Biological systematics or **Biosystematics** is the science through which life forms are discovered, identified, described, named, classified and catalogued, with their diversity, life histories, living habits, roles in an ecosystem, and spatial and geographical distributions recorded. In essence, it is biosystematics, the science that provides indispensable information to support many fields of research and beneficial applied programs. Biosystematics permits basic identification, makes information available, assembles information from a comparative perspective and allows synthesis and generates and stimulates ideas and hypothesis applicable to other fields.

In recent years a taxonomist is not only to describe, identify and arrange organisms in convenient categories but also to understand their evolutionary histories and mechanisms.

Classifications: the grouping of information or objects based on similarities.

Taxonomy: is the science of grouping and naming organisms. Taxonomy, like classification, has also been used to designate the end products of the taxonomic process.

- **Taxonomy** The science which deals with **describing**, **classifying**, and **naming** organisms.

For the identification of an insect for example , any of the six ways may be adopted

1- to get specimen identified by a professional
2- by comparing it with labeled specimens in a collection.
3- by comparing it with images and illustrations.
4- by comparing it with descriptions.
5- by the use of an identification key.
6- by a combination of two or more of these procedures.

Of these, first two methods may not always be available. Similarly, illustrations, etc. may not be included with description of an organism, and the best procedure is to use the suitable key.

The systematics/ taxonomic studies involves a series of characters which can be grouped as:

1- Morphological characters, general external morphology, special structures (e.g. genitalia) internal morphology, embryology, karyology (and other cytological differences).
2- Physiology characters, metabolic factors, serological, protein and other biological differences, body secretions, gene sterility factors.
3- Ecological characters, habitats and hosts.
4- Food, seasonal variations, parasites, host reactions.
5- Ethological characters, courtship and other ethological isolation, other behaviors patterns.
6- Molecular genetic characters, isozymes, nucleic acid sequences, gene expression and regulation.

The information gathered on these aspects provide better basis for understanding an organism and relationship with the environment as well as other organisms.

The Level of Taxonomy are:

α-taxonomy: description of species – 'descriptive taxonomy'

β-taxonomy: classification

γ-taxonomy: study of intraspecific variation

The seven types of activities definition of **taxonomy** consists of:

1. Recognition, description and naming of taxa (species, genera, families etc., also revision of older descriptions) (≈ α-taxonomy).
2. Comparison of taxa, including studies of relationship (phylogeny) (≈ part of β- taxonomy).
3. Classification of taxa (preferably based on phylogenetic analyses) (≈ part of β- taxonomy).
4. Study of (genetic) variation within species (≈ γ-taxonomy)
5. Construction of tools for identification (keys, DNA barcodes).
6. Identification of specimens (referring them to taxa, using the tools).
7. list record of taxa in specific areas or ecosystems (using the tools for identification)

The biological classification may belong to any of the types:

1) **Phenatic classification**: The taxa are classified either on the basis of few characters or overall characteristics, without direct reference to phylogeny.

2) **Natural classification**: The classification is based on the natural characters of taxa. In this system of classification, the organisms are placed into as many as groups and sub groups as are in similarities and dissimilarities.

3) **Cladistic** or **Phylogenetic Classification**: Cladistic classification is exclusively based on phylogenetic branching. It includes an attempt to map the sequence of phyletic branching through a determination of characters that are shared primitive (**plesiomorphic**) and that are shared-derived (**apomorphic**).

4) **Envolutionary classification**: It is based on the evolutionary relationship of organisms, not just their phylogeny. This classification provides foundations of all comparative studies in biology through the degree of genetic similarity existing between organisms and the phylogenetic sequence of events in their history.

Carolus Linnaeus, (1707-1778)

Swedish botanist, developed and published the first comprehensive and consistent classification system for both plants and animals:

Plants**: Species Plantarum 1753**

(described and classified all plants known in his time = 7300 species)

Animals**: Systema Naturae 1758**

The tenth edition of Systema Naturae in 1758 including global fauna. The reason for this is that Linnaeus introduced in this book he developed a method of a two word naming system called **Binomial Nomenclature.**

Binomial Nomenclature (scientific names):

Rules:

1. One binomial name for each species
2. Capitalized Genus, lowercase species.
   Ex: ***Homo sapiens***, ***Tyrannosaurus rex***
3. Constructed according to rules of Latin or Greek grammar
4. Discoverer of species gets naming rights
5. Typed in *italics*, underlined when written

Taxonomic Linnaean Hierarchy

The Linnaean system of classification consists of a hierarchy of graded taxonomic (named) ranks that are called as **taxa**. Any given **taxon** (singular) may contain several lower taxa, which can be usually distinguished based on certain common characteristics. Such lower ranks may in turn be divided into a succession of progressively smaller ranks. The lower the rank of a group, the more similar are the organisms grouped in it. If any two given organisms can be grouped under the same lower rank or taxon, it implies that the two organisms are structurally, functionally, embryologically similar and that they have had a comparable evolutionary history.

Within the living world as a whole, the biggest taxonomic rank is **Kingdom**. Today, many biologists consider Domains to be a classification above Kingdoms. The next higher rank within a kingdom is the **Phylum** or **Division** (in plant). It is customary to use the term phylum for major groups in the animal kingdom and the term division for major groups in the plant kingdom. The phylum or division is a broad grouping of more or less closely related organisms, sharing certain common characteristics.

Each phylum or division has the next taxon called **Class**. The members of each class exhibit certain distinguishing characters that are unique only to them.

In the same way, using comparable criteria of similarities and relationships, each class can be divided into **orders**, each order into **families**, each family into **genera** and each genus into **species**. Species is normally the basic or fundamental unit of classification. A species is therefore the narrowest taxonomic category and kingdom is the broadest category in the Linnaean hierarchy.

Kingdom,
Phylum,
Subphylum,
Class,
Subclass,
Cohort,
Superorder,
Order,
Suborder,
Infraorder,
Superfamily,
Family,
Subfamily,
Tribe,
Genus,
Subgenus,
Species,
Subspecies.

Below is an example of a hierarchial system for the group of animals that includes humans.

Phylum: Chordata (vertebrates + animals with notocords)

Subphylum: Vertebrata (mammals + fish, amphibians, reptiles, Aves)

Class – Mammalia (primates + rodents, ruminants, carnivores)

Order – Primates (great apes + monkeys)

Family –Hominidae

Genus – ***Homo***

Species – ***Homo sapiens***

What is a Species?

Species is generally the lowest taxonomic rank representing organisms that are very much closely related to one another. A species is defined as a group of closely related, structurally and functionally similar organisms which can breed among themselves, producing fertile offspring and which are reproductively isolated from such other groups. The members of a species could be spread over a wide geographical area in which considerable, constant environmental variations occur. Hence, a species is considered to be made up of different populations from different geographical areas and it is such local populations that often become the units of study rather than the entire species.

Definitions of species :

Biological Species Concept: a group of organisms capable of interbreeding and producing fertile offspring.

Typological species concept: A species is a group of organisms conforming to a common morphological plan.

Phylogenetic (Cladistic) species concept: A species is a set of organisms (an evolutionary lineage) between two branch points or between one branch point and an extinction happening or a modern population

Ecological species concept: A species is a set of organisms exploiting (or adapted to) a single niche.

Speciation: The evolutionary process of the origin of a new species.

Sibling Species: (cryptic species) :

Any of two or more related species that are morphologically nearly identical but are incapable of producing fertile hybrids. Sibling species can only be identified by genetic, biochemical, behavioral, or ecological factors, and are thought to have become divergent very recently.

Sympatric species:

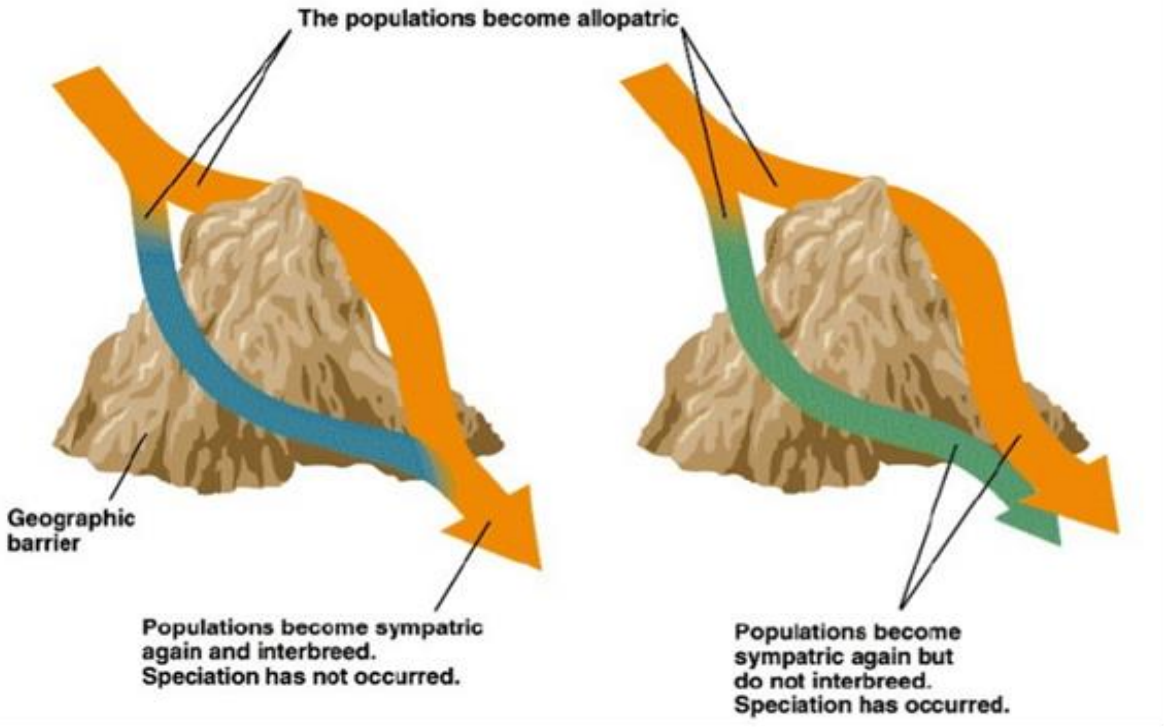
Occupying the same or overlapping geographic areas without interbreeding. Although they share the same geographic range, sympatric populations of related organisms become isolated from each other reproductively. This can happen by the development of subpopulations that become dependent on distinct food sources or that evolve distinct seasonal mating behavior.

sympatric speciation The development of new species as a result of the reproductive isolation of populations that share the same geographic range

allopatric species:

Occurring in separate, nonoverlapping geographic areas. Allopatric populations of related organisms are unable to interbreed because of geographic separation.

allopatric speciation The development of new species as a result of the geographic separation of populations



* Reproductive isolation Mechanisms

expresses the concept that biological factors impede members of two species from producing viable offspring. Reproductive barriers can be classified into two categories,

a- **prezygotic** barriers: Prevent mating from occurring or Prevents gametes from forming a zygote, meaning that they impede mating or hinder fertilization if mating does occur.

b- **postzygotic** barriers: Prevents hybrid zygotes from developing into viable, fertile adults

Prezygotic barriers:

1) **Habitat isolation** - two species that occupy different habitats within the same area may meeting each other rarely, if at all.

Water-dwelling *Thamnophis*

Terrestrial *Thamnophis*

2) **Temporal isolation** - species that breed during different times of the day, different seasons, or different years cannot mate.

Eastern spotted skunk (*Spilogale putorius*)

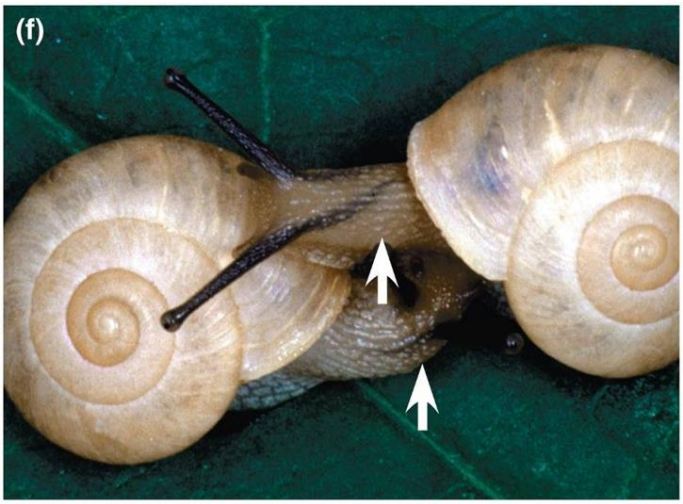
Western spotted skunk (*Spilogale gracilis*)

3) **Behavioral isolation** - certain behavioral patterns that attract mates or that are unique to a particular species are effective reproductive barriers.

Like : Different courtship rituals (Eastern and Western Meadowlarks

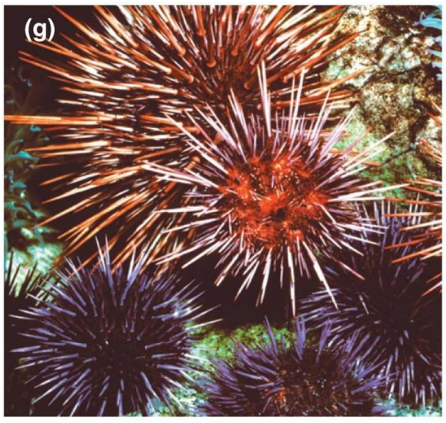
Isolated by Songs) other ex. Blue-Footed Booby

4) **Mechanical isolation** - morphological differences can prevent successful mating.



Bradybaena with shells spiraling in opposite directions

5) **Gametic isolation** - sperm of one species may not be able to fertilize the eggs of another species. Certain biochemical processes may prevent sperm from penetrating the egg of another species, or, the sperm may fail to survive in the reproductive tract of females of another species.
Example: Sea Urchins



Sea urchins

Postzygotic barriers:

1) Reduced hybrid viability - the interaction of genes between members of two different species may delay the ability of the hybrid to develop into a viable adult.

If Sheep and goats mate Hybrid zygotes Die before birth

a- hybrid breakdown, the first-generation of hybrids are fertile. However, when they reproduce (either by mating with one another or with one of their parent species), the next generation's offspring are feeble (weak) and sterile.

b- reduced hybrid fertility: the hybrids are sterile such as that of a cross between a donkey and a horse-a mule. This can happen if the two parent species have chromosomes with different structures because meiosis will fail to produce normal gametes in the hybrids. As a result, when the hybrids mate with either of their parental species, they cannot produce offspring. Thus, genes cannot freely flow between the species as the hybrids are infertile and cannot reproduce.

Types in zoology

In zoological nomenclature, the type of a species (or subspecies) is a specimen (or series of specimens), the type of a genus (or subgenus) is a species, and the type of a suprageneric taxon (e.g., family, etc.) is a genus. Names higher than superfamily rank do not have types. A "name-bearing type" "provides the objective standard of reference whereby the application of the name of a nominal taxon can be determined."

Type species*:*

Each genus must have a designated type species. The description of a genus is usually based primarily on its type species, modified and expanded by the features of other included species. The generic name is permanently associated with the name-bearing type of its type species.

Type genus

A type genus is that genus from which the name of a family or subfamily is formed. As with type species, the type genus is not necessarily the most representative, but is usually the earliest described, largest or best known genus. It is not uncommon for the name of a family to be based upon the name of a type genus that has passed into synonymy; the family name does not need to be changed in such a situation.

Kinds of Types: Holotype, Allotype, Paratype, Syntype and Lectotype

Primary Type: A specimen upon which the description of a new species-group name is based. Including:

Secondary Type (**supplementary type**) Specimen used by an author to supplement to correct knowledge of a previously defined species, including **plesiotype**, **neotype**

Primary Type are:

1- **Holotype** The single type specimen that is the sole representative of a named species-group taxon. Usually designated as such **or** A single specimen designated or indicated as the 'the type" by the original author at the time of the publication of the original description.

2- Allotype: The type specimen of the opposite sex of the holotype.

3- **Paratype:** All specimens other than the holotype upon which a species-group name is based and so designated.

4- **Syntype:** Any specimen upon which the author based the description of a new species-group name without designating a holotype, including specimens at hand.

5- **Lectotype** The after designated type specimen of a species that was originally based on more than one specimen and the author did not designate one of those specimens as a holotype.

Secondary Type are:

1- **Plesiotype:** A specimen used by an author for a redescription, supplementary description, or illustration published subsequent to the original description.

2- **Neotype:** The designated type specimen of a species whose type (holotype, lectotype, neotype) or type series (syntypes) has been shown to be lost or destroyed.

Taxonomic keys or Dichotomous keys

A key is a device, tool or mechanism, which properly constructed and used, enables a user to identify an organism.

Indented Keys: indents the choices (leads) of the couplet un equal distance from the left margin. The two choices of the couplet are usually labeled 1 and 1' or 1a and 1b. It is not necessary that the choices are numbered

Bracketed keys: provides both choices side-by-side. The choices of the couplet must be numbered (or lettered). It is very helpful if the previous couplet is given.

The following examples provide the keys for identification four species of frogs namely

Rana hexadactyla* ; *R. cyanophlictis; R. tigrina* and *R. limnochoris.

The Bracketed key (Genus : Rana)

(1a) Large size, snout - vent 100 – 200 mm …….....3
(1b) Small size, snout - vent less than 100 mm 2
(2a) Pointed snout .....*R. limnochori*
(2b) rarely pointed snout .....*R. hexadactyla*
(3a) tongue longer than others .....*R. tigrina*
(3b) tongue not longer ..... *R. cyanophlictis*.

The Indented key (Genus : Rana)

1a. Large sized body
2a. skin smooth ..... *R.hexadactyla*
2b. skin with folds ..... *R. tigrina*
1b. Small size
3a. blunt snout ..... *R. cyanophlictis*
3b. pointed or round snout ..... *R. limnochoris*

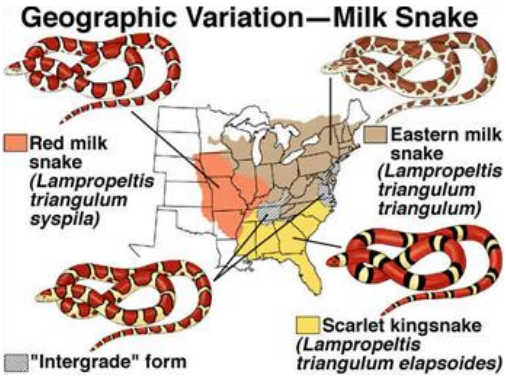
Variation in Taxonomic and Systematic Characters:

There are three major types of character variation within and between species that is typically observed in systematic and taxonomic studies. These include:

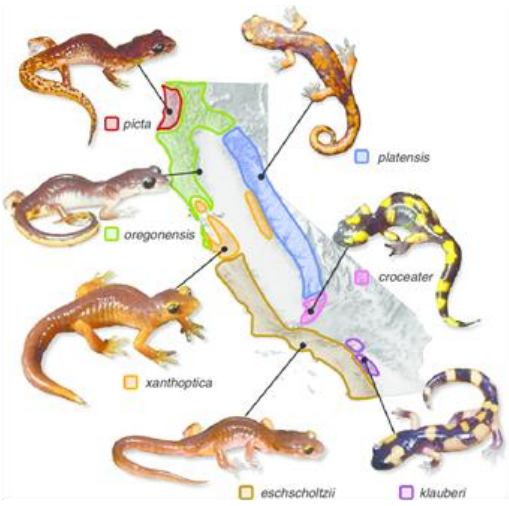
Geographic Variation	Variation in one or more characteristics over space.
Sexual Variation	Variation in one or more traits between or within a sex.
Individual Variation	Variation in one or more characteristics within the lifetime of an individual organism.

1. Geographic Variation

As implied by the name this type of variation occurs over geographic space. This includes, latitudinal, longitudinal, and altitudinal variation of characters.



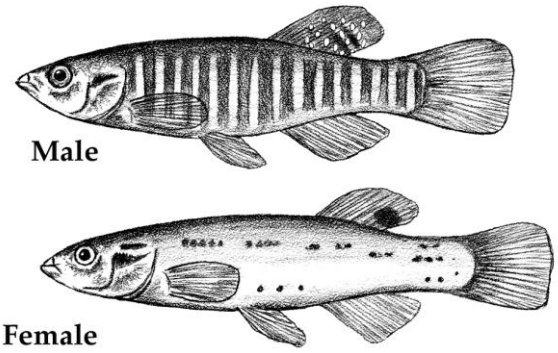
Geographic variation between the variants (subspecies) of buttermilk snake *Lampropeltis triangulum*



Geographic variation among races in the lizard *Ensatina eschscholtzii* ring species in California

2. Sexual Variation

As implied by the name of this type of variation males and females frequently vary from one another for characteristics.

Coloration in Fishes	

3. Individual Variation (Morphological Variation)

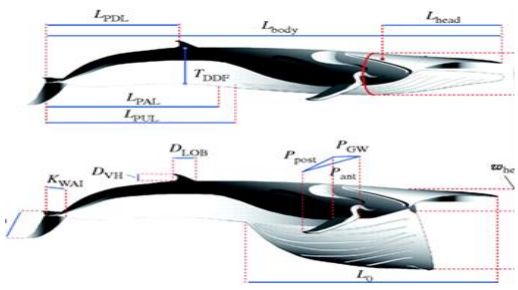
I. Age variations

Common in many groups of organisms to have different looking juveniles or larvae from adults. Many synonyms have resulted from this phenomenon.

For example, Linnaeus described the immature stages of many insects as a different species from adults.

a) Allometric Variation

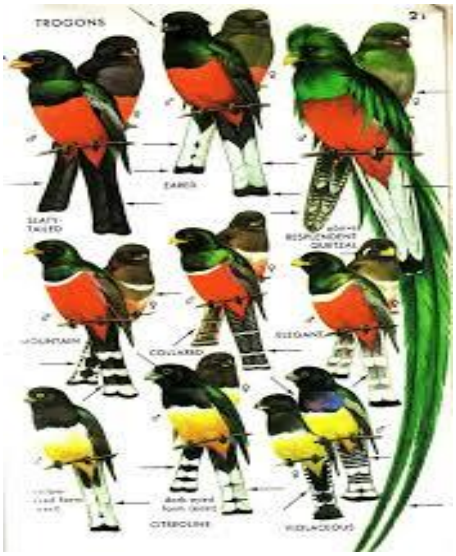
This type of variation is typically thought of as being under genetic control. **Allometric** growth or variation results when the size of some particular structure or number of structures is unequal relative to other structures or the rest of the body.



Allometric growth in Skull and buccal cavity of the Rorqual whales

b) Seasonal Variation in Individuals

In species that survive for more than one year or more than one reproductive season, characteristics may vary depending upon the season. For example, the feather of birds, antlers of some mammals, and general breeding coloration.



II. Social Variation

In some social insects (bees and wasps, termites) certain castes are developed (reproductive, workers, soldiers). The individuals may be males, females or both.

III. Ecological Variation

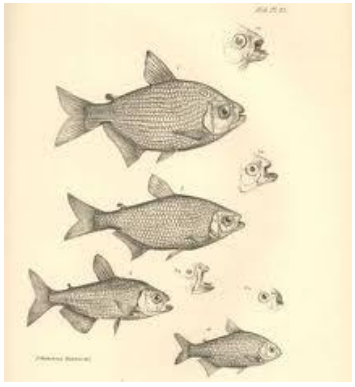
a) Habitat Variation

Populations of a single species may occur in different habitats in the same region and are often visibly different depending upon the habitat that they are found in.

Such as mollusks (snails and mussels). In these species those in the upper parts of rivers where there is cooler water and more flow have different forms from those in lower reaches with higher temperatures and lower flow.

b) Temporary Climatic Conditions

Some species have tremendous phenotypic plasticity and for some traits a different phenotype is produced in years of extreme conditions (drought, cold, warm weather) relative to those from other year classes under normal conditions. Fishes are commonly dwarfed in bad years.



c) Host-Determined Variation

Parasitic species may display different traits dependent upon the host on which they feed. **Cocoons** can vary in color depending upon wasp host. Some wasps may be winged or wingless, depending upon host.

Some hosts may display different characters when parasitized. Color patterns may vary with **fishes** sometimes if they are parasitized (usually this is obvious).

d) Density-Dependent Variation

Crowding can influence morphological variations. This can be a result of reduced food supply or not. Under crowded conditions the phenotypes may vary from those reared under less crowded conditions: This phenomenon is particularly common with locusts.

e) **Neurogenic or Neurohumoral Variation**

Color change in individuals due to regions in environment. Accomplished through the concentration or dispersal of color bearing bodies known as chromatophores. This has been observed in chameleons, some lower vertebrates, crustaceans, cephalopods, and flat fishes.

IV. Traumatic Variation

This type of variation occurs with varying frequency depending on the group. It is usually clear, but in some cases may be indirect and misleading.

a) **Parasite individual variation**

Typical patterns discovered in a host individual will include swelling, distortion, and perhaps mechanical injury.

- With insects parasites can alter head size, wing venation, and other structural features.

- Parasitized fishes may appear pale and soft, have darks spots on the body, have weak fin rays.

b) **Teratological or accidental**

Alterations in development. Usually these are externally induced but can be developmental and may be from hormonal control.

c) **Post-mortem Changes**

Common in some museum specimens that have been fixed or preserved or pinned. Colors are often lost or fade.

Genetic Variation

In addition to this non-inherited variation, there is much interpopulational variation which is primarily due to differences in genetic constitution. This variation can be more or less arbitrarily divided into two such classes:

I) Sex-Associated Variation

Among the genetically determined variants within a population, there may be some that are sexually associated. They may be sex-linked (expressed in one sex only) or be otherwise associated with one or the other sex.

a) **Primary sex differences -** Those that involve primary sex organs used in reproduction (gonads, genitalia). Where the sexes are otherwise quite similar, these will rarely be a source of taxonomic confusion.

b) **Secondary sex differences -** Many groups display pronounced sexual dimorphism. These differences can be quite prominent. Different sexes have frequently been described as different species until more work has been done on a group.

c) **Alteration of Generations -** In some groups there may be an agamic stage that looks quite different from a reproducing stage. In aphids the parthenogenetic females are wingless whereas the sexual females have wings.

d) **Gynandromorphs and Intersexes-**

Gynandromorphs display male characters on one part of the body and female on the other. Due to unequal somatic distribution of sex chromosomes. Spiders and butterfly.

Intersexes - exhibit a blending of male and female traits. Thought to result from upset in balance of male tendency and female tendency genes.

II. Non-Sex Associated Individual Variation

a) **Continuous Variation -** Most common type of variation due to slight genetic differences which exist between individuals. No two individuals are exactly alike in a population genetically or morphologically.

b) ***Discontinuous Variation*** **-** Differences between individuals in a population are, in general, slight and intergrading. In some species, however, can be grouped into different classes determined by some characters.

e.x. many **bird species** have been proposed to demonstrate this type of polymorphic variation within populations for morphological characteristics.

e.x. some **butterflies** which mimic poisonous species may have more than one morphotype in a population.