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BIOLOGICAL INTERACTION IN ECOLOGY

Biological interactions, also termed as **species interaction**, are the interactions between organisms in an ecological community, which is defined as an assemblage of populations of at least two different species that interact directly and indirectly within a defined geographic area. In a natural habitat, no organism exists in absolute isolation or alone, and thus every organism interacts with the environment and other organisms. It is said that this interaction between the organisms and its environment is the fundamental to the survival of that organism as well as balanced functioning of an ecosystem. Thus, species interactions form the basis for many ecosystem properties and processes such as nutrient cycling and food webs. Therefore, species interactions in the ecology are the relationships between two species each other in an ecosystem, which can be either of intraspecific interactions or interspecific interactions. **Intraspecific interactions** are those that occur between individuals of the same species, while interactions that occur between two or more species are called **interspecific interactions**. However, since most species occur within ecological communities, these interactions can be affected by, and indirectly influence, other species and their interactions. The most studied species interactions include **competition, predation, herbivory and symbiosis**. However, many more other types of species interactions also exist in nature.

The interactions between the species are meant to facilitate the movement of energy from one trophic level to another. However, the nature of these interactions greatly depends on the environmental conditions in which they occur and are linked to their evolutionary context. Depending upon the nature of effect of interactions, various categories of the effects of a change in abundance, or presence vs. absence of one species on another have been carried out, which are as follows;

- *Direct effects* refer to the impact of the presence (or change in abundance) of species A on species B in a two-species interaction.
- *Indirect effects* refer to the impact of the presence (or change in abundance) of species A on species C via an intermediary species (A → B → C).
- *Cascading effects* are those which extend across three or more trophic levels, and can be top-down (predator → herbivore → plant) or bottom-up (plant → herbivore → predator).
- *Keystone species* are those which produce strong indirect effects.

Keynote species: In nature there are big players and little players. The biggest players of all are referred to as keystone species. This is a species whose presence or absence, or substantial increase or decrease in abundance, profoundly affects other species in the community. Evidence usually comes from experiments in which one species is added to or removed from a community. The name derives from the center stone in an arch supporting its weight by inward-leaning stones. Removal of the keystone causes the balancing arch to collapse.

The example can be derived from the rocky inter-tidal zone of Washington state where starfishes have been shown to be a keystone species. The entire community lives on relatively vertical rock faces in the wave-swept inter-tidal zone in which the community of marine invertebrates and algae are adapted to cling or adhere to the rock face. These marine invertebrates, which is a bivalve mussel *Mytilus* (competitive dominant), fed upon the zooplankton coming through the tides and these mussels are fed upon by a starfish *Picaster* (predator) making space available for other species, and consequently is critical to maintaining a diverse biological community.

The interactions between the organisms are classified differently on different basis, such as classification of interactions on the basis of effect and classification of interactions on the basis of mechanism.

Types of interaction of organisms on the basis of effect

These types of classification of interactions among the organisms are based on the quality of benefit or harm in terms of fitness experienced by participants in an interaction. There are six possible combinations, ranging from mutually beneficial through neutral to mutually harmful interactions. The level of benefit or harm is continuous and not discrete, such that an interaction may be trivially harmful to deadly. It is important to note that these interactions are not always static. In many cases, two species interacts differently under different conditions. These interactions can be understood as follows;

Neutralism

It is the most common type of interaction in which neither population affects the other. In other words, it is the relationship between two species which interact but do not affect each other. It describes interactions where the fitness of one species has absolutely no effect whatsoever on that of the other. True neutralism is extremely unlikely or even impossible to prove. When dealing with the complex networks of interactions presented by ecosystems, one cannot say positively that there is absolutely no competition between the organisms or no benefit to either organism. Since true neutralism is rare or nonexistent, its usage is often extended to situations where interactions are merely insignificant or negligible. Example can be given by the existence of tarantula and cacti in dessert.

Amensalism

It is the relationship between two species in which one impedes or restricts the success of the other while the other species has no effect on it. It is a type of symbiosis. Usually this occurs when one organism exudes a chemical compound as part of its normal metabolism that is detrimental to another organism.

Example of this relationship is given by bread mold *Penicillium*, which secretes penicillin, a chemical that kills bacteria. A second example is the black walnut tree (*Juglans nigra*), which secrete **juglone**, a chemical that harms or kills some species of neighboring plants, from its roots. This interaction may still increase the fitness of the non-harmed organism though, by removing competition and allowing it access to greater scarce resources. In this sense the impeding organism can be said to be negatively affected by the other's very existence, making it a +/- interaction. A third simple example is when sheep or cattle make trails in grass that they trample on, and without realizing, they are killing the grass.

It is the contrast of commensalism and goes in line with antibiosis or allelopathy.

Competitions

It is generally based on common resource that is in limited supply, in which two organisms vie or compete eagerly each other in order to do or achieve something. More generally, it can be defined as the direct or indirect interaction of organisms that leads to a change in fitness when the organisms share the same resource. The outcome usually has negative effects on the weaker competitors. Therefore, competition is a mutually detrimental interaction between individuals, populations or species, but rarely between clades[1]. In extreme cases, such as in **synnecrosis**, interaction is so mutually detrimental that it results in death, as in the case of some parasitic relationship. Synnecrosis is a rare and necessarily short lived condition as evolution against it.

There are three major forms of competition, namely interference competition, exploitation completion, and apparent competition. Two of them, **interference competition** and **exploitative competition**, are categorized as real competition, while third form, **apparent competition**, is not considered as real competition. Interference competition occurs directly between individuals, while exploitation competition and apparent competition occur indirectly between individuals. These competitive interactions between the organisms can be outlined as follows;

Type of interaction	Effect on X	Effect on Y
Neutralism	*0*	*0*
Amensalism	-	*0*
Commensalism	+	*0*
Competition	-	-
Mutualism	+	+
Predation or Parasitism	+	-

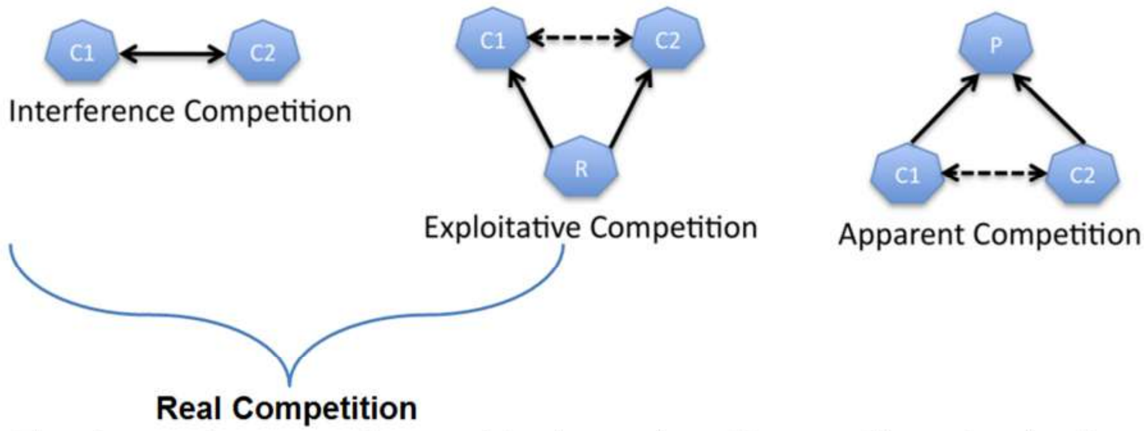
Some types of relationships listed by the effect they have on each partner. '0' is no effect, '-' is detrimental, and '+' is beneficial. *Source: Wikia.org*

Interference competition: This type of competition between organisms involves direct interaction by fighting for scarce resources. This applies to both intraspecific and interspecific competition. In ***intraspecific competition***, the competing organisms are of the same species, such as large aphids defend feeding sites on cottonwood leaves by kicking and shoving smaller aphids from better sites, and male deer lock horns when competing with other individual of the same species. All these competing organisms of same species vie for same resources such as territory, mater, food, etc. In ***interspecific competition***, the opposing organisms are of different species, such as the rivalry between a lion and a tiger competing for the same prey.

Exploitative competition: This type of interaction between organisms involves indirect interaction but in spite of that resulting in the depletion of the amount of resources thereby limiting the availability of these resources for other organisms. Similar to interference competition, the exploitation competition applies to both intraspecific and interspecific competition. In ***intraspecific competition***, the competing organisms are of the same species. They vie for same resources such as territory, mate, food, etc. An indirect type of competition between the same species is exhibited by bears that vie for food in the same area. The bear that catches fish in the river means that the fish would no longer be available for the other bears along

[1] A group of organisms believed to comprise all the evolutionary descendants of a common ancestor e.g. the great ape and human clade.

the same river at different points. In this one, there is no direct interaction but there is still a competition among them for food. In ***interspecific competition***, the opposing organisms are of different species. An example is the competition for light between tall trees and smaller plants in the same ecological area in the forest.



The three major types of competitive interactions: Diagrams illustrating the three major types of competitive interactions where the dashed lines indicate indirect interactions and the solid lines indicate direct interactions that are part of ecological communities. C1 = Competitor #1, C2 = Competitor #2, P = Predator, R = Resource.

Apparent competition: This is a form of competition between species or group of organisms indirectly competing for resources that affect each other indirectly by being prey for the same predator, for example, a hawk that preys both on squirrels and mice. In this relationship, if the squirrel population increases, then the mouse population may be positively affected since more squirrels will be available as prey for the hawks. However, an increased squirrel population may eventually lead to a higher population of hawks requiring more prey, thus, negatively affecting the mice through increased predation pressure as the squirrel population declines. The opposite effect could also occur through a decrease in food resources for the predator. If the squirrel population decreases, it can indirectly lead to a reduction in the mouse population since they will be the more abundant food source for the hawks. Apparent competition can be difficult to identify in nature, often because of the complexity of indirect interactions that involve multiple species and changing environmental conditions.

Whether by interference or exploitation, over time a superior competitor can eliminate an inferior one from the area, resulting in **competitive exclusion** which is usually avoided by adopting alternative life history and dispersal strategies that reduces competitive interactions and increase opportunities for new colonization and nutrient acquisition. The success of this dispersal is sometimes dependent on some natural events such as tide, flood, or fire disturbances. If the disturbance is too frequent the inferior competitor wins, but if the disturbance is rare then the superior competitor slowly outcompetes the inferior competitor, resulting in competitive exclusion. This is known as the **intermediate disturbance hypothesis**. Usually, Lotka – Volterra model is used to predict the outcomes of competition between two species, which is given by Volterra 1926, Lotka 1932. This model relates the population density and carrying capacity of two species to each other and includes their overall effect on each other.

Antagonism

In antagonistic interactions, one species benefits at the expense of another. This relationship is better exhibited in predator – prey relationship, where one organism becomes a prey of other organism, named as predator; in other words, one organism that acts as predator captures biomass of another organism that is prey. It is generally used as a synonym for carnivory, but it is exhibited by all organisms eating another, regardless of trophic level like herbivory, closeness of association like parasitism and **parasitoidism**[2], and harm done to prey e.g. grazing. Other interactions that cannot be classified as predation however are still possible, such as **Batesian mimicry**, where an organism bears a superficial similarity of at least one short, such as a harmless plant coming to mimic a poisonous one. **Intraguild predation** occurs when an organism preys upon another of different species but at the same trophic level e.g. coyotes kill and ingest gray foxes in southern California.

Ecological felicitation

It is type of relationship between the organisms in which at least one organism is benefited and resulted in no harm to either. Facilitative interactions can be categorized as mutualisms, in which both species benefit, or commensalisms, in which one species benefits and the other is unaffected. The both type of interactions are dealt as follows;

Mutualism

It is an interspecific interaction between two or more species that benefits both members (mutual benefits). Basically it is a symbiotic interaction, in which, populations of each species grow, survive and/or reproduce at a higher rate in the presence of the other species consequently resulting in increased carrying capacity. It is widespread in nature, and occur among many different types of organisms. Mutualism can be considered as **obligate** or **facultative**. Species involved in obligate mutualism cannot survive without the relationship, while facultative mutualistic species can survive individually when separated but often not as well. For example, leafcutter ants and certain fungi have an obligate mutualistic relationship. The ant larvae eat only one kind of fungi, and the fungi cannot survive without the constant care of the ants. As a result, the colonies activities revolve around cultivating the fungi. They provide it with digested leaf material, can sense if a leaf species is harmful to the fungi, and keep it free from pests. A good example of a facultative mutualistic relationship is found between mycorrhizal fungi and plant roots. It has been suggested that 80% of vascular plants form relationships with mycorrhizal fungi (Deacon 2006). Yet the relationship can turn parasitic when the environment of the fungi is nutrient rich, because the plant no longer provides a benefit (Johnson *et al*. 1997). Thus, the

[2] It is a form of parasitism wherein an organism called as parasitoid lives on or inside the host at one phase in its life cycle, and usually ends up in the death of the host. An example is a wasp which deposits eggs into the body of an alfalfa aphid; the larvae after being released from the eggs, feed on the tissue of aphid till the larval stage completes.

nature of the interactions between two species is often relative to the abiotic conditions and not always easily identified in nature.

Leaf cutter ants carrying pieces of leaves back to the colony where the leaves will be used to grow a fungus that is then used as food. The ants will make "trails" to an acceptable leaf source to harvest it rapidly.

A mutualism between certain ants and acacia, provides an excellent example of an obligate mutualism.
The acacia provides a number of benefits to the ants, including shelter (hollow thorns), protein (beltian bodies at tip of leaflets), nectar (secreted near base of leaves). The ant (*Pseudomyrmex*) provides several forms of protection. It attacks and removes herbivorous insects, It also removes vines that might overgrow the acacia, and kills the growing shoots of nearby plants that might become competitors. It clears away leaf litter from near the plant, and since the acacia grows in a seasonally dry environment where it occasionally is threatened by fire, the ant's activities protect the tree from fire damage as well. ***Source: https://globalchange.umich.edu/globalchange1/current/lectures/ecol_com/ecol_com.html#:~:text=Summary,can%20have%20far%2Dreaching%20effects.***

Commensalism

It is an interaction between the two organisms in which one individual benefits while the other is neither benefited nor harmed. A good example is the association of remora with a shark, where remora eats left over food from the shark and shark is not affected in the process. Another example is the growing of orchids (an example of epiphytes) on the branches of trees in tropical forests in which growing of orchids on the branches in order to access light, but the presence of the orchids does not affect the trees. Sometimes, commensalism can be difficult to identify because the individual that benefits may have indirect effects on the other individual that are not readily noticeable or detectable. If the orchid from the previous example grew too large and broke off the branch or shaded the tree, then the relationship would become parasitic.

<u>Types of interaction of organisms on the basis of mechanism</u>

This group of interaction includes symbiosis and competition, which are as follows;

Symbiosis

It is an interaction characterized by two or more species living purposefully in direct contact with each other. The term symbiosis (Greek: living together) can be used to describe degrees of close relationship between organisms of different species. Sometimes it is used only for cases where both organisms benefit, sometimes it is used more generally to describe all varieties of relatively tight relationships, i.e. even parasitism, but not predation. Some even go so far as to use it to describe predation. It can be used to describe relationships where one organism lives on or in another, or it can be used to describe cases where organisms are related by mutual stereotypic behaviors.

Common Clownfish (*Amphiprion ocellaris*) in their Ritteri sea anemone (*Heteractis magnifica*) home. Both the fish and anemone benefit from this relationship, a case of mutualistic symbiosis.

In either case, symbiosis is much more common in the living world and much more important than is generally assumed. Almost every organism has many internal parasites. A large percentage of herbivores have mutualistic gut fauna that help them digest plant matter, which is more difficult to digest than animal prey. Coral reefs are the result of mutalisms between coral organisms and various types of algae that live inside them. Most land plants and thus, one might say, the very existence of land ecosystems rely on mutualisms between the plants which fix carbon from the air, and Mycorrhyzal fungi which help in extracting minerals from the ground. The evolution of all eukaryotes (plants, animals, fungi, protists) is believed to have resulted from a symbiosis between various sorts of bacteria: endosymbiotic theory.

Competition

As described above, competition is a mutually detrimental between individuals, populations or species, but rarely between clades. Synnecrosis is a particular case in which the interaction is so mutually detrimental that it results in death, as in the case of some parasitic relationships. It is a rare and necessarily short-lived condition as evolution selects against it, and therefore the term is seldom used. Bees and its prey is one of the fine examples of synnecrosis where bees die after stinging to protect the hive, inflicting pain to the prey.

Types of interaction of organisms on the basis of nature of association

All species need to interact with both the abiotic and biotic factors in order to survive and flourish; they can't live in total isolation in nature. The association of species with the biotic factors of amongst the species or population is either beneficial or detrimental. Therefore, the interaction between the two or three species can be grouped on the basis of nature of association into two types, namely positive association and negative association.

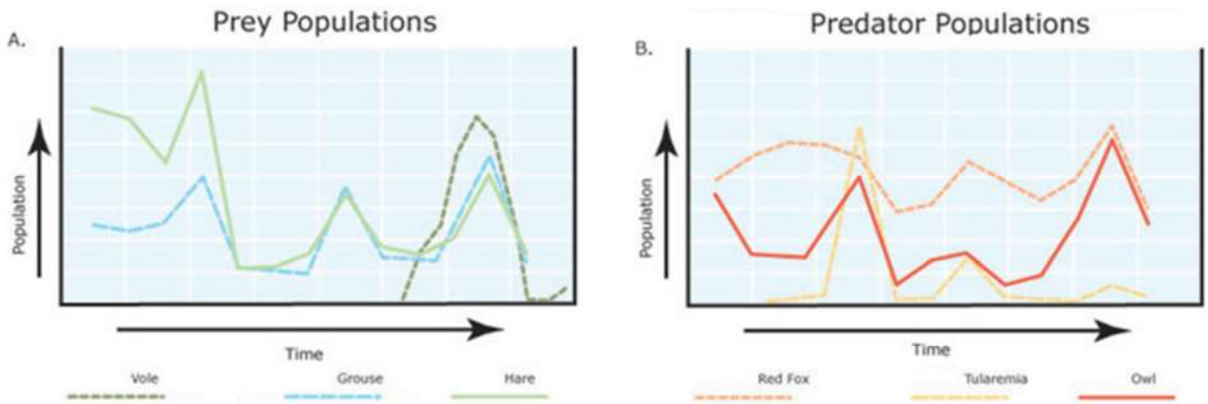
Positive association

If two species interact directly within a shared environment, they sustain their life as co-existence, which is known as positive association. The positive association between the species can be understood by studying predator – prey relationship and symbiotic relationship between the species.

Predator – prey relationship

Predation is a biological interaction whereby one organism hunt and feeds on another organism. The organism which hunt on other organism is known as **predator** and the organisms which are being hunted are known as **prey**. Because the predator relies on the prey as a food source, their population levels are inextricably intertwined. If the prey population drops (due to over-feeding), predator number decreases as intra-specific competition increases. If the prey population rises, predator number increases as a result of the overabundance of a food source. Ecologists have long wondered about the factors that regulate such fluctuations, and early research suggested that resource availability plays an important role. Researchers found that when resources (food, nesting sites, or refuges) were limited, populations would decline as individuals competed for access to the limiting resources. Such bottom-up control helped to regulate the population around carrying capacity. More recently, scientists have discovered that predation can also influence the size of the prey population by acting as a top-down control. In reality, the interaction between these two forms of population control work together to drive changes in populations over time. Additional factors, such as parasites and disease can further influence population dynamics.

Population cycles in predator – prey system: Some of the species living in same location experiences large cyclic swings in population size due to several factors, which affects predator – prey interaction. 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 as evident from figure given below. 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 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 behavior coincides with a population decline (Figure 1.A.). 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.

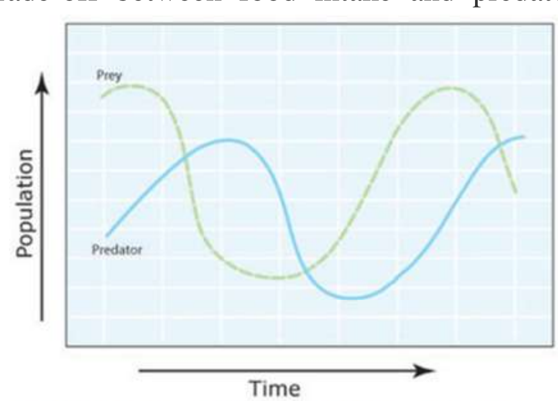


Population cycles in a Swedish forest community
The top figure (a) shows changes in population size for voles and small game. The striped arrows indicate years in which voles consumed tree bark as a marginal food. The bottom figure (b) illustrates how predator populations change in relation to prey abundance.

Source: https://www.nature.com/scitable/knowledge/library/dynamics-of-predation-13229468/

Foxes prefer to consume voles and other small rodents, but will occasionally eat grouse and hares when voles are less abundant, and consequently, the fox population also increases (Figure 1. B.). Owl populations cycle in a similar manner, closely following the abundance of voles. Thus, as populations of predator increase, they put greater strain on the prey populations and acts as a top down control, pushing them toward a state of decline. In this manner, predation, along with availability of food, also responsible for regulating population sizes (of both prey & predator).

Modeling of predator – prey relationship: For the survival and reproduction of species, they need to obtain sufficient food resources while simultaneously avoiding becoming a food itself for a predator. Experimental study on predator – prey relationship performed by Charles J. Krebs and colleagues on the influence of food abundance and predation on snowshoe hare (*Lepus americanus*) populations in Canada. This 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 behavior and predator-prey dynamics, just as economists and atmospheric scientists do.



Graphical view of the Lotka-Volterra model
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.

With this respect, 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 in a manner similar to that observed in the populations described above (as seen in figure).

Symbiotic relationship

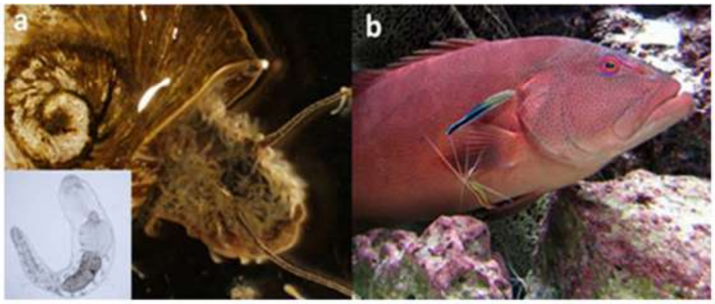
As also mentioned above, the symbiosis describes the close and persistent (long-term) interaction between two species. The term is derived from two greek/latin words; ‘sym’ which has meaning ‘with’ and ‘bio’ which has meaning ‘to live’ or ‘living’. Therefore, it refers a relationship where two organisms live together in which at least one organism benefits from the relationship. It may be obligate symbiosis i.e. symbiotic relationship which is required for survival, or facultative symbiosis i.e. symbiotic relationship which advantageous but not necessary. This type relationship includes mutualism, commensalism, and parasitism. We have already discussed mutualism and commensalism; therefore we need to discuss only parasitic relationship in this section.

Parasitism: It is a type of relationship between the two organisms in which one organism benefits to the detriment of the other species. The organism which detriments other organism and is itself benefited, is known as **parasite**. They may be of two types; macroparasites and microparasites.

- *Macroparasites:* Those parasites which do not multiply within their definitive host, cycling instead through transmission stages (e.g. eggs and larvae) and pass to the outside, such as helminthes, arthropods, etc. These are multicellular, eukaryotic organisms that are large enough to be seen with the naked eye; hence it is called as macraoparasites. It includes parasitoid also.
- *Microparasites:* Those parasites which multiply within their definitive host. These are smaller than other parasites and short-lived such as viruses, bacteria, fungi and protozoa.

It has been thought that most mutual interactions evolved from originally parasitic interactions (presence of mitochondria in animals and chloroplast in plants). Many parastites live their lives secretively, in intimate contact with their host, but invisible to the outside world. With some notable exceptions (e.g., tapeworms), parasites also tend to be very small. It may be easy to assume then, that since parasites are generally inconspicuous, they play less important roles in community ecology than free-living organisms. Yet advances in the field of disease ecology have revealed that parasites are not only ecologically important, but can sometimes exert influences that equal or surpass those of free-living species in shaping community structure. In fact parasitism is more common than traditional predation as a consumer lifestyle (De Meeûs & Renaud 2002), and arguably represents the most widespread life-history strategy in nature (Price 1980). Parasites also influence host behavior and fitness, and can regulate host population sizes, sometimes with profound effects on trophic interactions, food webs, competition, biodiversity and keystone species. These interactions suggest that parasites are integral components in shaping community- and ecosystem structure.

Parasites can function as both predators and prey. Parasites that feed on hosts engage in a special type of predation. Alternatively, parasites can also serve as important sources of prey such as oligochaete worms (see figure below). For example, predators on islands in the Gulf of California, including lizards, scorpions and spiders, are one- to two orders of magnitude more abundant on islands with sea bird colonies because they feed on bird ectoparasites. Predators also inadvertently consume parasites during the consumption of infected. When macroparasites are relatively large, such as nematodes in the gut of vertebrate hosts, the contributions of parasites to the diet of predators can be significant. The roles of parasites as predators and prey suggest that considerable amounts of energy may directly flow through parasites in food webs, despite their small size and cryptic nature.



Parasites as prey: (A) Oligochaete worms (Chaetogaster sp., see lower-left inset) feed on trematode parasites that emerge from an infected freshwater snail host. (B) Cleaner wrasse (Labroides dimidiatus) and cleaner shrimp (Lysamata sp.) removing ectoparasites from a coral trout. Parasites may be an important food resource to predators, especially in ecosystems where parasites are highly productive.

Pacific chorus frog (Pseudacris regilla) that has three extra hindlimbs due to infection with a trematode parasite (Ribeiroia ondatrae): Limb deformities reduce the frog's ability to evade predators, possibly making it more susceptible to being eaten by the definitive host of the trematode

Source: https://www.nature.com/scitable/knowledge/library/ecological-consequences-of-parasitism-13255694//

In some cases, predation can serve as a vehicle of transmission, allowing a parasite with a complex life cycle to move from one host to another. Parasites that infect new hosts via trophic transmission frequently alter their host's behavior or morphology in ways that increase predation risk, thereby aiding the parasite in reaching the next host in its life cycle. For example, estuarine killifish infected with the trematode *Euhaplorchis californiensis* exhibit erratic swimming behavior that ultimately makes them up to 30 times more susceptible to bird definitive hosts. Another trematode endoparasite, *Ribeiroia ondatrae,* causes amphibians to develop severe limb deformities, including extra or missing limbs, which impair the host's ability to jump and swim, and presumably make them more susceptible to predation by bird definitive hosts. The roles of parasites in predator-prey interactions are rarely obvious, yet they may influence the outcome of trophic interactions at the community scale.

Considering the prominent roles played by parasites in trophic interactions, we might expect parasites to strongly influence food web characteristics. Recent efforts to include parasites in food webs have revealed sharp changes in the topology of food webs, including species richness, the total number of links, food chain length (the number of trophic levels in a web), and connectance. Parasites can also influence biodiversity when they alter the outcome of competitive interactions between host species, a phenomenon termed **parasite-mediated competition** (Price *et al.* 1986). In some cases, this occurs when a tolerant host species amplifies a parasite's abundance, causing an indirect negative effect on a second, less tolerant host species. For example, the displacement of red squirrels by grey squirrels in Britain may have been facilitated by a parapoxvirus. The virus infects both species, but native red squirrels are highly susceptible, whereas invasive grey squirrels experience relatively minor negative effects. In this case, a microparasite has probably facilitated a biological invasion, thereby reducing local biodiversity by eliminating populations of one host species.

Negative association

If two or more species interact directly or indirectly within a shared environment but neither benefited, then the association is known as negative association. The negative association between the species can be understood by competition between or amongst the species, which is already described above.

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