diffusion of carbon dioxide and oxygen is approximately 10,000 times slower in water than it is in air. When soils become flooded, they quickly lose oxygen and transform into a low-concentration (hypoxic -with less than 2 mg O_2l^{-1}) environment and eventually become completely (anoxic) environment where anaerobic bacteria thrive among the roots. Water also influences the spectral composition and amount of light as it reflects off the water surface and submerged particles.

Aquatic plants exhibit a wide variety of morphological and physiological adaptations that allow them to survive, compete and diversify these environments. For example, the roots and stems develop large air spaces (Aerenchyma) that regulate the efficient transportation gases (for example, CO_2 and O_2) used in respiration and photosynthesis. In drained soil, microorganisms use oxygen during respiration. In aquatic environments, anaerobic soil microorganisms use nitrate, manganese ions, ferric ions, sulfate, carbon dioxide and some organic compounds. The activity of soil microorganisms and the chemistry of the water reduces the oxidation-reduction potentials of the water. Carbon dioxide, for example, is reduced to methane (CH_4) by methanogenic bacteria.

Salt water plants (or halophytes) have specialized physiological adaptations, such as the development of special organs for shedding salt and osmoregulate their internal salt (NaCl) concentrations, to live in estuarine, brackish, or oceanic environments. The physiology of fish is also specially adapted to deal with high levels of salt through osmoregulation. Their gills form electrochemical gradients that mediate salt excresion in saline environments and uptake in fresh water.

2. Gravity

The shape and energy of the land is affected to a large degree by gravitational forces. On a larger scale, the distribution of gravitational forces on the earth are uneven and influence the shape and movement of tectonic plates as well as having an influence on geomorphic processes such as orogeny and erosion. These forces govern many of the geophysical properties and distributions of ecological biomes across the Earth. On an organism scale, gravitational forces provide directional cues for plant and fungal growth (gravitropism), orientation cues for animal migrations, and influence the biomechanics and size of animals. Ecological traits, such as allocation of biomass in trees during growth are subject to mechanical failure as gravitational forces influence the position and structure of branches and leaves. The cardiovascular systems of all animals are functionally adapted to overcome pressure and gravitational forces that change according to the features of organisms (e.g., height, size, shape), their behaviour (e.g., diving, running, flying), and the habitat occupied (e.g., water, hot deserts, cold tundra).

3. Pressure

Climatic and osmotic pressure places physiological constraints on organisms, such as flight and respiration at high altitudes, or diving to deep ocean depths. These constraints influence vertical limits of ecosystems in the biosphere as organisms are physiologically sensitive and adapted to atmospheric and osmotic water pressure differences.

Oxygen levels, for example, decrease with increasing pressure and are a limiting factor for life at higher altitudes. Water transportation through trees is another important ecophysiological parameter where osmotic pressure gradients factor in. Water pressure in the depths of oceans requires that organisms adapt to these conditions. For example, mammals, such as whales, dolphins and seals are specially adapted to deal with changes in sound due to water pressure differences. Different species of hagfish provide another example of adaptation to deep-sea pressure through specialized protein adaptations.

4. Light intensity

It may be interesting to note that even something as simple as the level of light present in an environment or ecosystem can greatly affect the organisms in that ecosystem. As you know, photosynthesis is the main form of energy consumption for plants, which means that all plants need a certain level of light to create their own food. Some plants in dark ecosystems have evolved to a point where they make do with minimal amounts of light, such as the plants found deep in the oceans where light doesn't reach.

Some plants have evolved for optimum growth in bright sunlight. An example of this is a cactus houseplant. Cacti originally come from deserts where they grow in bright sunlight. Other plants have evolved to grow in shade.

Many orchids, which are also kept as houseplants, grow on trees in the rainforest and have evolved for optimum growth in darker conditions. If you were to put an orchid on a bright windowsill and a cactus in a dark corner of your room neither plant would grow well.

5. Temperature

Temperature is a limiting factor for photosynthesis - and low temperature therefore limits growth of plants. In cold climates, the number of plants is usually low - which limits the number of herbivores that can live there. Both animals and plants have evolved to grow healthily at their optimum temperatures. If you planted either your cactus or orchid houseplants outside in cold temperatures, they would die. Similarly, animals that have evolved to live at the North Pole, such as the polar bear, could not survive in warmer conditions.

6. Moisture levels

More people kill houseplants by overwatering than by under-watering them. Many plants cannot survive in waterlogged soils. Their roots are unable to respire, they rot and the plant dies. Other plants, such as pitcher plants, grow best in bogs where the moisture levels are high. Soil moisture meters can accurately determine how wet an area is.

7. Soil pH content

The pH balance of an ecosystem refers to the general level of acidity or alkalinity present in the environment. Pure water has a pH of 7, meaning it is neutral. Acidic mixtures have a pH balance of less than 7 while alkaline mixtures have a pH balance of more than 7. This also affects the organisms in an environment, because many creatures or plants, or microorganisms cannot survive in certain pH ranges.

The pH of soils can have a huge effect on the plants that are able to grow in them. Some plants, like azaleas, grow best in acidic soils and will quickly die if planted in alkaline soils. Others, like clematis, prefer alkaline soils. Some, like the hydrangea, can grow in both. These plants are unusual in that their flower colour changes in different soils. Just like universal indicator paper, hydrangea flowers are pink in acidic soils and blue in alkaline soils.

The pH of water can also affect the aquatic organisms that are found there. Different species have evolved to survive at different pH levels found within water.

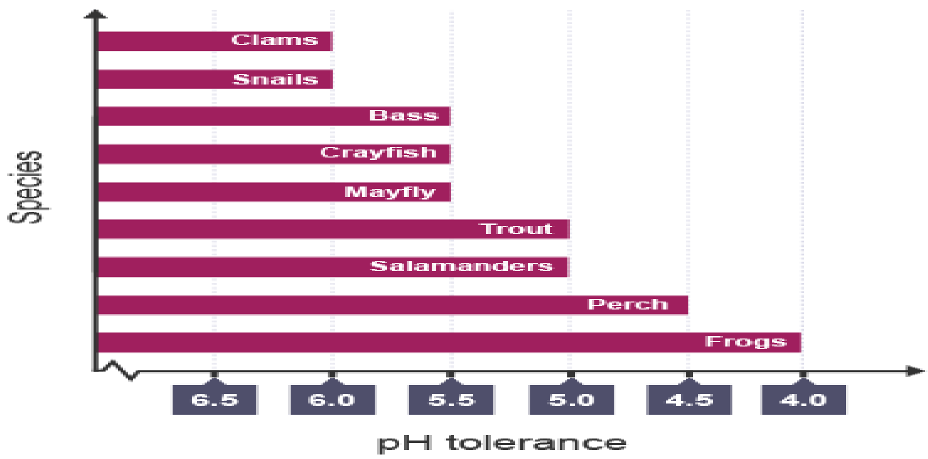

Fig 1: The graph highlights the various pH tolerance of different species found in water

8. Wind and turbulence

The architecture of inflorescence in grasses is subject to the physical pressures of wind and shaped by the forces of natural selection facilitating wind-pollination (or anemophily).

Turbulent forces in air and water have significant effects on the environment and ecosystem distribution, form and dynamics. On a planetary scale, ecosystems are affected by circulation patterns in the global trade winds. Wind power and the turbulent forces it creates can influence heat, nutrient, and biochemical profiles of ecosystems. For example, wind running over the surface of a lake creates turbulence, mixing the water column and influencing the environmental profile to create thermally layered zones, partially governing how fish, algae, and other parts of the aquatic ecology are structured. Wind speed and turbulence also exert influence on rates of evapotranspiration rates and energy budgets in plants and animals. Wind speed, temperature and moisture content can vary as winds travel across different land features and elevations.

9. Soil mineral content

Many plants require high levels of soil minerals to grow well. An example of this is magnesium, which is required to produce chlorophyll. Plants with unnaturally yellow leaves may have a magnesium deficiency. Carnivorous plants, such as pitcher plants, have evolved to catch insects to supplement the low levels of minerals found in the soils in which they grow.

10. Carbon dioxide levels for plants

Carbon dioxide is a reactant in photosynthesis which means plants need it to survive. Areas with higher levels of carbon dioxide are more likely to have healthy plants growing. Farmers often release carbon dioxide within their greenhouses to maximise their crop yield. Woodlands often have higher carbon dioxide levels than open grassland, so many plants living in open areas have evolved mechanisms to overcome a shortage of carbon dioxide.

11. Oxygen levels for aquatic animals

Oxygen from the air and oxygen produced by aquatic plants dissolves in water. Without this, aquatic animals would suffocate and die. Healthy lakes and rivers have high levels of oxygen, and polluted waters often have low levels of oxygen. This pollution means that only certain species can survive there such as sludge worms. These are bio-indicator species because their presence or absence informs us about the condition of the habitat.

12. Fire

Forest fires modify the land by leaving behind an environmental mosaic that diversifies the landscape into different seral stages and habitats of varied quality. Some species are adapted to forest fires, such as pine trees that open their cones only after fire exposure.

Approximately 350 million years ago (near the Devonian period) the photosynthetic process brought the concentration of atmospheric oxygen above 17%, which allowed combustion to occur. Fire releases CO_2 and converts fuel into ash and tar. Fire is a significant ecological parameter that raises many issues pertaining to its control and suppression in management.

Fire creates environmental mosaics and a patchiness to ecosystem age and canopy structure. Native North Americans were among the first to influence fire regimes by controlling their spread near their homes or by lighting fires to stimulate the production of herbaceous foods and basketry materials. The altered state of soil nutrient supply and cleared canopy structure also opens new ecological niches for seedling establishment. Most ecosystem are adapted to natural fire cycles. Plants, for example, are equipped with a variety of adaptations to deal with forest fires. Some species (e.g., *Pinus halepensis*) cannot germinate until after their seeds have lived through a fire. This environmental trigger for seedlings is called serotiny. Some compounds from smoke also promote seed germination. Fire plays a major role in the persistence and resilience of ecosystems.

13. Natural Disaster

A drastic change in the environment destabilizes or even exterminates a population. Natural calamities such as earthquake, volcanic eruptions etc. cause drastic changes in the environment leading to the destruction of the resources. What is the important of Moisture levels in plant population?

Self-Assessment Exercises 2

Attempt this exercises to measure what you have learnt so far. This should not take you more than 5 minutes. 1. Write on the important of oxygen levels for aquatic animals.

2.4 Summary

Populations are not stable and always exhibit up and down variations in response to changes in environmental or intrinsic factors. The irregular variations in size of populations are called fluctuations or population cycle. This irregularity may be as result of living or non-living factors affecting the organisms. As explained in this unit. Some of the example of the factors are natality and mortality rate, immigration and emigration, abiotic and biotic factors and carrying capacity etc.

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2.6 Possible Answers to SAEs

Answers to SAEs 1

1. Seasonally, the timing of migration is influenced by internal “clocks” that are influenced by day length and perhaps also weather. For example – Consider a species of the deer that live in a certain park. They would migrate to warmer places during winter if the park they reside is harsh for them to survive. But, if they are living near a place, where they can graze throughout the year, then there is no need for their migration.

Answers to SAEs 1

1. Oxygen from the air and oxygen produced by aquatic plants dissolves in water. Without this, aquatic animals would suffocate and die. Healthy lakes and rivers have high levels of oxygen, and polluted waters often have low levels of oxygen. This pollution means that only certain species can survive there such as sludge worms. These are bio-indicator species because their presence or absence informs us about the condition of the habitat.

Unit 3: Measurement of Population Dynamics

Contents

3.1 Introduction
3.2 Intended Learning Outcomes (ILOs)
3.3 Population Dynamics
3.4 Summary
3.5 References/Further Readings/Web Sources
3.6 Possible Answers to Self-Assessment Exercises

3.1 Introduction

There are a number of methods to describe populations from field measurements such as, dynamic and static life tables, and transition matrices. All are based on using census on individuals in groups, categorized according to their state (age, size, or stage). They are used to explain population dynamics in relation to demographic processes, and to predict the fate of the population. The methods differ because it depends on the following;

a) convenience of data collection,
b) basic assumptions and
c) the way they derive population growth rate.

Because this also depends on the general biology and life cycle of the organism, some methods are better for some kinds of populations, but not for others.

3.2 Intended Learning Outcomes (ILOs)

At the end of this unit, student should be able to explain the measurement of population dynamics and the survival ship curve

3.3 Population Dynamics

Dynamic life tables describe survivorship and fecundity (production of eggs, seeds, or young) at different ages of a cohort (a sample of individuals recruited approximately at the same time). Usually the cohort is followed until the last member dies. Survivorship is calculated as the relative change in the number of individuals of the cohort between two successive censuses. The census is very simple, since individuals need only be recognized to differentiate them from other cohorts in the same population, and thus are only counted. No marking is needed, because for an individual to be counted means it survived since last census, and determines its age unambiguously. Transition models, as will be discussed later, require more elaborate censuses.

Age may be convenient to use in cohort studies, but it does not always play a primary role in the development and life cycle of the organisms. This is probably true for all plant and most animal taxa, except birds and mammals. The latter's determinate growth (an individually fixed adult size) and hormonal clock, combined with their ability to learn, make age a suitable attribute to describe population dynamics. In most other cases, size is biologically more important, as it determines resource acquisition, competitive ability, survivorship and sexual maturity and reproductive output. Only if size and age are strongly correlated in such a population, age may be preferable.

Stage is very useful in cohort studies of annual organisms if surviving organisms all pass through relatively short stages, so that stages hardly overlap (occur at the same time), and stage and age are correlated. However, if size or stage is attained at different rates for different individuals in the population, as is often the case, they are not useful for constructing life tables. Then, transition models are more appropriate. What is Dynamics Life table? Dynamic life table is used for what kind of animals?

i) **Survivorship** Curve

Two kinds of information are derived from these cohort studies: survivorship curves and population growth rates. Survivorship curves show how mortality varies with age of the individuals of the cohort or is a graph that measures the proportion of individuals in a given species that are alive at different ages. Age-specific mortality, as well as age-specific fecundity, is due to changing susceptibilities and capabilities of the individual, and the variation in its environmental exposure. Depending on the age at which most of the mortality takes place, organisms can have different survivorship curves. Deevey (1947) described three types of curves (Fig. 1):

1. A type I survivorship curve shows individuals that have a high probability of surviving through early and middle life but have a rapid decline in the number of individuals surviving into late life. This basically means that most of the individuals will make it to adulthood but the proportion surviving into old age is greatly decreased. A type I survivorship curve is plotted as a convex curve on a graph.
2. A type II survivorship curve shows a roughly constant mortality rate for the species through its entire life. This means that the individual's chance of dying is independent of their age. Type II survivorship curves are plotted as a diagonal line going downward on a graph.
3. A type III survivorship curve depicts species where few individuals will live to adulthood and die as they get older because the greatest mortality

for these individuals is experienced early in life. This type of survivorship curve is drawn as a concave curve on a graph

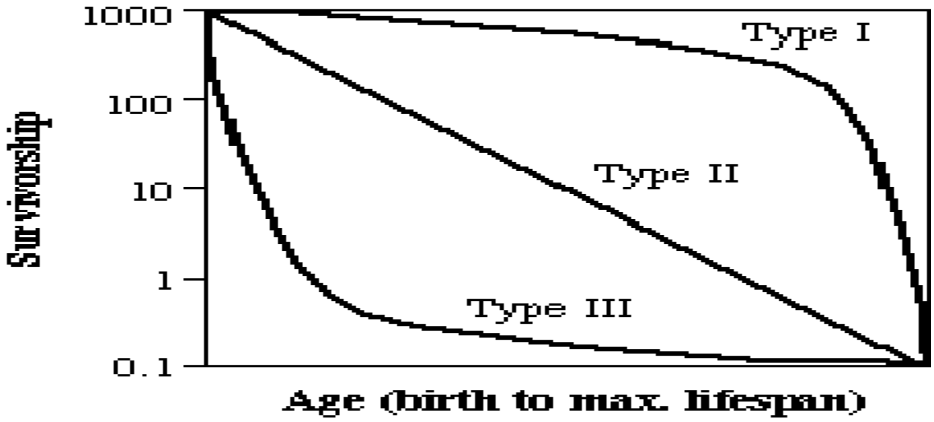

Fig.1. Three types of survivorship curves (Begon et al. 1990, Deevey 1947).

A classic example of a type I survivorship curve is the human population. Advances in medicine and technology have made the chances of surviving through early and middle life highly probably for humans. The highest levels of mortality appear in late life. Type II survivorship curves indicate that the chance if dying is independent of age. Type II survivorship curves are used for animals, such as birds, who have many random chances of being killed or dying at all stages of their life. Type III individuals initially have a rather low chance of survival. Those that do survive may live to an advanced age. Examples include many fish and other marine organisms

Table 1: Showing the diffeeces in Survivorship strategies between Type 1 and Types III

	Type I	**Type III**
Habitats	Stable	Disturbed
Life span	Long	Short
Reproductive age	Later in Life	Early in Life
Gestation period	Long	Short
Number of Offspring	Low	High
Care of Offspring	Greater	Little
Infant Mortality	Low	High
Dispersal	Low	High
Growth Curve	Logistic-K	Exponential - r

(Source: Begon *et al*. 1990)

What is survivorship curve?

Self-Assessment Exercises 1

Attempt this exercises to measure what you have learnt so far. This should not take you more than 5 minutes.

1. What does Survivorship curve type I indicate?

II) Population growth rate

Population growth rate of a cohort is defined as the basic reproductive rate R_0 for a generation over its lifetime. Using dynamic life tables is best suited for semelparous animals include many insects or monocarpic plants (those that flower, set seeds and then die), especially annual organisms, as in the study on the annual plant species *Phlox drummondii* by Leverich and Levin (1979) (Table 2). These have a single cohort per year, and thus have no overlapping generations.

Perennial iteroparous /polycarpic organisms (reproductive strategy) do have overlapping generations, which makes the method less straightforward, though often still useful. Connell (1970) used this method on the long-lived barnacle *Balanus glandula* (Table 3). Basic reproductive rate R_0 measures the mean number of offspring that an individual of the cohort produces in its lifetime. Offspring denotes the number of individuals in the first stage of the life cycle (zygotes or young, depending on the organism).

Table 2. A cohort life-table for Phlox drumondii (after Leverich and Levin 1979).

Age interval (days) $x-x'$	Number surviving to day x a_x	Proportion of original cohort surviving to day x l_x	Proportion of original cohort dying during interval d_x	Mortality rate per day q_x	$\log_{10} l_x$	Daily killing power k_x	F_x	m_x	$l_x m_x$
0–63	996	1.000	0.329	0.005		0.003	—	—	—
63–124	668	0.671	0.375	0.009	−0.17	0.006	—	—	—
124–184	295	0.296	0.105	0.006	−0.53	0.003	—	—	—
184–215	190	0.191	0.014	0.002	−0.72	0.001	—	—	—
215–264	176	0.177	0.004	0.001	−0.75	<0.001	—	—	—
264–278	172	0.173	0.005	0.002	−0.76	0.001	—	—	—
278–292	167	0.168	0.008	0.003	−0.78	0.002	—	—	—
292–306	159	0.160	0.005	0.002	−0.80	0.001	53.0	0.33	0.05
306–320	154	0.155	0.007	0.003	−0.81	0.001	485.0	3.13	0.49
320–334	147	0.148	0.043	0.021	−0.83	0.011	802.7	5.42	0.80
334–348	105	0.105	0.083	0.057	−0.98	0.049	972.7	9.26	0.97
348–362	22	0.022	0.022	1.000	−1.66	—	94.8	4.31	0.10
362–	0	0	—			—	—	—	
							2408.2		2.41

$$R_0 = \sum l_x m_x = \frac{\sum F_x}{a_0} = 2.41.$$

Table 3. A cohort life-table and fecundity schedule for the barnacle *Balanus glandula* at Pile Point, San Juan Island, Washington

Age, years x	a_x	l_x	m_x	$l_x m_x$	$x l_x m_x$
0	1 000 000	1.000	0	0	
1	62	0.0000620	4600	0.285	0.285
2	34	0.0000340	8700	0.296	0.592
3	20	0.0000200	11600	0.232	0.696
4	15.5*	0.0000155	12700	0.197	0.788
5	11	0.0000110	12700	0.140	0.700
6	6.5*	0.0000065	12700	0.082	0.492
7	2	0.0000020	12700	0.025	0.175
8	2	0.0000020	12700	0.025	0.200
				1.282	3.928

$R_0 = 1.282$

$T_c = \frac{3.928}{1.282} = 3.1$

$r = \frac{\ln R_0}{T_c} = 0.08014$.

(Conell, 1970). (* - estimated by interpolation from the survivorship curve).

There are two ways to arrive at the basic reproductive rate.
The first method is $R_0 = \sum F_x / a_0$, where $\sum F_x$, the sum of the F_x's, is the number of offspring over the life span of the cohort, and a_0 is the first stage. The ratio shows the relative change in population size / density from one generation of the cohort to the next. R_0 is also measured as $R_0 = \sum l_x m_x$, the sum of l_x, the chance of an individual surviving to age x (the time from the birth of the cohort to the census x, not necessarily in years), times m_x, the number of offspring produced during the time from age x-1 to x. The advantage of this model is, that it is explicit about the relation between overall population growth and the actual demographic processes that take place through time in the cohort. For annual organisms this sequence of processes tracks the changing of the seasons.

In cohort studies, R_0 is determined over the generation time. If the organism is an annual plant or animal, R_0 also denotes population growth rate R, defined per year: $R = R_0$. In perennial semelparous or monocarpic organisms, R_0 should be corrected for generation time T (>1 year).

Since $R_0 = R^T$, so that $\ln R = (\ln R_0)/T$.
However, for organisms with overlapping generations, it is difficult to estimate annual growth rate accurately since generation time T is in fact unknown. Instead of T, R is given by $\ln R = (\ln R_0)/T_c$.

R_0 is corrected by T_c, the average cohort lifespan, which is the average time from the birth of an individual to the birth of one of its offspring, calculated as the sum of lengths of time of the offspring of all individuals divided by the total number of offspring:

$T_c = (\sum x.\, l_x m_x) / \sum l_x m_x \; \sum x.\, l_x m_x) / R_0$.

The presence of three generations at the same time, i.e. if some individuals have produced offspring themselves while their parents are still alive, cannot be incorporated in the equation. What is population growth rate?

Self-Assessment Exercises 2

Attempt this exercises to measure what you have learnt so far. This should not take you more than 5 minutes.

1. How is R_0 determined In cohort studies?

III) Static life tables

A static life table is similar to a cohort life table but introduces a few complications. A static life table contains the age groups in a population at one particular period of time. Thus, cohorts are not followed in time, but reconstructed using one-time observations. These can be used to calculate population growth only if an assumption is made. The assumption is that the mortality experienced by the cohort at any age stays constant in time. In other words, birth rates and age-specific survivorship are assumed to be independent of the actual year in which the observations are made. Only rarely is this assumption truly justified. Therefore, the conclusions tell us how a cohort should behave, if we would have observed it and if conditions are constant between years. An example is the study of red deer by Lowe (1969) (Table 4), described in Begon et al. (1990).

A second, less problematic application of static life tables is using them in order to reconstruct past events, as Crisp and Lange (1976) did with the desert shrub *Acacia burkitii* (Begon et al. 1990, page 144 and 145). They were able to show, among others, the effects of grazing, because they compared two stands using one as a control

Table 3. A static life-table for red deer hinds on the island of Rhum, based on the reconstructed age-structure of the population in 1957 (After Lowe, 1969)

Age (years) x	Number of individuals observed of age x a_x	l_x	d_x	q_x	Smoothed l_x	Smoothed d_x	Smoothed q_x
1	129	1.000	0.116	0.116	1.000	0.137	0.137
2	114	0.884	0.008	0.009	0.863	0.085	0.097
3	113	0.876	0.251	0.287	0.778	0.084	0.108
4	81	0.625	0.020	0.032	0.694	0.084	0.121
5	78	0.605	0.148	0.245	0.610	0.084	0.137
6	59	0.457	−0.047	—	0.526	0.084	0.159
7	65	0.504	0.078	0.155	0.442	0.085	0.190
8	55	0.426	0.232	0.545	0.357	0.176	0.502
9	25	0.194	0.124	0.639	0.181	0.122	0.672
10	9	0.070	0.008	0.114	0.059	0.008	0.141
11	8	0.062	0.008	0.129	0.051	0.009	0.165
12	7	0.054	0.038	0.704	0.042	0.008	0.198
13	2	0.016	0.008	0.500	0.034	0.009	0.247
14	1	0.080	−0.023	—	0.025	0.008	0.329
15	4	0.031	0.015	0.484	0.017	0.008	0.492
16	2	0.016	—	—	0.009	0.009	1.000

What is Static life table?

3.4 Summary

The measurement of population dynamics is very important in ecological study of animals. To be able to assess the status of any ecosystem there is necessity for continuous measurement of the animal population, either quantitatively or qualitatively.

3.5 References/Further Readings/Web Sources

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3.6 Possible Answers to SAEs

Answer to SAEs 1

1. A type I survivorship curve shows individuals that have a high probability of surviving through early and middle life but have a rapid decline in the number of individuals surviving into late life. This basically means that most

of the individuals will make it to adulthood but the proportion surviving into old age is greatly decreased. A type I survivorship curve is plotted as a convex curve on a graph.

Answer to SAEs 2

1. In cohort studies, R_0 is determined over the generation time. If the organism is an annual plant or animal, R_0 also denotes population growth rate R, defined per year: $R = R_0$. In perennial semelparous or monocarpic organisms, R_0 should be corrected for generation time T (>1 year).

Unit 4: Life Tables and K-values

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4.1 Introduction

A population's growth potential has much to do with how often individual members reproduce. Some species (e.g., most invertebrates) have only one reproductive event in their lifetime, while others (e.g., most birds and mammals) are capable of multiple events over an extended portion of their lives. The former are called semelparous and the latter, iteroparous life cycles. There is a large amount of variation, however, within these broad categories. For example, some semelparous species have overlapping generations of young so that, at any one time, there may one-, two-, and three-year-old individuals present in the population. A common form of semelparity in insects of temperate regions is an annual species.

In this case, the insect overwinters as an egg or larval resting stage until spring, then grows throughout the warm months and emerges into the reproductive adult. Adults mate and lay eggs that, again, remain dormant throughout the winter. Still other semelparous species complete several generations each summer. It is easy to imagine, then, how the frequency of reproductive events, the number of young produced in each event, and the length of each generation can greatly influence how fast a population can grow.

4.2 Intended Learning Outcomes (ILOs)

At the end of this unit the student should be able to explain with examples the different type of life tables and life expectancy in hypothetical population

4.3 Life Table

A life table is a record of survival and reproductive rates in a population, broken out by age, size, or developmental stage (e.g., egg, hatchling, juvenile, adult). Wildlife population ecologists have found life tables useful in understanding patterns and causes of mortality, predicting the future growth or decline of populations, and managing populations of Threaten & Endangered species. Constructing a life table is often a simple method for keeping track of births, deaths, and reproductive output in a population of interest. Basically, there are three methods of constructing such a table:

1. the cohort life table follows a group of same-aged individuals from birth (or fertilized eggs) throughout their lives,
2. a static life table is made from data collected from all ages at one particular time it assumes the age distribution is stable from generation to generation, and
3. a life table can be made from mortality data collected from a specified time period and also assumes a stable age distribution.

Note: For organisms that have separate sexes, life tables frequently follow only female individuals.

Predicting the growth and decline of a wildlife population is an important application of life table use. As you might expect, whether the population increases or decreases depends in part on reproductive rate (i.e., litter or clutch size) and longevity, especially how long the females produce young. But it may surprise you to learn that population growth or decline is also driven by the age at which the females begin to have their young. A major part of this exercise will explore the effects of changing patterns of survival and reproduction on population dynamics

Another use of life tables is in species conservation efforts, such as in the case of loggerhead sea turtles (*Caretta caretta*), which occur off the coast of the southeastern United States. We will explore loggerhead sea turtle population dynamics in more detail in problem set 3, but generally speaking, loggerhead populations are declining in part because egg and hatchling mortality is high. This situation has led conservation biologists to advocate the protection of nesting beaches. When these measures proved ineffective in halting the population decline, compiling and analyzing a life table for loggerheads indicated that reducing mortality of older turtles would have a greater probability of reversing the population decline. Therefore, management 2 efforts shifted to persuading fishermen to install turtle exclusion devices (TEDs) on their nets to prevent older turtles from drowning. Examples of life tables are shown below. What is a Life table?

i. Stage-dependent life –table

Stage-dependent life tables are used mainly for insects and other terrestrial invertebrates. Stage-dependent life tables are built in the cases when;

1. The life-cycle is partitioned into distinct stages (e.g., eggs, larvae, pupae and adults in insects)
2. Survival and reproduction depend more on organism stage rather than on calendar age
3. Age distribution at particular time does not matter (e.g., there is only one generation per year)

Specific features of stage-dependent life tables are as follow:

1. There is no reference to calendar time. This is very convenient for the analysis of poikilothermous organisms.
2. Gypsy moth development depends on temperature but the life table is relatively independent from weather.
3. Mortality processes can be recorded individually and thus, this kind of life table has more biological information than age-dependent life tables.

Table 1: Life table of Gypsy moth (*Lymantria dispar* L.) in New England (modified from Campbell 1981)

Stage	Mortality Factor	Initial no. of insect	No. of deaths	Mortality (d)	Survival (s)	K-value {ln(s)}
Egg	Predation, etc.	450.0	67.5	0.150	0.850	0.1625
Egg	Parasites	382.5	67.5	0.176	0.824	0.1942
Larvae I-III	Dispersion, etc.	315.0	157.5	0.500	0.500	0.6932
Larvae IV-VI	Predation, etc.	157.5	118.1	0.750	0.250	1.3857
Larvae IV-VI	Disease	39.4	7.9	0.201	0.799	0.2238
Larvae IV-VI	Parasites	31.5	7.9	0.251	0.749	0.2887

Prepupae	Desiccation,etc.	23.6	0.7	0.030	0.970	0.0301
Pupae	Predation	22.9	4.6	0.201	0.799	0.2242
Pupae	Other	18.3	2.3	0.126	0.874	0.1343
Adults	Sex ratio	16.0	5.6	0.350	0.650	0.4308
Adult females		10.4				
TOTAL			439.6	97.69	0.0231	3.7674

What are the specific features of stage- dependent life table?

ii. Static (Vertical) Life Table Based on Living Individuals

Most organisms have more complex life histories than those found in the above example, and while it is possible to follow a single cohort from birth to death, it is often too costly or time-consuming to do so. Another, less accurate, method is the static, or vertical, life table. Rather than following a single cohort, the static table compares population size from different cohorts, across the entire range of ages, at a single point in time. Static tables make two important assumptions: 1) the population has a stable age structure Ñ that is, the proportion of individuals in each age class does not change from generation to generation, and 2) the population size is, or nearly, stationary.

iii. Static (Vertical) Life Table Based on Mortality Records

Static life tables can also be made from knowing, or estimating, age at death for individuals from a population. This can be a useful technique for secretive large mammals (e.g., moose) from temperate regions where it is difficult to sample the living members. Because the highest mortality of large herbivores occurs during the winter, an early spring survey of carcasses from starvation and predator kills can yield useful information in constructing a life table. Keep in mind, however, that all static tables suffer from the same two assumptions stated above.

Because we keep good birth and death records on humans, static life tables can also be used to answer questions concerning our populations. For instance, we know that females today have a larger mean life expectancy than men. But, if we may ask, was this true for our population 100 years ago? We can use data collected from cemetery grave markers to construct a static life table and reveal interesting features of human populations from past generations. The following data were collected from a random sample of 30 females and 30 males off grave markers located in an Ann Arbor cemetery.

Table 2. Male and female age at death frequencies from a random sample of 60 Ann Arbor grave markers of individuals born prior to 1870. (From G. Belovsky, unpubl.)

Age at death	**Females**	**Males**
0-5	1	2

6-10	0	0
11-15	1	0
16-20	2	1
21-25	1	1
26-30	0	2
31-35	0	0
36-40	1	2
41-45	1	0
46-50	2	1
51-55	1	0
56-60	2	3
61-65	0	4
66-70	0	4
71-75	1	3
76-80	6	1
81-85	4	1
86-90	7	3
91-95	0	0
96-100	0	2

Besides R_0, the basic reproductive rate, several other population characteristics can be determined from life tables. Some of the most common features are the cohort generation time (T_x), life expectancy (e_x), and the intrinsic growth rate (r). Cohort generation time is quite easy to obtain from our first example, a semelparous annual life cycle (T_x = 1 year), but generation time is less obvious for more complex life cycles. Generation time can be defined as the average length of time between when an individual is born and the birth of its offspring. Therefore, it can be calculated by summing all the lengths of time to offspring production for the entire cohort divided by the total offspring produced by the survivors:

Life expectancy is a useful way of expressing the probability of living (x) number of years beyond a given age. We usually encounter life expectancy in newspaper articles comparing the mean length of life for individuals of various populations. However, this value is actually the life expectancy at birth. One can also calculate the mean length of life beyond any given age for the population. Life expectancy is a somewhat complicated calculation. Because lx is only the proportion surviving to the beginning of a particular age class, we must first calculate the average proportion alive at that age (Lx):

$$Lx = \frac{lx + lx + 1}{2}$$

Next, the total number of living individuals at age x and beyond (T_x) is:

$$Tx = Lx + Lx + 1 +¼+ Lx + n$$

Finally, the average amount of time yet to be lived by members surviving to a particular age (ex) is:

$$Ex = \frac{Tx}{lx}$$

The following example shows life expectancy changes in a hypothetical population that experienced 50% mortality at each age:

Table3. Life expectancy in a hypothetical population.

Age (years)	Ix	Lx	Tx	Ex (years)
0	1.0	0.75	1.375	1.375
1	0.5	0.375	0.625	1.25
2	0.25	0.1875	0.25	1.0
3	0.125	0.0625	0.0625	0.5
4	0.0	-	-	-

The basic reproduction rate (R_0) converts the initial population size to the new size one generation later as:

$$N_T = N_0 \times R_0$$

If R_0 remains constant from generation to generation, then we can also use it to predict population size several generations in the future. To predict population size at any future time, it is more convenient to use a parameter that already takes generation time into account. This term is Ô*r*Õ, the intrinsic rate of natural increase, and it can be calculated (or approximated for complex life cycles) by the following equation:

$$r \ @ \ \frac{\ln R0}{Tc}$$

The term, *r*, is used in mathematical models of population growth discussed later
How is Static (Vertical) Life table on Mortality records estimated?

Self-Assessment Exercises 1

Attempt this exercises to measure what you have learnt so far. This should not take you more than 5 minutes.

1. What is life expectancy?

K-value is just another measure of mortality. The major advantage of k-values as compared to percentages of died organisms is that k-values are additive: the k-value of a combination of independent mortality processes is equal to the sum of k-values for individual processes.

Mortality percentages are not additive. For example, if predators alone can kill 50% of the population, and diseases alone can kill 50% of the population, then the combined effect of these process will not result in 50+50 = 100% mortality. Instead, mortality will be 75%
Survival is a probability to survive, and thus we can apply the theory of probability. In this theory, events are considered independent if the probability of the combination of two events is equal to the product of the probabilities of each individual event. In our case event is survival. If two mortality processes are present, then organism survives if it survives from each individual process. For example, an organism survives if it was simultaneously not infected by disease and not captured by a predator.
Assume that survival from one mortality source is s1 and survival from the second mortality source is s2. Then survival from both processes, s12, (if they are independent) is equal to the product of s1 and s2:

$$s_{12} = s_1 s_2$$

This is a "survival multiplication rule". If survival is replaced by 1 minus mortality [s=(1-d)], then this equation becomes:

$$d_{12} = 1 - (1 - d_1)(1 - d_2)$$

For example, if mortality due to predation is 60% and mortality due to diseases is 30%, then the combination of these two death processes results in mortality of d = 1-(1-0.6)(1-0.3)=0.72 (=72%).
Varley and Gradwell (1960) suggested to measure mortality in k-value which is the negative logarithms of survival:

k = -ln(s)

We use natural logarithms (with base e=2.718) instead of logarithms with base 10 used by Varley and Gradwell. The advantages of using natural logarithms will be shown below. It is easy to show that k-values are additive:

$$k_{12} = -\ln(s_{12}) = -\ln(s_1 s_2) = [-\ln(s_1)] + [-\ln(s_2)] = k_1 + k_2$$

The k-values for the entire life cycle (K) can be estimated as the sum of k-values for all mortality processes:

$$K = \sum k_i$$

In the life table of the gypsy moth (see above), the sum of all k-values (K = 3.7674) was equal to the k-value of total mortality.

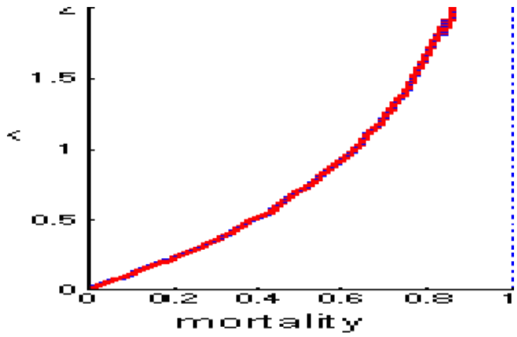

Fig 1: Showing the relations between mortality and the K-value

From the above, when mortality is low, then the k-value is almost equal to mortality. This is the reason why the k-value can be considered as another measure of mortality. However, at high mortality, the k-value grows much faster than mortality. Mortality cannot exceed 1, while the k-value can be infinitely large.

The following example shows that the k-value represents mortality better than the percentage of dead organisms: One insecticide kills 99% of cockroaches and another insecticide kills 99.9% of cockroaches. The difference in percentages is very small (<1%). However the second insecticide is considerably better because the number of survivors is 10 times smaller. This difference is represented much better by k-values which are 4.60 and 6.91 for the first and second insecticides, respectively.

If k-values are estimated for a number of years, then the dynamics of k-values over time can be compared with the dynamics of the generation K-value. The following graph shows the dynamics of k-values for the winter moth in Great Britain.

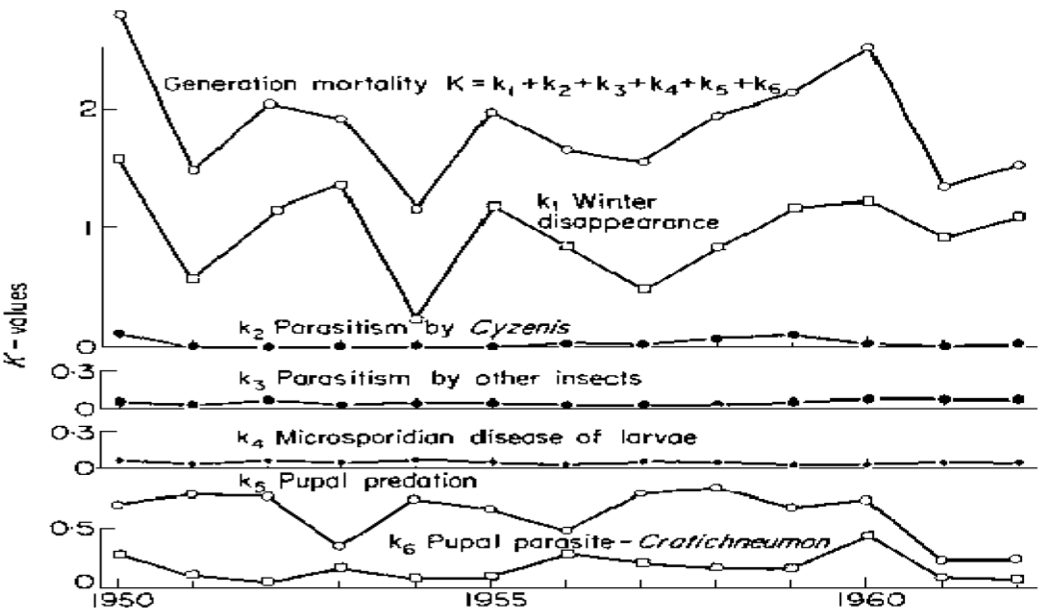

Fig 2: Showing the dynamics of K-values for the winter moth in Great Britain

It is seen that the dynamics of winter disappearance (k1) is most resembling the dynamics of total generation K-value. The conclusion was made that winter

disappearance determines the trend in population numbers (whether the population will grow or decline), and thus, it can be considered as a "key factor". T
The key-factor analysis was often considered as a substitute for modeling. It seems so easy to compare time series of k-values and to find key-factors without the hard work of developing models of ecological processes. However, reliable predictions can be obtained only from models.

This critique does not mean that life-tables have no value. Life-tables are very important for gathering information about ecological processes which is necessary for building models. It is the key-factor analysis that has little sense.

A population that experience constant mortality during a specific stage (e.g., larval stage of insects) change in numbers according to the exponential model with a negative rate r. We cannot call r intrinsic rate of natural increase because this term is used for the entire life cycle, and here we discuss a particular stage in the life cycle. According to the exponential model:

$$N_t = N_0 \cdot \exp(r \cdot t)$$

Population numbers decrease and thus, Nt < N0. Survival is: s = Nt/N0 . Now we can estimate the k-value:
k = -r t

Instantaneous mortality rate, m, is equal to the negative exponential coefficient because mortality is the only ecological process considered (there is no reproduction):
m = -r,

k = m t

Exponential coefficient r is negative (because population declines), and mortality rate, m, is positive.

We proved that if mortality rate is constant, then k-value is equal to the instantaneous mortality rate multiplied by time. This is analogs to physics: distance is equal to speed multiplied by time. Here, instantaneous mortality rate is like speed, and k-value is like distance. K-value shows the result of killing organisms with specific rate during a period of time. If the period of time when mortality occurs is short then the effect of this mortality on population is not large.

If instantaneous mortality rate changes with time, then the k-value is equal to its integral over time. In the same way, in physics, distance is the integral of instantaneous speed over time.

Example. Annual mortality rates of oak trees due to animal-caused bark damage are 0.08 in the first 10 years and 0.02 in the age interval of 10-20 years. We need to estimate total k-value (k) and total mortality (d) for the first 20 years of oak growth.

k = 0.08 × 10 + 0.02 × 10 = 1.0

d = 1 – exp (-k) = 0.63

Thus, total mortality during 20 years is 63%.

The limitation of the k-value concept is that all organisms are assumed to have equal dying probabilities. In nature, dying probabilities may vary because of spatial heterogeneity and individual variation (both inherited and non-inherited).

i) Estimation of k-values in natural populations

Estimation of k-values for individual death processes is difficult because these processes often go simultaneously. The problem is to predict what mortality could be expected if there was only one death process. In order to separate death processes it is important to know the biology of the species and its interactions with natural enemies. Below you can find several examples of separation of death processes.

Example 1. Insect parasitoids oviposit on host organisms. Parasitoid larva hatches from the egg and starts feeding on host tissue. Parasitized host can be alive for a long period. Finally, it dies and parasitoid emerges from it. Insect predators usually don't distinguish between parasitized and non-parasitized prey. If an insect was killed by a predator, then it is usually impossible to detect if this insect was parasitized before. Thus, mortality due to predation is estimated as the ratio of the number of insects numbers destroyed by predators to the total number of insects, whereas mortality due to parasitism is estimated as the ratio of the number of insects killed by parasitoids to the number of insects that survived predation. In this example, predation masks the effect of parasitism, and thus, insects killed by predators are ignored in the estimation of the rate of parasitism. The effect is the same as if predation occurred before parasitism in the life cycle. Thus, in the gypsy moth life table, predation was always considered before parasitism. Diseases also mask the effect of parasitism and thus they are considered before parasitism.

Example 2. It is often possible to distinguish between organisms destroyed by different kinds of predators. For example, small mammals and birds open sawfly cocoons in a different way. Suppose, 20% of cocoons were opened by birds, 50% were opened by mammals, and remaining 30% were alive. The question is what would be the rate of predation if birds and mammals were acting alone. We assume that sawfly cocoons have no individual variation in predator attack rate, and that cocoons destroyed by one predator cannot be attacked by another predator. First, we estimate total k-value for both predator groups: k_{12} = -ln(0.3) = 1.204. Second, we subdivide the total k-value into two portions proportionally to the number of cocoons destroyed by each kind of predator. Thus, for birds k_1 = 1.204×20/(20+50) = 0.344, and for mammals k_2 = 1.204×50/(20+50) = 0.860. The third step is to convert k-values into expected mortality if each predator was alone: for birds d1 = 1- exp. (-0.344) = 0.291, and for mammals d_2 = 1- exp. (-0.860) = 0.577. What is K-value?
What are the limitations of the k-values concept?

Self-Assessment Exercises 2

Attempt this exercises to measure what you have learnt so far. This should not take you more than 5 minutes.

1. Why is the estimation of K-values in natural population difficult?

4.5 Summary

K-values analysis has been applied to a variety of animal species in order to assess the role of natural enemies in population fluctuations. In general, this technique is not applicable to tropical insects because in most species the generations overlap.

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4.7 Possible Answers to SAEs

Answer to SAEs 1

1. Life expectancy is a useful way of expressing the probability of living (x) number of years beyond a given age.

Answer to SAEs 2

1. Estimation of k-values for individual death processes is difficult because these processes often go simultaneously. The problem is to predict what mortality could be expected if there was only one death process. In order to separate death processes it is important to know the biology of the species and its interactions with natural enemies

Unit 5: Key-Factor Analysis

Contents

5.1 Introduction
5.2 Intended Learning Outcomes (ILOs)
5.3 Key-Factor Analysis
    5.3.1 Type of factor analysis
5.4 Summary
5.5 References/Further Readings/Web Sources
5.6 Possible Answers to Self-Assessment Exercises

5.1 Introduction

Key-factor analysis has been applied to a variety of animal species in order to assess the role of natural enemies in population fluctuations. In general, this technique is not applicable to tropical insects because in most species the generations overlap. However, a unique feature in the life system of *Andraca bipunctata* Walker is that it has four generations that are fairly well differentiated in a year, and it does not have a fixed seasonal peak. These features make the species amenable to analysis using life-tables.

5.2 Intended Learning Outcomes (ILOs)

At the end of this unit the student should be able to explain with examples the different type of Factor Analysis and crieteria for determining of number of factors.

5.3 Factor Analysis

Factor analysis is a statistical method used to describe variability among observed variables in terms of a potentially lower number of unobserved variables called **factors**. In other words, it is possible, for example, that variations in three or four observed variables mainly reflect the variations in a single unobserved variable, or in a reduced number of unobserved variables. Factor analysis searches for such joint variations in response to unobserved latent variables. The observed variables are modelled as linear combinations of the potential factors, plus "error" terms. The information gained about the interdependencies between observed variables can be used later to reduce the set of variables in a dataset. Factor analysis originated in psychometrics, and is used in behavioural sciences, social sciences, marketing, product management, operations research, and other applied sciences that deal with large quantities of data.

Factor analysis is related to principal component analysis (PCA), but the two are not identical. Because PCA performs a variance-maximizing rotation of the variable space, it takes into account all variability in the variables. In contrast, factor analysis estimates how much of the variability is due to common factors ("communality"). The two methods become essentially equivalent if the error terms in the factor analysis model (the variability not explained by common factors, see below) can be assumed to all have the same variance.

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Definition

Suppose we have a set of *p* observable random variables, $x_1, \ldots, x_p$ with means $\mu_1, \ldots, \mu_p$.

Suppose for some unknown constants l_{ij} and *k* unobserved random variables F_j, where

$i \in 1, \ldots, p$ and $j \in 1, \ldots, k$, where $k < p$, we have

$$x_i - \mu_i = l_{i1}F_1 + \cdots + l_{ik}F_k + \varepsilon_i.$$

Here, they are independently distributed error terms with zero mean and finite variance, which may not be the same for all *i* Let $\mathrm{Var}(\varepsilon_i) = \psi_i$ so that we have

$$\mathrm{Cov}(\varepsilon) = \mathrm{Diag}(\psi_1, \ldots, \psi_p) = \Psi \text{ and } \mathrm{E}(\varepsilon) = 0.$$

In matrix terms, we have

$$x - \mu = LF + \varepsilon.$$

If we have *n* observations, then we will have the dimensions $x_{p\times n}$, $L_{p\times k}$, and $F_{k\times n}$. Each column of *x* and *F* denote values for one particular observation, and matrix *L* does not vary across observations.

Also we will impose the following assumptions on *F*.

1. *F* and ε are independent.
2. E(*F*) = 0
3. Cov(*F*) = *I*

Any solution of the above set of equations following the constraints for *F* is defined as the *factors*, and *L* as the *loading matrix*.
Suppose Cov(*x* − μ) = Σ. Then note that from the conditions just imposed on *F*, we have

$$\mathrm{Cov}(x - \mu) = \mathrm{Cov}(LF + \varepsilon),$$

or

$$\Sigma = L\mathrm{Cov}(F)L^T + \mathrm{Cov}(\varepsilon),$$

or

$$\Sigma = LL^T + \Psi.$$

Note that for any orthogonal matrix *Q* if we set $L = LQ$ and $F = Q^T F$, the criteria for being factors and factor loadings still hold. Hence a set of factors and factor loadings is identical only up to orthogonal transformations.

The following example is a fictionalized simplification for expository purposes, and should not be taken as being realistic. Suppose a psychologist proposes a theory that there are two kinds of intelligence, "verbal intelligence" and "mathematical intelligence", neither of which is directly observed. Evidence for the theory is sought in the examination scores from each of 10 different academic fields of 1000 students. If each student is chosen randomly from a large population, then each student's 10 scores are random variables. The psychologist's theory may say that for each of the 10 academic fields, the score averaged over the group of all students who share some common pair of values for verbal and mathematical "intelligences" is some constant times their level of verbal intelligence plus another constant times their level of mathematical intelligence, i.e., it is a linear combination of those two "factors". The numbers for a particular subject, by which the two kinds of intelligence are multiplied to obtain the expected score, are posited by the theory to be the same for all intelligence level pairs, and are called **"factor loadings"** for this subject. For example, the theory may hold that the average student's aptitude in the field of amphibiology is

{10 × the student's verbal intelligence} + {6 × the student's mathematical intelligence}.

The numbers 10 and 6 are the factor loadings associated with amphibiology. Other academic subjects may have different factor loadings.
Two students having identical degrees of verbal intelligence and identical degrees of mathematical intelligence may have different aptitudes in amphibiology because individual aptitudes differ from average aptitudes. That difference is called the "error" — a statistical term that means the amount by which an individual differs from what is average for his or her levels of intelligence (see errors and residuals in statistics).

The observable data that go into factor analysis would be 10 scores of each of the 1000 students, a total of 10,000 numbers. The factor loadings and levels of the two kinds of intelligence of each student must be inferred from the data.

Mathematical model of the same example

In the example above, for i = 1, ..., 1,000 the ith student's scores are

$$\begin{matrix} x_{1,i} & = & \mu_1 * 1_{1\times 1000} & + & \ell_{1,1}v_i & + & \ell_{1,2}m_i & + & \varepsilon_{1,i} \\ \vdots & & \vdots & & \vdots & & \vdots & & \vdots \\ x_{10,i} & = & \mu_{10} * 1_{1\times 1000} & + & \ell_{10,1}v_i & + & \ell_{10,2}m_i & + & \varepsilon_{10,i} \end{matrix}$$

where
1. $x_{k,i}$ is the ith student's score for the kth subject
2. μ_k is the mean of the students' scores for the kth subject (assumed to be zero, for simplicity, in the example as described above, which would amount to a simple shift of the scale used)
3. v_i is the ith student's "verbal intelligence",
4. m_i is the ith student's "mathematical intelligence",
5. $\ell_{k,j}$ are the factor loadings for the kth subject, for j = 1, 2.
6. $\varepsilon_{k,i}$ is the difference between the ith student's score in the kth subject and the average score in the kth subject of all students whose levels of verbal and mathematical intelligence are the same as those of the ith student,

In matrix notation, we have

$$X = \mu \otimes 1_{1\times N} + LF + \epsilon$$

Where:

1. N is 1000 students
2. X is a 10 × 1,000 matrix of *observable* random variables,
3. μ is a 10 × 1 column vector of *unobservable* constants (in this case "constants" are quantities not differing from one individual student to the

next; and "random variables" are those assigned to individual students; the randomness arises from the random way in which the students are chosen),

4. L is a 10 × 2 matrix of factor loadings (*unobservable* constants, ten academic topics, each with two intelligence parameters that determine success in that topic),
5. F is a 2 × 1,000 matrix of *unobservable* random variables (two intelligence parameters for each of 1000 students),
6. ε is a 10 × 1,000 matrix of *unobservable* random variables.

Observe that by doubling the scale on which "verbal intelligence"—the first component in each column of F—is measured, and simultaneously halving the factor loadings for verbal intelligence makes no difference to the model. Thus, no generality is lost by assuming that the standard deviation of verbal intelligence is 1. Likewise for mathematical intelligence. Moreover, for similar reasons, no generality is lost by assuming the two factors are uncorrelated with each other. The "errors" ε are taken to be independent of each other. The variances of the "errors" associated with the 10 different subjects are not assumed to be equal.

Note that, since any rotation of a solution is also a solution, this makes interpreting the factors difficult. See disadvantages below. In this particular example, if we do not know beforehand that the two types of intelligence are uncorrelated, then we cannot interpret the two factors as the two different types of intelligence. Even if they are uncorrelated, we cannot tell which factor corresponds to verbal intelligence and which corresponds to mathematical intelligence without an outside argument.

The values of the loadings L, the averages μ, and the variances of the "errors" ε must be estimated given the observed data X and F (the assumption about the levels of the factors is fixed for a given F). What is Factor Analysis?

5.3.1 Types of Factor Analysis

There are two types of factor analysis and are listed below:

1. **Exploratory factor analysis*:*** *(EFA)* is used to uncover the underlying structure of a relatively large set of variables. The researcher's *a priori* assumption is that any indicator may be associated with any factor. This is the most common form of factor analysis. There is no prior theory and one uses factor loadings to intuit the factor structure of the data.

2. **Confirmatory factor analysis*:*** *(CFA)* seeks to determine if the number of factors and the loadings of measured (indicator) variables on them confirm to what is expected on the basis of pre-established theory. Indicator variables are selected on the basis of prior theory and factor analysis is used to see if they load as predicted on the expected number of factors. The researcher's à priori assumption is that each factor (the number and labels of which may be specified à priori) is associated with a specified subset of indicator variables. A minimum requirement of confirmatory factor analysis is that one hypothesizes beforehand the number of factors in the model, but usually also the researcher will posit expectations about which variables will load on which

factors. The researcher seeks to determine, for instance, if measures created to represent a latent variable really belong together.

i) Different Factoring in Factor analysis

1. **Principal component analysis** (PCA): The most common form of factor analysis, PCA seeks a linear combination of variables such that the maximum variance is extracted from the variables. It then removes this variance and seeks a second linear combination which explains the maximum proportion of the remaining variance, and so on. This is called the principal axis method and results in orthogonal (uncorrelated) factors.
2. **Canonical factor analysis** (CFA), also called Rao's canonical factoring, is a different method of computing the same model as PCA, which uses the principal axis method. CFA seeks factors which have the highest canonical correlation with the observed variables. CFA is unaffected by arbitrary rescaling of the data.
3. **Common factor analysis**, also called principal factor analysis (PFA) or principal axis factoring (PAF), seeks the least number of factors which can account for the common variance (correlation) of a set of variables.
4. **Image factoring**: based on the correlation matrix of predicted variables rather than actual variables, where each variable is predicted from the others using multiple regression.
5. **Alpha factoring**: based on maximizing the reliability of factors, assuming variables are randomly sampled from a universe of variables. All other methods assume cases to be sampled and variables fixed.

ii) Terminology used in Factor analysis

1. ***Factor loadings:*** The factor loadings, also called component loadings in PCA, are the correlation coefficients between the variables (rows) and factors (columns). Analogous to Pearson's r, the squared factor loading is the percent of variance in that indicator variable explained by the factor. To get the percent of variance in all the variables accounted for by each factor, add the sum of the squared factor loadings for that factor (column) and divide by the number of variables. (Note the number of variables equals the sum of their variances as the variance of a standardized variable is 1.) This is the same as dividing the factor's eigenvalue by the number of variables.

2. ***Interpreting factor loadings**:* By one rule of thumb in confirmatory factor analysis, loadings should be .7 or higher to confirm that independent variables identified a priori are represented by a particular factor, on the rationale that the .7 level corresponds to about half of the variance in the indicator being explained by the factor. However, the .7 standard is a high one and real-life data may well not meet this criterion, which is why some researchers, particularly for exploratory purposes, will use a lower level such as .4 for the central factor and .25 for other factors call loadings above .6 "high" and those below .4 "low". In any event, factor loadings must be interpreted in the light of theory, not by arbitrary cut off levels.

In oblique rotation, one gets both a pattern matrix and a structure matrix. The structure matrix is simply the factor loading matrix as in orthogonal rotation, representing the variance in a measured variable explained by a factor on both a unique and common contributions basis. The pattern matrix, in contrast, contains coefficients which just represent unique contributions. The more factors, the lower the pattern coefficients as a rule since there will be more common contributions to variance explained. For oblique rotation, the researcher looks at both the structure and pattern coefficients when attributing a label to a factor.

3. ***Communality (h2)**:* The sum of the squared factor loadings for all factors for a given variable (row) is the variance in that variable accounted for by all the factors, and this is called the communality. The communality measures the percent of variance in a given variable explained by all the factors jointly and may be interpreted as the reliability of the indicator.
4. ***Spurious solutions**:* If the communality exceeds 1.0, there is a spurious solution, which may reflect too small a sample or the researcher has too many or too few factors.
5. *Uniqueness of a variable:* 1-h2. That is, uniqueness is the variability of a variable minus its communality.
6. ***Eigenvalues**:/**Characteristic roots**:* The eigenvalue for a given factor measures the variance in all the variables which is accounted for by that factor. The ratio of eigenvalues is the ratio of explanatory importance of the factors with respect to the variables. If a factor has a low eigenvalue, then it is contributing little to the explanation of variances in the variables and may be ignored as redundant with more important factors. Eigenvalues measure the amount of variation in the total sample accounted for by each factor.
7. ***Extraction sums of squared loadings**:* Initial eigenvalues and eigenvalues after extraction (listed by SPSS as "Extraction Sums of Squared Loadings") are the same for PCA extraction, but for other extraction methods, eigenvalues after extraction will be lower than their initial counterparts. SPSS also prints "Rotation Sums of Squared Loadings" and even for PCA, these eigenvalues will differ from initial and extraction eigenvalues, though their total will be the same.
8. ***Factor scores**:* Also called component scores in PCA, factor scores are the scores of each case (row) on each factor (column). To compute the factor score for a given case for a given factor, one takes the case's standardized score on each variable, multiplies by the corresponding factor loading of the variable for the given factor, and sums these products. Computing factor scores allows one to look for factor outliers. Also, factor scores may be used as variables in subsequent modelling

iii) Criteria for determining the number of factors

1. **Comprehensibility:** Though not a strictly mathematical criterion, there is much to be said for limiting the number of factors to those whose dimension of meaning is readily comprehensible. Often this is the first two or three. Using one or more of the methods below, the researcher determines an appropriate range of solutions to investigate. For instance, the Kaiser criterion may suggest three factors and the scree test may suggest 5, so the researcher may request 3-, 4-, and 5-factor solutions and select the solution which generates the most comprehensible factor structure.
2. **Kaiser criterion:** The Kaiser rule is to drop all components with eigenvalues under 1.0. The Kaiser criterion is the default in SPSS and most computer programs but is not recommended when used as the sole cut-off criterion for estimating the number of factors.

3. **Scree plot:** The Cattell scree test plots the components as the X axis and the corresponding eigenvalues as the Y-axis. As one moves to the right, toward later components, the eigenvalues drop. When the drop ceases and the curve makes an elbow toward less steep decline, Cattell's scree test says to drop all further components after the one starting the elbow. This rule is sometimes criticised for being amenable to researcher-controlled "fudging". That is, as picking the "elbow" can be subjective because the curve has multiple elbows or is a smooth curve, the researcher may be tempted to set the cut-off at the number of factors desired by his or her research agenda.
4. **Horn's Parallel Analysis (PA):** A Monte-Carlo based simulation method that compares the observed eigenvalues with those obtained from uncorrelated normal variables. A factor or component is retained if the associated eigenvalue is bigger than the 95th of the distribution of eigenvalues derived from the random data. PA is one of the most recommendable rules for determining the number of components to retain, but only few programs include this option.
5. **Variance explained criteria:** Some researchers simply use the rule of keeping enough factors to account for 90%; (sometimes 80%) of the variation. Where the researcher's goal emphasizes parsimony (explaining variance with as few factors as possible), the criterion could be as low as 50%
   Before dropping a factor below one's cut-off, however, the researcher should check its correlation with the dependent variable. A very small factor can have a large correlation with the dependent variable, in which case it should not be dropped

iv) Different types of Rotation methods

Rotation serves to make the output more understandable and is usually necessary to facilitate the interpretation of factors.

1. ***Varimax rotation*** is an orthogonal rotation of the factor axes to maximize the variance of the squared loadings of a factor (column) on all the variables (rows) in a factor matrix, which has the effect of differentiating the original variables by extracted factor. Each factor will tend to have either large or small loadings of any particular variable. A varimax solution yields results which make it as easy as possible to identify each variable with a single factor. This is the most common rotation option.
2. ***Quartimax rotation*** is an orthogonal alternative which minimizes the number of factors needed to explain each variable. This type of rotation often generates a general factor on which most variables are loaded to a high or medium degree. Such a factor structure is usually not helpful to the research purpose.
3. ***Equimax rotation*** is a compromise between Varimax and Quartimax criteria.
4. ***Direct oblimin rotation*** is the standard method when one wishes a non-orthogonal (oblique) solution – that is, one in which the factors are allowed to be correlated. This will result in higher eigenvalues but diminished interpretability of the factors.
5. ***Promax rotation*** is an alternative non-orthogonal (oblique) rotation method which is computationally faster than the direct oblimin method and therefore is sometimes used for very large datasets. What is Principal component analysis?

Self-Assessment Exercises 1

Attempt these exercises to measure what you have learnt so far. This should not take you more than 5 minutes.

1. What is Factor Loading?
2. What is Eigenvalues:/Characteristic roots?

5.4 Summary

Key-factor analysis has been applied to a variety of animal species in order to assess the role of natural enemies in population fluctuations. In general, this technique is not applicable to tropical insects because in most species the generations overlap.

5.5 References/Further Readings/Web Sources

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5.6 Possible Answers to SAEs

Answers to SAEs 1

1. The factor loadings, also called component loadings in PCA, are the correlation coefficients between the variables (rows) and factors (columns). Analogous to Pearson's r, the squared factor loading is the percent of variance in that indicator variable explained by the factor. To get the percent of variance in all the variables accounted for by each factor, add the sum of the squared factor loadings for that factor (column) and divide by the number of variables. (Note the number of variables equals the sum of their variances as the variance of a standardized variable is 1.) This is the same as dividing the factor's eigenvalue by the number of variables.

2. The eigenvalue for a given factor measures the variance in all the variables which is accounted for by that factor. The ratio of eigenvalues is the ratio of explanatory importance of the factors with respect to the variables. If a factor has a low eigenvalue, then it is contributing little to the explanation of variances in the variables and may be ignored as redundant with more important factors. Eigenvalues measure the amount of variation in the total sample accounted for by each factor

Glossary

°C= degrees Celsius
cm = centimeters
CO_2 = Carbondioxide
CECAF= Fishery Committee for the Eastern Central Atlantic

CH_4 = methane (CH_4)
ft = feets
°F = degree Fahrenheit
Hz = Hertz
in = inches
Ib = pounds
Kgs = kilograms.
km = kilometers
m = meters
mm = millimeters
NaCl = Sodium Chloride
O_2 = Oxygen
oz = ounce
pH = Hydrogen ion concentration
TEDs = turtle exclusion devices
L = length
HIV = Human immunodeficiency virus
% = percentage
g = grams
spp = species

End of the Module Questions

1. What is Population density?
2. State the two growth pattern in animal population?
3. What is migration in animal?
4. What is survivorship curve?
5. What is Life table?

Module 3: Population Cycle in Animal Ecology

Module Introduction

Introduce the module and state the units under the module.

Unit 1: Competition in Animal Ecology
Unit 2: Population Cycle
Unit 3: Population Cycles in a Predator-Prey System
Unit 4: Ecology of African Bat
Unit 5: Behavioural Ecology
GLossary

Unit 1: Competition in Animal Ecology

Contents
1.1 Introduction
1.2 Intended Learning Outcomes (ILOs)
1.3 Competition in Animal
 1.3.1 Types of competition
 1.3.2 Resources contributing to competition among organisms
 1.3.3 Evolutionary strategies
1.4 Summary
1.5 References/Further Readings/Web Sources
1.6 Possible Answers to Self-Assessment Exercises

1.1 Introduction

Competition is an interaction between organisms or species, in which the fitness of one is lowered by the presence of another. Limited supply of at least one resource (such as food, water, and territory) used by both is required. Competition both within and between species is an important topic in ecology, especially community ecology.

Fig 1: Showing Hyena competing for food (Resources)

1.2 Intended Learning Outcomes (ILOs)

At the end of this unit, students should be able to:

1. Define competition?
2. List factors/resources that contribute to competition among organisms
3. Explain evolution strategies and state the formula selection theory

1.3 Competition in Animal

Competition is one of many interacting biotic and abiotic factors that affect community structure. Competition among members of the same species is known as intraspecific competition, while competition between individuals of different species is known as interspecific competition. Competition is not always straightforward, and can occur in both a direct and indirect fashion.

According to the competitive exclusion principle, species less suited to compete for resources should either adapt or die out. According to evolutionary theory, this competition within and between species for resources plays a critical role in natural selection, however, competition may play less of a role than expansion among larger groups such as families

1.3.1 Types of Competition

1.3.1.1 Competiton by Mechanism

The following terms describe mechanisms by which competition occurs, which can generally be divided into direct and indirect. These mechanisms apply equally to intraspecific and interspecific competition.

Fig 2: Male-male competition in red deer during rut is an example of interference competition within a species.

1. Interference competition Occurs *directly* between individuals via aggression etc. when the individuals interfere with foraging, survival, reproduction of others, or by directly preventing their physical establishment in a portion of the habitat.

2. Exploitation competition Occurs *indirectly* through a common limiting resource which acts as an intermediate. For example, use of resources depletes the amount available to others, or they compete for space. Also known as exploitative competition.

3. Apparent competition Occurs *indirectly* between two species which are both preyed upon by the same predator. For example, species A and species B are both prey of predator C. The increase of species A will cause the decrease of species B because the increase of As would increase the number of predator Cs which in turn will hunt more of species B

1.3.1.2 Competition by Species

1. Intraspecific competition: Intraspecific competition occurs when members of the same species vie for the same resources in an ecosystem. For example, two trees growing close together will compete for light above ground, and water and nutrients in the soil. Therefore, getting less resources, they will usually perform less well than if they grew by themselves. Although in this situation it may actually be more useful to think in terms of resource availability than competition. Adaptations to such an environment include growing taller, (where the specific prediction provided by the competition model is that all species in such a situation will grow as tall as possible) or developing a larger root system (where the specific prediction is that all species in the system will develop very deep root systems).

2. Interspecific compeptition: Interspecific competition may occur when individuals of two separate species share a limiting resource in the same area. If the resource cannot support both populations, then lowered fecundity, growth, or survival may result in at least one species. Interspecific competition has the potential to alter populations, communities and the evolution of interacting species.

An example among animals could be the case of cheetahs and lions; since both species feed on similar prey, they are negatively impacted by the presence of the other because they will have less food, however they still persist together, despite the prediction that under competition one will displace the other. In fact, lions sometimes steal prey items killed by cheetahs. Potential competitors can also kill each other, and this phenomenon is called 'intraguild predation'. For example, in southern California coyotes often kill and eat gray foxes and bobcats, all three carnivores sharing the same stable prey (small mammals).

Competition has been observed between individuals, populations and species, but there is little evidence that competition has been the driving force in the evolution of large groups. For example, between reptiles and mammals. Mammals lived beside reptiles for many millions of years of time but were unable to gain a competitive edge until dinosaurs were devastated by the K-T Extinction. What is Competition? Define Apparent competition.

1.3.2 Resources contributing to competition among organisms

1.3.2.1 Territory (Animal)

In ethology the term territory refers to any sociographical area that an animal of a particular species consistently defends against conspecifics (and, occasionally, animals of other species). Animals that defend territories in this way are referred to as territorial.

1.3.2.2 Classic territories

Territorial animals defend areas that contain a nest, den or mating site and sufficient food resources for themselves and their young. Defence rarely takes the form of overt fights: more usually there is a highly noticeable display, which may be visual (as in the red breast of the robin), auditory (as in much bird song, or the calls of gibbons) or olfactory, through the deposit of scent marks. Many territorial mammals use scent-marking to signal the boundaries of their territories; the marks may be deposited by urination, by defecation, or by rubbing parts of the bodies that bear specialised scent glands against the substrate. For example, dogs and other canids scent-mark by urination and defecation, while cats scent-mark by rubbing their faces and flanks against objects, as well as by the notoriously persistently smelly spraying of urine by tomcats. Many prosimians use territorial marking; for example, the Red-bellied Lemur creates territories for groups of two to ten individuals in the rainforests of eastern Madagascar by scent marking: the male Diademed Sifaka also scent marks defended territories in some of these same rainforests. The male Western fence lizard defends a territory by posturing and combat, but less intensely after the mating season. Invertebrates which show territorality include some ants and bees, and the owl limpet.

1.3.2.3 Spraying

Spraying (also known as territorial marking) is behaviour used by animals to identify their territory. Most commonly, this is scent marking, accomplished by depositing strong-smelling chemicals such as urine at prominent locations within the territory. Often the scent contains carrier proteins, such as the major urinary proteins, to stabilize the odours and maintain them for longer.

Not only does the marking communicate to others of the same species, but it is also noted by prey species and avoided. For example felids such as leopards and jaguars mark by rubbing themselves against vegetation. Some prosimians, such as the Red-bellied Lemur, also use scent marking to establish a territory. Many ungulates, for example the Blue Wildebeest, use scent marking from two glands, the preorbital gland and a scent gland in the hoof.

Fig 3: A wolf marking its territory.

1.3.2.4 Defence

Territories may be held by an individual, a mated pair, or a group. Territoriality is not a fixed property of a species: for example, robins defend territories as pairs during the breeding season and as individuals during the winter, while some nectarivores defend territories only during the mornings (when plants are richest in nectar). In species that do not form pair bonds, male and female territories are often independent, in the sense that males defend territories only against other males, and females only against other females; in this case, if the species is polygynous, one male territory will probably contain several female territories, while in some polyandrous species such as the Northern Jacana, this situation is reversed.

Quite often territories that only yield a single resource are defended. For example, European Blackbirds may defend feeding territories that are distant from their nest sites, and in some species that form leks, for example the Uganda kob (a grazing antelope), males defend the lek site (which is used only for mating)

Territoriality is only shown by a minority of species. More commonly, an individual or a group of animals will have an area that it habitually uses but does not necessarily defend; this is called its home range. The home ranges of different groups often overlap, and in the overlap areas the groups will tend to avoid each other rather than seeking to expel each other. Within the home range there may be a *core area* that no other individual group uses, but again this is as a result of avoidance rather than defense.

Behavioural ecologists have argued that food distribution determines whether a species will be territorial or not. This however, though true as far as it goes, is too narrow a point of view. As mentioned above, there are several kinds of territoriality; for example, the defence of lek areas by kob has nothing to do with food. Many other examples of territorial defence, including fish, birds or even invertebrates, are related to competition for mates or safe lairs, rather than food. Territoriality will emerge where there is a focused resource that provides enough for the individual or group, within a boundary that is small enough to be defended without the expenditure of too much effort.

Many birds, particularly seabirds, though they nest in dense communities, are none the less territorial in that they defend their nesting site to within the distance that they can reach while brooding. This is necessary to prevent attacks on their own chicks or nesting material from neighbours. Commonly the resulting superimposition of the short-range repulsion onto the long range attraction characteristically leads to the well-known roughly hexagonal spacing of nests. Interestingly, one gets a similar hexagonal spacing resulting from the territorial behaviour of gardening limpets such as species of Scutellastra. They vigorously defend their gardens of particular species of algae,that extend for perhaps 1–2 cm around the periphery of their shells. Territoriality is least likely with insectivorous birds, where the food supply is plentiful but unpredictably distributed. Swifts rarely defend an area larger than the nest. Conversely, other insectivorous birds that occupy more constrained territories, such as the ground-nesting Blacksmith Lapwing may be very territorial, especially in the breeding season, where they not only threaten or attack many kinds of intruders, but have stereotyped display behaviour to deter conspecifics sharing neighbouring nesting spots.

Conversely, large solitary (or paired) carnivores, such as bears and the bigger raptors require an extensive protected area to guarantee their food supply. This territoriality will only break down when there is a glut of food, for example when Grizzly Bears are attracted to migrating salmon.

1.3.2.5 Sunlight

Sunlight, in the broad sense, is the total frequency spectrum of electromagnetic radiation given off by the Sun. On Earth, sunlight is filtered through the Earth's atmosphere, and solar radiation is obvious as daylight when the Sun is above the horizon. Sunlight is a key factor in photosynthesis, a process vital for life on Earth.

Fig 4: Sunlight shining through the large tree in the forest.

Rainforests around the globe have a remarkably consistent pattern of tree sizes. Now researchers have found that the reason for this structure has to do with the competition for sunlight after a large tree falls and leaves an opening in the canopy. In a new study using data from a rainforest in Panama, researchers determined that competition for sunlight is the underlying cause of this common structure, which is observed in rainforests around the globe despite differences in plant species and geography.

After a large tree falls, many small individuals are able to grow due to an increase in available sunlight (T=1). Once they have grown to touch one another (T=2), they begin to overtop one another and leave individuals behind in the understory (T=3). (below)

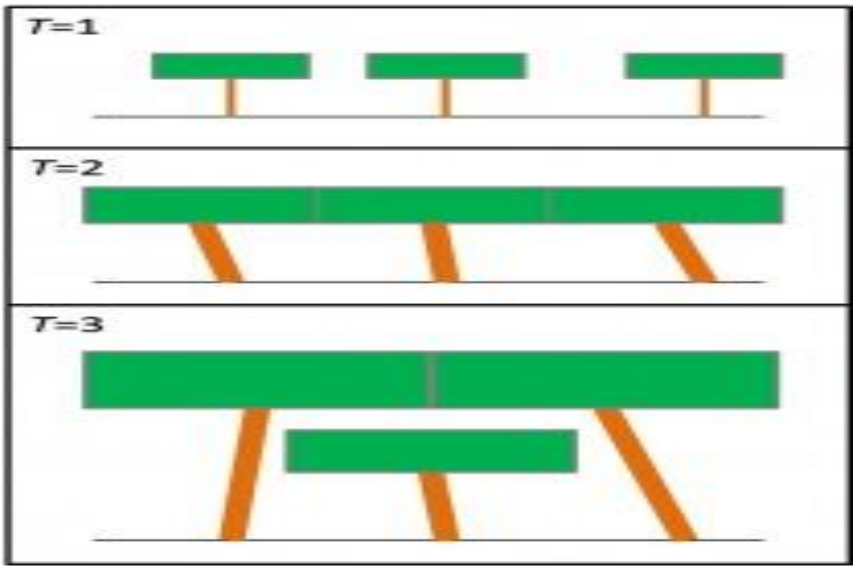

Fig 5: Showing the effects of sunlight of trees in a rainforest

The researchers found that the rainforest structure stems from what happens after a tall tree falls and creates a gap in the canopy. The gap enables sunlight to reach the forest floor and fuel the rapid growth of small trees. Over time, the trees' crowns grow to fill the gap until the point where not all of the trees can fit in the sunlit patch. Some will be left behind in the shade of their competitors.

Also, Sunlight can only filter through the water at about 30 meters or 100 feet below the water's surface. Therefore only the upper layer of the aquatic life zone will support photosynthesis. Sea life that depends on photosynthesis such as algae can only survive at this level. What is Territory? What do you understand by a Territory?

1.3.3 Evolutionary strategies

In evolutionary contexts, competition is related to the concept of r/K selection theory, which relates to the selection of traits which promote success in particular environments. The theory originates from work on island biogeography by the ecologists Robert MacArthur and E. O. Wilson (1967).

In r/K selection theory, selective pressures are hypothesised to drive evolution in one of two stereotyped directions: *r*- or *K*-selection. These terms, r and K, are derived from standard ecological algebra, as illustrated in the simple Verhulst equation of population dynamics:

$$\frac{dN}{dt} = rN\left(1 - \frac{N}{K}\right)$$

where *r* is the growth rate of the population (*N*), and *K* is the carrying capacity of its local environmental setting. Typically, r-selected species exploit empty niches, and produce many offspring, each of whom has a relatively low probability of surviving to adulthood. In contrast, K-selected species are strong competitors in crowded niches, and invest more heavily in much fewer offspring, each of whom has a relatively high probability of surviving to adulthood. Explain the concept of r/K selection theory.

Self-Assessment Exercises 1

Attempt these exercises to measure what you have learnt so far. This should not take you more than 5 minutes.

1. What is Intraspecific competition?
2. What is Exploitation competition?

1.4 Summary

According to the competitive exclusion principle, species less suited to compete for resources should either adapt or die out. According to evolutionary theory, this competition within and between species for resources plays a critical role in natural selection, however, competition may play less of a role than expansion among larger groups such as families.

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1.6 Possible Answers to SAEs

Answers to SAEs 1

1. Intraspecific competition occurs when members of the same species vie for the same resources in an ecosystem. For example, two trees growing close together will compete for light above ground, and water and nutrients in the soil. Therefore, getting less resources, they will usually perform less well than if they grew by themselves. Although in this situation it may actually be more useful to think in terms of resource availability than competition. Adaptations to such an

environment include growing taller, (where the specific prediction provided by the competition model is that all species in such a situation will grow as tall as possible) or developing a larger root system (where the specific prediction is that all species in the system will develop very deep root systems).

2. Exploitation competition Occurs *indirectly* through a common limiting resource which acts as an intermediate. For example, use of resources depletes the amount available to others, or they compete for space. Also known as exploitative competition.

Unit 2: Population Cycle

Contents
2.1 Introduction
2.2 Intended Learning Outcomes (ILOs)
2.3 Population Cycle
2.4 Summary
2.5 References/Further Readings/Web Sources
2.6 Possible Answers to Self-Assessment Exercises

2.1 Introduction

A population is a group of individuals of the same species living and interbreeding within a geographical area. The area that is used to define the population is such that inter-breeding is possible between any pair within the area and more probable than cross-breeding with individuals from other areas. Normally breeding is substantially more common within the area than across the border.

2.2 Intended Learning Outcomes (ILOs)

At the end of this unit, students should be able to define population cycle and List factors that causes or contribute to population cycle

2.3 Population Cycle

A population cycle in zoology is a phenomenon where populations rise and fall over a predictable period of time. There are some species where population numbers have reasonably predictable patterns of change although the full reasons for population cycles is one of the major unsolved ecological problems. There are a number of factors which influence population change such as availability of food, predators, diseases and climate

Olaus Magnus, the Archbishop of Uppsala in central Sweden, identified that species of northern rodents had periodic peaks in population and published two reports on the subject in the middle of the 16th century. In North America, the phenomenon was identified in populations of the snowshoe hare. In 1865, trappers with the Hudson's Bay Company were catching plenty of animals. By 1870, they were catching very few. It was finally identified that the cycle of high and low catches ran over approximately a ten year period.

The most well-known example of creatures which have a population cycle is the lemming. The biologist Charles Elton first identified in 1924 that the lemming had regular cycles of population growth and decline. When their population outgrows the resources of their habitat, lemmings migrate, although contrary to popular myth, they do not jump into the sea.

Lemmings have period population booms and then disperse in all directions, seeking food and shelter their natural habitats cannot provide. The Norway lemming and brown lemming are two of the few vertebrates which reproduce so quickly that their population fluctuations are chaotic, rather than following linear growth to a carrying capacity or regular oscillations. Why lemming populations fluctuate with such great variance roughly every four years, before numbers drop to near extinction, is not known. Lemming behaviour and appearance are markedly different from those of other rodents, which are inconspicuously coloured and try to conceal themselves from their predators. Lemmings, by contrast, are conspicuously coloured and behave aggressively toward predators and even human observers. The lemming defence system is thought to be based on aposematism (warning display). Fluctuations in the lemming population affect the behaviour of predators, and may fuel irruptions of birds of prey such as snowy owls to areas further south. For many years, the population of lemmings was believed to change with the population cycle, but now some evidence suggests their predators' populations, particularly those of the stoat, may be more closely involved in changing the lemming population. While the phenomenon is often associated with rodents, it does occur in other species such as the ruffed grouse. There are other species which have irregular population explosions such as grasshoppers where overpopulation results in locust swarms in Africa and Australia.

There is also an interaction between prey with periodic cycles and predators. As the population expands, there is more food available for predators. As it contracts, there is less food available for predators, putting pressure on their population numbers.
Define Population cycle.

Self-Assessment Exercises 1

Attempt this exercises to measure what you have learnt so far. This should not take you more than 5 minutes. 1. Write on Lemmings as a case study of population cycle?

2.4 Summary

There are some species where population numbers have reasonably predictable patterns of change although the full reasons for population cycles is one of the major unsolved ecological problems.

2.5 References/Further Readings/Web Sources

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2.6 Possible Answers to SAEs

Answers to SAEs 1

1. Lemmings have period population booms and then disperse in all directions, seeking food and shelter their natural habitats cannot provide. The Norway lemming and brown lemming are two of the few vertebrates which reproduce so quickly that their population fluctuations are chaotic, rather than following linear growth to a carrying capacity or regular oscillations. Why lemming populations fluctuate with such great variance roughly every four years, before numbers drop to near extinction, is not known. Lemming behaviour and appearance are markedly different from those of other rodents, which are inconspicuously coloured and try to conceal themselves from their predators. Lemmings, by contrast, are conspicuously coloured and behave aggressively toward predators and even human observers. The lemming defence system is thought to be based on aposematism (warning display). Fluctuations in the lemming population affect the behaviour of predators, and may fuel irruptions of birds of prey such as snowy owls to areas further south. For many years, the population of lemmings was believed to change with the population cycle, but now some evidence suggests their predators' populations, particularly those of the stoat, may be more closely involved in changing the lemming population.

Unit 3: Population Cycles in a Predator-Prey System

Contents

3.1 Introduction
3.2 Intended Learning Outcomes (ILOs)
3.3 Modelling Predator-Prey Interactions
3.4 Evolutionary Dynamics of Predator-Prey Systems: An Ecological Perspective
3.5 Summary
3.6 References/Further Readings/Web Sources
3.7 Possible Answers to Self-Assessment Exercises

3.1 Introduction

There is also an interaction between prey with periodic cycles and predators. As the population expands, there is more food available for predators. As it contracts, there is less food available for predators, putting pressure on their population numbers.

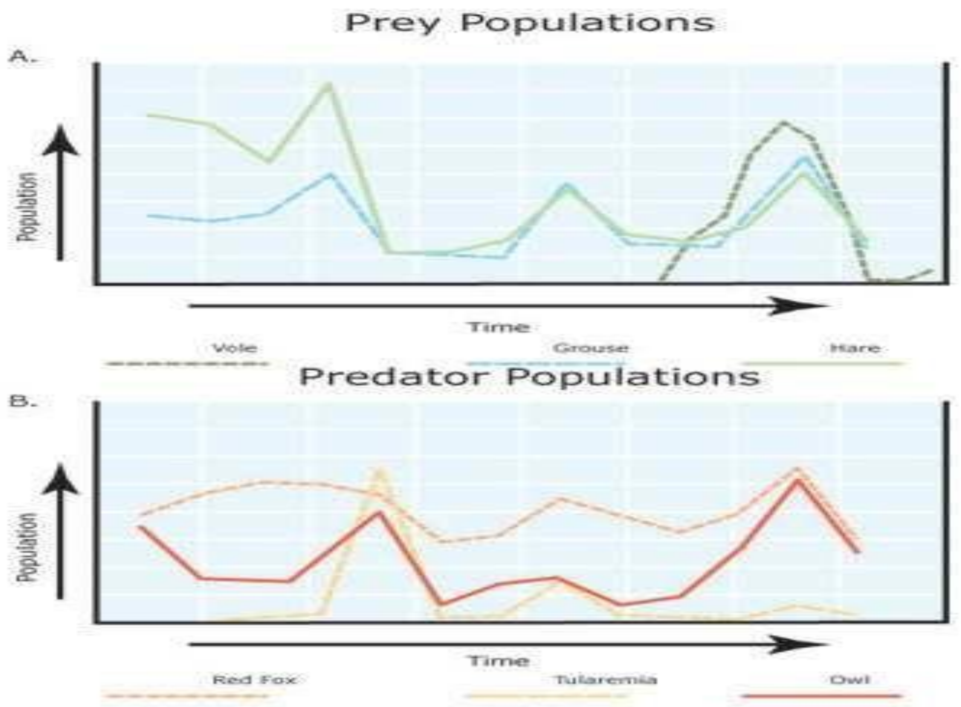

Figure 1: Population cycles in a Swedish forest community (www.encoguru,com)

The top figure (a) shows changes in population size for voles and small game. The striped arrows indicate years in which voles consumed tree bark as a marginal food. The bottom figure (b) illustrates how predator populations change in relation to prey abundance.

Some of the most notable examples of population changes occur in species that experience large, cyclic swings in population size. Quite often, these cycles co-occur with population cycles of other species in the same location. For example, red foxes (*Vulpes vulpes*) in northern Sweden prey on voles, grouse, and hares. Studies of these species have demonstrated linked population cycles in each of the prey species, with population peaks every 3-4 years (Figure 1). What drives these cycles?

Grouse, hares, and voles feed on vegetation, and the availability of their preferred foods will influence the population size of each. The availability of food acts as a bottom-up control that affects population size. In years when their preferred food items are abundant, populations will grow. When preferred foods are scarce, individuals must turn to less desirable foods to prevent starvation. They grow more slowly, reproduce less, and populations decline. When vole populations peak and competition for food is strongest, they turn to bark as a marginal food, and this shift in foraging behaviour coincides with a population decline (Figure 1a). Grouse and hare populations cycle in a manner comparable to those of voles, which suggests that food availability plays a role in regulating populations of these herbivores.

Foxes prefer to consume voles and other small rodents, but will occasionally eat grouse and hares when voles are less abundant. We would expect that the number of foxes in the population would increase as availability of their preferred food increases, and studies have demonstrated that this does, in fact, occur (Figure 1b). Owl populations cycle in a similar manner, closely following the abundance of voles.

As predator populations increase, they put greater strain on the prey populations and act as a top down control, pushing them toward a state of decline. Thus both availability of resources and predation pressure affect the size of prey populations. We cannot easily determine the extent to which each of these controls drives population cycles in the Swedish boreal forest, because this system is not amenable to caging experiments, but studies show that food and predation work together to regulate population sizes.

3.2 Intended Learning Outcomes (ILOs)

At the end of this unit, students should be able to explain Population cycles in animal and predator-prey interaction using Lotka-Volterra models with Vole-fox system

3.3 Modeling Predator-Prey Interactions

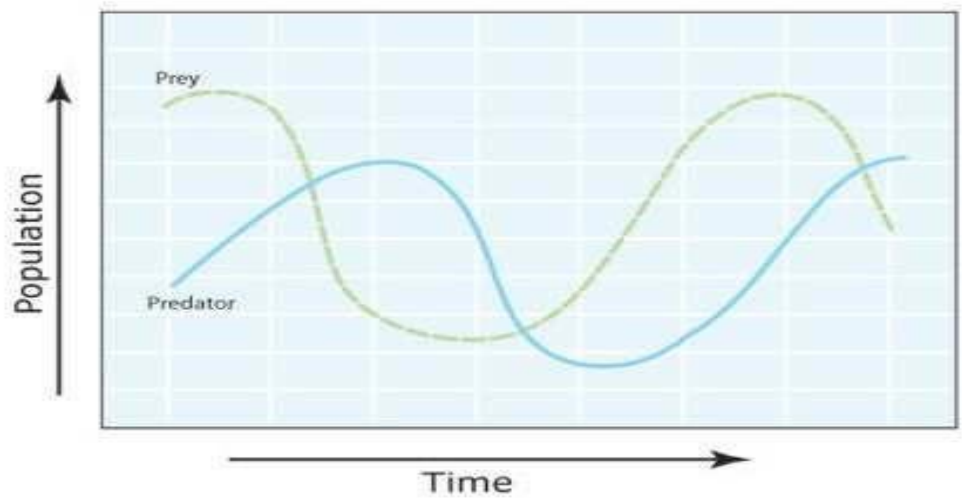

Figure 2: Graphical view of the Lotka-Volterra model (www.encoguru.com)

Predator and prey populations cycle through time, as predators decrease numbers of prey. Lack of food resources in turn decrease predator abundance, and the lack of predation pressure allows prey populations to rebound.

To survive and reproduce, individuals must obtain sufficient food resources while simultaneously avoiding becoming food for a predator. The snowshoe hare study demonstrates the role of both predator avoidance and food availability on population sizes. The trade-off between food intake and predator avoidance is not easily addressed in the field, and ecologists have turned to mathematical models to better understand foraging behaviour and predator-prey dynamics, just as economists and atmospheric scientists do.

Lotka-Volterra models provide a useful tool to help population ecologists understand the factors that influence population dynamics. They have been particularly useful in understanding and predicting predator-prey population cycles. Although the models greatly simplify actual conditions, they demonstrate that under certain circumstances, predator and prey populations can oscillate over time (Figure 2) in a manner similar to that observed in the populations described above.

Few systems oscillate in the cyclical manner of those described thus far. In reality, predator-prey systems are complex; they often involve multiple predators and multiple types of prey. What factors influence the type of prey an individual predator takes? What influences the foraging behaviour of prey species? Under ideal circumstances, an individual will encounter high-quality food items on a regular basis. These preferred foods provide the most nutritional benefit with the fewest costs. Costs for an organism may be handling time (e.g., time required to catch prey or remove a nut from its shell) or presence of chemicals, such as tannins, that reduce the nutritional quality of the food item.

When preferred foods are scarce, organisms must switch to other, less-desirable alternatives. The point at which an organism should make this shift is not easy to predict. It depends upon many factors, including the relative abundance of each of the foods, the potential costs associated with each food, and other factors, such as the risk of exposure to predators while eating.

Consider the vole-fox system described in the first section. Field voles (*Microtus agrestis*) and bank voles (*Clethrionomys glareolus*) preferentially consume forbs and grasses, but they will turn to the bark from trees when their preferred foods become scarce. Bark contains poorer quality nutrients than do grasses and forbs. In addition, voles must venture into the open to approach trees to feed on bark, making them more vulnerable to predation by foxes, which rely on sight to find their prey. Only when the preferred foods are very difficult to find—as occurs during times of population peaks—do voles switch to bark.

3.4 Evolutionary Dynamics of Predator-Prey Systems: An Ecological Perspective

Evolution takes place in an evolutionary setting that typically involves interactions with other organisms. To describe such evolution, a structure is needed which incorporates the simultaneous evolution of interacting species. Here a formal framework for this purpose is suggested, extending from the microscopic interactions between individuals- the immediate cause of natural selection, through the mesoscopic population dynamics responsible for driving the replacement of one mutant phenotype by another, to the macroscopic process of phenotypic evolution arising from many such substitutions. The process of coevolution that results from this is illustrated in the predator-prey systems. With no more than qualitative information about the evolutionary dynamics, some basic properties of predator-prey coevolution become evident. More detailed understanding requires specification of an evolutionary dynamic; two models for this purpose are outlined, one from our own research on a stochastic process of mutation and selection and the other from quantitative genetics. Much of the interest in coevolution has been to characterize the properties of fixed points at which there is no further phenotypic evolution. Stability analysis of the fixed points of evolutionary dynamical systems is reviewed and leads to conclusions about the asymptotic states of evolution rather than different from those of game-theoretic methods. These differences become especially important when evolution involves more than one species.What information does the Lotka-Volterra models provide?

Self-Assessment Exercises 1

Attempt this exercises to measure what you have learnt so far. This should not take you more than 5 minutes. 1. What happen when preferred foods are scarce in Predator-prey relationship?

3.5 Summary

Species interactions occur on many levels, as part of a complex, dynamic system in ecological communities. Predators, prey, plants, and parasites all influence changes in population sizes over time. Simple systems may undergo large, cyclical changes, but communities with more complex food webs are likely to experience more subtle shifts in response to changes in parasite load, predation pressure, and herbivore. Consider, however, that humans have impacted many ecological communities by removing predators or reducing the availability of resources. How will such changes affect population fluctuations in the rest of the community?

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3.7 Possible Answers to SAEs

Answers to SAEs 1

1. When preferred foods are scarce, organisms must switch to other, less-desirable alternatives. The point at which an organism should make this shift is not easy to predict. It depends upon many factors, including the relative abundance of each of the foods, the potential costs associated with each food, and other factors, such as the risk of exposure to predators while eating

Unit 4: Ecology of African Bat

Contents

4.1 Introduction
4.2 Intended Learning Outcomes (ILOs)
4.3 Classification and Evolution of Bat
4.4 Summary
4.5 References/Further Readings/Web Sources
4.6 Possible Answers to Self-Assessment Exercises

4.1 Introduction

Bats are flying mammals in the order Chiroptera. The forelimbs of bats are webbed and developed as wings, making them the only mammals naturally capable of true and sustained flight. By contrast, other mammals said to fly, such as flying squirrels, gliding possums and colugos, glide rather than fly, and can only glide for short distances. Bats do not flap their entire forelimbs, as birds do, but instead flap their spread out digits, which are very long and covered with a thin membrane or patagium. *Chiroptera* comes from two Greek words, *cheir* (χείρ) "hand" and *pteron* (πτερόν) "wing."

There are about 1,100 bat species worldwide, which represent about twenty percent of all classified mammal species. About seventy percent of bats are insectivores. Most of the rest are frugivores, or fruit eaters. A few species such as the Fish-eating Bat feed from animals other than insects, with the vampire bats being the only mammalian parasite species. Bats are present throughout most of the world and perform vital ecological roles such as pollinating flowers and dispersing fruit seeds. Many tropical plant species depend entirely on bats for the distribution of their seeds.

The smallest bat is the Kitti's Hog-nosed Bat, measuring 29–34 mm (1.14–1.34 in) in length, 15 cm (5.91 in) across the wings and 2–2.6 g (0.07–0.09 oz) in mass, The largest species of bat is the Giant Golden-crowned Flying-fox, which is 336–343 mm (13.23–13.50 in) long, has a wingspan of 1.5 m (4 ft 11 in) and weighs approximately 1.1–1.2 kg (2–3 lb).

4.2 Intended Learning Outcomes (ILOs)

At the end of unit, students should be able to explain the classification and evolution of bat and its general characteristics.

4.0 Classification and Evolution of Bat

Bats are mammals. Sometimes they are mistakenly called "flying rodents" or "flying rats", and they can also be mistaken for insects and birds. There are two traditionally recognized suborders of bats:

1. Megachiroptera (megabats)
2. Microchiroptera (microbats / echolocating bats)

Not all megabats are larger than microbats. The major distinctions between the two suborders are:

1. Microbats use echolocation: megabats do not with the exception of *Rousettus* and relatives.
2. Microbats lack the claw at the second toe of the forelimb.
3. The ears of microbats do not close to form a ring: the edges are separated from each other at the base of the ear.

4. Microbats lack underfur: they are either naked or have guard hairs.

Megabats eat fruit, nectar or pollen while most microbats eat insects; others may feed on the blood of animals, small mammals, fish, frogs, fruit, pollen or nectar. Megabats have a well- developed visual cortex and show good visual acuity, while microbats rely on echolocation for navigation and finding prey.

i) Fossil bats

There are few fossilized remains of bats, as they are terrestrial and light-boned. An Eocene bat, *Onychonycteris finneyi*, was found in the fifty-two-million-year-old Green River Formation in South Dakota, United States, in 2004. It had characteristics indicating that it could fly, yet the well-preserved skeleton showed that the cochlea of the inner ear lacked development needed to support the greater hearing abilities of modern bats. This provided evidence that flight in bats developed well before echolocation. The team that found the remains of this species, named *Onychonycteris finneyi*, recognized that it lacked ear and throat features present not only in echolocating bats today, but also in other known prehistoric species. Fossil remains of another Eocene bat, *Icaronycteris*, were found in 1960.

The appearance and flight movement of bats 52.5 million years ago were different from those of bats today. *Onychonycteris* had claws on all five of its fingers, whereas modern bats have at most two claws appearing on two digits of each hand. It also had longer hind legs and shorter forearms, similar to climbing mammals that hang under branches such as sloths and gibbons. This palm-sized bat had broad, short wings suggesting that it could not fly as fast or as far as later bat species. Instead of flapping its wings continuously while flying, *Onychonycteris* likely alternated between flaps and glides while in the air. Such physical characteristics suggest that this bat did not fly as much as modern bats do, rather flying from tree to tree and spending most of its waking day climbing or hanging on the branches of trees.

ii) Habitats

Flight has enabled bats to become one of the most widely distributed groups of mammals. Apart from the Arctic, the Antarctic and a few isolated oceanic islands, bats exists all over the world. Bats are found in almost every habitat available on Earth. Different species select different habitat during different seasons — ranging from sea-sides to mountains and even deserts — but bat habitats have two basic requirements: roosts, where they spend the day or hibernate, and places for foraging. Bat roosts can be found in hollows, crevices, foliage, and even human-made structures; and include "tents" that bats construct by biting leaves.

iii) Echolocation

Bat echolocation is a perceptual system where ultrasonic sounds are emitted specifically to produce echoes. By comparing the outgoing pulse with the returning echoes the brain and auditory nervous system can produce detailed images of the bat's surroundings. This allows bats to detect, localize and even classify their prey in complete darkness. At 130 decibels in intensity, bat calls are some of the most intense airborne animal sounds.

To clearly distinguish returning information, bats must be able to separate their calls from the echoes they receive. Microbats use two distinct approaches.

1. Low Duty Cycle Echolocation: Bats can separate their calls and returning echos by time. Bats that use this approach time their short calls to finish before echoes return. This is important because these bats contract their middle ear muscles when emitting a call so that they can avoid deafening themselves. The time interval between call and echo allows them to relax these muscles so they can clearly hear the returning echo. The delay of the returning echos provide the bat with the ability to estimate range to their prey.

2. High Duty Cycle Echolocation: Bats emit a continuous call and separate pulse and echo in frequency. The ears of these bats are sharply tuned to a specific frequency range. They emit calls outside of this range to avoid self-deafening. They then receive echoes back at the finely tuned frequency range by taking advantage of the Doppler shift of their motion in flight. The Doppler shift of the returning echos yield information relating to the motion and location of the bat's prey. These bats must deal with changes in the Doppler shift due to changes in their flight speed. They have adapted to change their pulse emission frequency in relation to their flight speed so echoes still return in the optimal hearing range.

iv) Behaviour

Most microbats are nocturnal and are active at twilight. A large portion of bats migrate hundreds of kilometres to winter hibernation dens, some pass into torpor in cold weather, rousing and feeding when warm weather allows for insects to be active. Others retreat to caves for winter and hibernate for six months. Bats rarely fly in rain as the rain interferes with their echo location, and they are unable to locate their food.

The social structure of bats varies, with some bats leading a solitary life and others living in caves colonized by more than a million bats. The fission-fusion social structure is seen among several species of bats. The term "fusion" refers to a large numbers of bats that congregate together in one roosting area and "fission" refers to breaking up and the mixing of subgroups, with individual bats switching roosts with others and often ending up in different trees and with different roostmates.

70% of bat species are insectivorous, locating their prey by means of echolocation. Of the remainder, most feed on fruits. Only three species sustain themselves with blood. Some species even prey on vertebrates: these are the leaf-nosed bats (*Phyllostomidae*) of Central America and South America, and the two bulldog bat (*Noctilionidae*) species, which feed on fish. At least two species of bat are known to feed on bats: the Spectral Bat, also known as the American False Vampire bat, and the Ghost Bat of Australia. One species, the Greater Noctule bat, catches and eats small birds in the air. Predators of bats include bat hawks and bat falcons.

v) Reproduction

Most bats have a breeding season, which is in the spring for species living in a temperate climate. Bats may have one to three litters in a season, depending on the species and on environmental conditions such as the availability of food and roost sites. Females generally have one offspring at a time, which could be a result of the mother's need to fly to feed while pregnant. Female bats nurse their youngsters until they are nearly adult size; this is because a young bat cannot forage on its own until its wings are fully developed.

Female bats use a variety of strategies to control the timing of pregnancy and the birth of young, to make delivery coincide with maximum food ability and other ecological factors. Females of some species have delayed fertilization, in which sperm are stored in the reproductive tract for several months after mating. In many such cases, mating occurs in the fall, and fertilization does not occur until the following spring. Other species exhibit delayed implantation, in which the egg is fertilized after mating, but remains free in the reproductive tract until external conditions become favorable for giving birth and caring for the offspring. In yet another strategy, fertilization and implantation both occur but development of the fetus is delayed until favorable conditions prevail. All of these adaptations result in the pup being born during a time of high local production of fruit or insects.

At birth the wings are too small to be used for flight. Young microbats become independent at the age of 6 to 8 weeks, while megabats do not until they are four months old.

A single bat can live over 20 years, but the bat population growth is limited by the slow birth rate.

vi) Feeding

Newborn bats rely on the milk from their mother’s nipples for sustenance. When they are a few weeks old, bats are expected to fly and hunt on their own. It is up to them to find and catch their prey, along with satisfying their thirst. The majority of food consumed by bats includes insects, fruits and flower nectar, vertebrates (fish, frogs, lizards, birds, and sometimes other bats) and blood. Almost three-fourths of the world’s bats are insect eaters. Insects consumed by bats include both aerial insects, and ground-dwelling insects. Each bat is typically able to consume one third of its body weight in insects each night, and several hundred insects in a few hours. This means that a group of one thousand bats could eat four tons of insects each year. If bats were to become extinct, the insect population is calculated to reach an alarmingly high number.

vii) Pathogens and role in the transmission of zoonoses

Among ectoparasites, bats occasionally carry fleas, but are one of the few mammalian orders that cannot host lice (most of the others are water animals).

Bats are natural reservoir for a large number of zoonotic pathogen including rabies, severe acute respiratory syndrome (SARS), Henipavirus (i.e. Nipah virus and Hendra virus) and possibly ebola virus. Their high mobility, broad distribution, and social behaviour (communal roosting, fission-fusion social structure) make bats favourable hosts and vectors of disease. Many species also appear to have a high tolerance for harbouring pathogens and often do not develop disease while infected.

If a bat is found in a house and the possibility of exposure cannot be ruled out, the bat should be sequestered and an animal control officer called immediately, so that the bat can be analysed. This also applies if the bat is found dead. If it is certain that nobody has been exposed to the bat, it should be removed from the house. The best way to do this is to close all the doors and windows to the room except one that opens to the outside. The bat should soon leave.

Due to the risk of rabies and also due to health problems related to their faecal droppings (guano), bats should be excluded from inhabited parts of houses. The Center for Disease Control and Prevention provides full detailed information on all aspects of bat management, including how to capture a bat, what to do in case of exposure, and how to bat-proof a house humanely. In certain countries, it is illegal to handle bats without a license.List the two suborders of bats?

Self-Assessment Exercises 1

Attempt this exercises to measure what you have learnt so far. This should not take you more than 5 minutes.

1. What has made Bat the most successful groups of mammals?
2. What is Bat Echolocation?

4.4 Summary

Bats are flying mammals in the order Chiroptera. There are about 1,100 bat species worldwide, which represent about twenty percent of all classified mammal species. About seventy percent of bats are insectivores. Most of the rest are frugivores, or fruit eaters. Flight has enabled bats to become one of the most widely distributed groups of mammals.

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4.6 Possible Answers to SAEs

Answers to SAEs 1

1. Flight has enabled bats to become one of the most widely distributed groups of mammals. Apart from the Arctic, the Antarctic and a few isolated oceanic islands, bats exists all over the world. Bats are found in almost every habitat available on Earth. Different species select different habitat during different seasons — ranging from sea-sides to mountains and even deserts.

2. Bat echolocation is a perceptual system where ultrasonic sounds are emitted specifically to produce echoes. By comparing the outgoing pulse

with the returning echoes the brain and auditory nervous system can produce detailed images of the bat's surroundings. This allows bats to detect, localize and even classify their prey in complete darkness. At 130 decibels in intensity, bat calls are some of the most intense airborne animal sounds

Unit 5: Behavioural Ecology

Contents

5.1 Introduction
5.2 Intended Learning Outcomes (ILOs)
5.3 Proximate causation and Optimization theory
  5.3.1 Evolutionarily stable strategies (ESS)
  5.3.2 Tinbergen's Four Questions
5.4 Summary
5.5 References/Further Readings/Web Sources
5.6 Possible Answers to Self-Assessment Exercises

5.1 Introduction

Behavioural ecology, or **ethoecology**, is the study of the ecological and evolutionary basis for animal behavior, and the roles of behaviour in enabling an animal to adapt to its environment (both intrinsic and extrinsic). Behavioural ecology emerged from ethology after Niko Tinbergen (a seminal figure in the study of animal behaviour) outlined the four causes of behaviour.

If an organism has a trait which provides them with a selective advantage (i.e. has an adaptive significance) in a new environment natural selection will likely favour it. Adaptive significance therefore refers to the beneficial qualities, in terms of increased survival and reproduction, a trait conveys.

For example, the behaviour of flight has evolved numerous times in reptiles (Pterosaur), birds, many insects and mammals (bats) due to its adaptive significance—for many species, flight has the potential to increase an animal's ability to escape from predators and move swiftly between habitat areas, among other things, thereby increasing the organism's chances of survival and reproduction. In all instances, the organism adapting to flight had to have "pre-adaptions" to these behavioural and anatomical changes. Feathers in birds initially evolving for thermoregulation then turned to flight due to the benefits conveyed (see Origin of avian flight); insect wings evolving from enlarged gill plates used to efficiently "sail" across the water, becoming larger until capable of flight are two good examples of this. At every stage slight improvements mean higher energy acquisition, lower energy expenditure or increased mating opportunities causing the genes that convey these traits to increase within the population. If these organisms did not have the required variation for natural selection to act upon either due to phylogenetic or genetic constraints, these behaviours would not be able to evolve.

However, it is not sufficient to apply these explanations where they seem convenient. Viewing traits and creating unsubstantiated theories or "Just So Stories" as to their adaptive nature have been deeply criticized. Stephen Jay Gould and Richard Lewontin (1979) described this as the "adaptationist programme". To be rigorous, hypotheses regarding adaptations must be theoretically or experimentally tested as with any scientific theory.

The hypothesis of the evolution of insect flight for example has been tested through wing manipulation experiments. Empirical observations which adhere to the conditions prosed also provide evidence. For instance, one can suppose that when birds are not at risk of being eaten they might lose the ability to fly as the construction of functional wings are costly to produce and take away energy which could be used to increase offspring production or survival, a trend many island flightless birds such as the Kakapo, the Penguin and the now extinct Dodo demonstrate in the absence of natural predators.

5.2 Intended Learning Outcomes (ILOs)

At the end of this unit, students should be able to:

- Understand behavioural ecology and the importance of the Tinbergen's Four Questions.
- Explain optimization theory and evolutionarily stable strategies (ESS)

5.3 Proximate causation and Optimization theory

Proximate causation is divided into two factors which are ontogenetic and mechanistic. Ontogenetic factors are the entire sum of experience throughout the lifetime of an individual from embryo to death. Hence, factors included are learning the genetic factors giving rise to behaviour in individuals. Mechanistic factors, as the name implies, are the processes of the body that give rise to behaviour such as the effects of hormones on behaviour and neuronal basis of behaviour.

Behavioural ecology, along with other areas of evolutionary biology, has incorporated a number of techniques which have been borrowed from optimization theory. Optimization is a concept that stipulates strategies that offer the highest return to an animal given all the different factors and constraints facing the animal. One of the simplest ways to arrive at an optimal solution is to do a cost/benefit analysis. By considering the advantages of a behaviour and the costs of a behaviour, it can be seen that if the costs outweigh the benefits then a behaviour will not evolve and vice versa. This is also where the concept of the trade-off becomes important. This is because it rarely pays an animal to invest maximally in any one behaviour. For example, the amount of time an ectothermic animal such as a lizard spends foraging is constrained by its body temperature. The digestive efficiency of the lizard also increases with increases in body temperature. Lizards increase their body temperature by basking in the sun. However, the time spent basking decreases the amount of time available for foraging. Basking also increases the risk of being discovered by a predator. Therefore, the optimal basking time is the outcome of the time necessary to sufficiently warm itself to carry out its activities such as foraging. This example shows how foraging is constrained by the need to bask (intrinsic constraint) and predation pressure (extrinsic constraint).

An often quoted behavioural ecology hypothesis is known as Lack's brood reduction hypothesis (named after David Lack). Lack's hypothesis posits an evolutionary and ecological explanation as to why birds lay a series of eggs with an asynchronous delay leading to nestlings of mixed age and weights. According to Lack, this brood behaviour is an ecological insurance that allows the larger birds to survive in poor years and all birds to survive when food is plentiful.

Ultimately, behaviour is subject to natural selection just as with any other trait. Therefore animals that employ optimal behavioural strategies specific to their environment will generally leave greater numbers of offspring than their suboptimal conspecifics. Animals that leave a greater number of offspring than others of their own species are said to have greater fitness. However, environments change over time. What might be good behaviour today might not be the best behaviour in 10,000 years' time or even 10 years' time. The behaviour of animals has and will continue to change in response to the environment. Behavioural ecology is one of the best ways to study these changes. As geneticist Theodosius Dobzhansky famously wrote, "nothing in biology makes sense except in the light of evolution."

5.3.1 Evolutionarily stable strategies (ESS)

The value of a social behaviour depends in part on the social behaviour of an animal's neighbors. For example, the more likely a rival male is to back down from a threat, the more value a male gets out of making the threat. The more likely, however, that a rival will attack if threatened, the less useful it is to threaten other males. When a population exhibits a number of interacting social behaviours such as this, it can evolve a stable pattern of behaviours known as an evolutionarily stable strategy (or ESS). This term, derived from economic game theory, became prominent after John

Maynard Smith (1982), recognized the possible application of the concept of a Nash equilibrium to model the evolution of behavioural strategies.

In short, evolutionary game theory asserts that only strategies that, when common in the population, cannot be "invaded" by any alternative (mutant) strategy will be an ESSs, and thus maintained in the population. In other words, at equilibrium every player should play the best strategic response to each other. When the game is two player and symmetric each player should play the strategy which is the best response to itself.

Therefore, the ESS is considered to be the evolutionary end point subsequent to the interactions. As the fitness conveyed by a strategy is influenced by what other individuals are doing (the relative frequency of each strategy in the population), behaviour can be governed not only by optimality but the frequencies of strategies adopted by others and are therefore frequency dependent (frequency dependence).Behavioural evolution is therefore influenced by both the physical environment and interactions between other individuals.

5.3.2 Tinbergen's Four Questions

Most behavioural ecologists focus on answering one of the following questions in their studies. They want to know either what is the cause of the behaviour; how did the behaviour develop within the individual's lifetime; what function, or functions, does the behaviour serve; or how did the behaviour evolve? These questions are known as Tinbergen's Four Questions and are named after the behaviourist Niko Tinbergen who developed them.

Question number one deals with both environmental and internal factors that may cause behaviours, such as hormones or infringing on another animal's territory. The answers to question number two may include both genetics and the animal's past experiences, similar to the "nature versus nurture" problem in psychology. Question number three asks how the behaviours will impact the animal immediately and its ability to adapt, such as asking what will happen if an animal's territory is taken by another. Question number four concentrates on how the behaviours originated and how they have changed or will change, such as a horse's flight instinct being exacerbated by modern horse-keeping practices.

There are several reasons to study behavioural ecology. Behavioural ecology can be used as a way to interpret human social problems (several ground-breaking psychological studies were based on observing animal behaviour), applied to the study of neurobiology (neuroethology combines animal behaviour and neuroscience) , find solutions to environmental issues (animal behaviour is indicative of health of the environment), help with animal welfare (behavioural observation is necessary for deciding how to protect endangered species), and bring in new interest in biological sciences (many students find animal behaviour more interesting than other science disciplines). There is also a lot of interest in animal behaviour from the public.

Consider all of the recent documentaries and books that have come out, and the popularity of safari trips.

Dr. Jennifer Borgo, a visiting assistant professor at Coker College in Hartsville, SC, is a wildlife behavioural ecologist who has studied flying squirrels, ducks, woodpeckers, and grouse. She studies ultimate behaviours as opposed to proximate behaviours. Proximate behaviours refer to question one of Tinbergen's Four Questions, and ultimate behaviours refer to question three. Dr. Borgo focuses on interspecific interaction, which she describes as the interactions between members of different species (such as one animal hunting another). What is behavioural ecology? What is Ontogenetic factors?

Self-Assessment Exercises 1

Attempt this exercises to measure what you have learnt so far. This should not take you more than 5 minutes.

1. State Tinbergen's Four Questions?
2. What is Optimization theory?

5.4 Summary

Behavioural ecology emerged from ethology after Niko Tinbergen (a seminal figure in the study of animal behaviour) outlined the four causes of behaviour.

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5.6 Possible Answers to SAEs

Answers to SAEs 1

1. Answer: Most behavioural ecologists focus on answering one of the following questions in their studies. They want to know either what is the cause of the behaviour; how did the behaviour develop within the individual's lifetime; what function, or functions, does the behaviour serve; or how did the behaviour evolve?

2. Optimization is a concept that stipulates strategies that offer the highest return to an animal given all the different factors and constraints facing the animal.

Glossary

°C= degrees Celsius
cm = centimeters
CO_2 = Carbondioxide
CECAF= Fishery Committee for the Eastern Central Atlantic
CH_4 = methane (CH_4)
ft = feets
°F = degree Fahrenheit
Hz = Hertz
in = inches
Ib = pounds
Kgs = kilograms.
km = kilometers
m = meters
mm = millimeters
NaCl= Sodium Chloride
O_2 = Oxygen
oz = ounce
pH = Hydrogen ion concentration
TEDs = turtle exclusion devices
L = length
HIV = Human immunodeficiency virus
% = percentage
g = grams

spp = species

End of the Module Questions

1. What is Apparent Competition?
2. What is Terrestrial animal?
3. What is population cycle?
4. List few characteristic features of African bat?
5. What is behavioural ecology?