Predator-prey relationships: coevolution versus escalation

Species on Earth interact in many different ways (Abrams, 2000). These interactions have evolved over millions of years to become an incredibly complex web of inter-species relationships and understanding these relationships enables science to model future species interactions (Abrams, 2000). From symbiosis to parasitism, Earth seems to have every type of relationship imaginable (Dietl and Kelley, 2002). One of the most intriguing and commonly studied relationships is that of predator and prey.

The predator-prey relationship can manifest itself in many forms, be it two animals, an insect and a plant or a parasite and its host (Dietl and Kelley, 2002). Predators evolve different offensive mechanisms such as speed, large canines and claws, or resistances to toxins, while prey develop defensive mechanisms such as camouflage, bright colours, toxins, burrowing or behaviours such as ‘ playing dead’ (Ebner, 2006). The main topic of study within this relationship is discovering how this relationship develops between two species (Ebner, 2006). The two main hypotheses for its occurrence are coevolution and escalation (Ebner, 2006).

Coevolution is the process by which beneficial evolutionary changes in one species, that increase the species’ fitness, influence evolutionary changes in the other (Ottino-Lofler et al. , 2007). The two species (predator and its prey) selectively influence each other’s characteristics through an evolutionary ‘ arms race’, each attempting to gain the upper hand through genetic mutation, drift and random chance (Ottino-Lofler et al. , 2007). This is a very circular process, causing cyclic fluctuations in predator and prey populations, with a lag time in between (Ottino-Lofler et al. 2007). One species, for example the prey evolves a new defense mechanism enabling it to better escape its predator; there will be a lag time as the predator either evolves a new predation method or learns a way around the new defense mechanism (Marrow et al. , 1992).

The development of the defense mechanism allows prey populations to increase, until the predator develops a method to capture its prey once again, causing the predator population to rise, and prey population to fall, until the prey develops a new defense mechanism and the cycle repeats (Ottino-Lofler et al. 2007). There are usually three possible outcomes of coevolution in predator-prey relationships:

1) the prey evolves an impenetrable defense and the predator goes extinct, 2) the predator evolves an unstoppable offense which drives the prey to extinction and 3) the evolution of defensive and offensive strategies by prey and predator balance each other leading to the aforementioned cyclic population fluctuations (Marrow et al. , 1992, Ottino-Lofler et al. , 2007). The third outcome is known as the Red Queen effect (Marrow et al. , 1992, Ottino-Lofler et al. 2007), after Lewis Carroll's Through the Looking Glass in which the Red Queen says, " Now here you see it takes all the running you can do, to keep in the same place. If you want to get somewhere, you have to run at least twice as fast as that" (Carroll, 1871). The cyclic nature of the struggle between predator and prey to maintain their existence epitomizes the Red Queen's line, in that defenses developed by prey are counteracted by offenses by predators, leaving the two species in the same place as before (Marrow et al. , 1992, Ottino-Lofler et al. , 2007).

Alternatively, escalation is entirely predator determined (Marrow et al. , 1992, Ottino-Lofler et al. , 2007). Prey evolves defense mechanisms to its predator; however that predator does not evolve based on the changes in its prey (Marrow et al. , 1992, Ottino-Lofler et al. , 2007). The predator evolves based on its own predator, creating a ‘ trophic escalated’ evolutionary arms race (Rikvold and Zia, 2003). While both processes may occur in the wild, coevolution is the more dominant force, playing a larger role in determining the evolutionary development of species.

This can be shown through the relationship between the cheetah (Acinonyx jubatus) (Hudson et al. , 2011) and gazelle (Gazella granti) (Frey and Riede, 2003)Gazella grantiGazella grantiGazella granti, monarch butterfly (Danaus plexippus) (Brower, 1995) and milkweed (Asclepias syriaca) (Brower, 1995) and the trypanosome parasite (Trypanosoma brucei) (Hamilton et al. , 2007) and its host, cows (Bos Taurus) (Hamilton et al. , 2007). The cheetah-gazelle relationship is one of the most common examples of the development of predator-prey relations through coevolution.

It is commonly known that the cheetah is the fastest land species; however, what makes the species interesting is how and why the cheetah has evolved to become the fastest (Christiansen and Mazak, 2009). Furthermore, if no animal is faster than the cheetah on land, how is it that the gazelle, the cheetah’s main food source, has not been driven to extinction? The cheetah has many adaptations which aid in increasing speed (Hudson et al. , 2011).

First, the cheetah has comparably longer legs and a much smaller body weight (43kg for males and 38kg for females on average) than other top feline predators which allows for a longer stride with less weight to carry (Hudson et al. , 2011). Furthermore, the flexibility of the cheetah's spine has been shown to increase the stride length by 11%, the claws lack skin sheaths which adds traction and the canines have reduced roots which allows for a larger nasal capacity for air intake (Christiansen and Mazak, 2009, Hudson et al. 2011).

All of these adaptations allow the cheetah to sprint at speeds up to 112 kph over short distances (200-300m) (Christiansen and Mazak, 2009, Hudson et al. 2011). The gazelle also has an incredible capacity for speed combined with agility (Frey and Riede, 2003). Like the cheetah, a gazelle has long, thin legs combined with a relatively small body weight (Frey and Riede, 2003). Gazelles have been measured at speeds up to 97 kph and are able to maintain high speeds because they have evolved a complex evaporative heat relief system enabling it to outrun a cheetah over longer sprints (Frey and Riede, 2003).

To compensate for this, the cheetah's coat camouflages it in the tall African grasses, allowing the cheetah to get close enough to a gazelle to catch it over a short distance (Christiansen and Mazak, 2009, Hudson et al. 2011). Despite the camouflage, cheetahs are not always successful because gazelles spend most of their time in large groups, utilizing many sets of eyes to watch for predators rather than just one (Frey and Riede, 2003). Thus the cheetah and gazelle clearly illustrate the cyclic nature of coevolution with both species influencing the one another.

Another example of the cyclic pattern of coevolution caused by the Red Queen effect is the relationship between the monarch butterfly and milkweed plant. The milkweed plant is fed on by many different insects, but has evolved the ability to produce foul-tasting toxins called cardenolide glycosides to deter predation (Brower, 1995). The monarch butterfly has not only evolved a resistance to the toxin, but also the ability to use the toxin to its advantage (Brower, 1995).

The monarch butterfly lays its eggs on the leaves of the milkweed, and the resulting larvae feed on the plant until becoming a chrysalis and emerging as an adult butterfly (Garland and Davis, 2002). While feeding on the milkweed, the larvae store the cardenolide in its body tissues thereby making the larvae and adult butterfly toxic to its own predators (Garland and Davis, 2002). While the point could be made that this is an example of escalation, coevolution is the driving force; the butterfly has evolved an offensive mechanism to get around the defensive mechanism of the milkweed (Brower, 1995).

The milkweed will eventually develop a new toxin that will force the monarch butterfly to evolve a new resistance mechanism (Garland and Davis, 2002). Finally, coevolution as the dominant force in the evolution of predator-prey relationships can be shown in the interaction between the trypanosome parasite and cows (Gilchrist and Sasaki, 2002). The trypanosome parasite causes African sleeping sickness in many African species including humans (Hamilton et al. , 2007). Cows are the main host however, and are infected, like humans, by an intermediate host, the tse tse fly (Hamilton et al. , 2007).

The tse tse fly is unaffected by the parasite because the parasite is dormant until it enters its true host. The levels of the parasite in the blood of the host fluctuate roughly weekly as the cow’s immune system produces antibodies to the antigen (any foreign substance, in this case the parasite) (Gilchrist and Sasaki, 2002, Hamilton et al. , 2007). Mammals have evolved an adaptive immune system as a defense mechanism (Gilchrist and Sasaki, 2002, Hamilton et al. , 2007). Upon stimulation by a foreign substance, a unique antibody (immunoglobulin protein) is produced and in combination with ? nd T cells the immune system works to eliminate the trypanosome parasite (Gilchrist and Sasaki, 2002, Hamilton et al. , 2007).

Despite this defense mechanism, the immune system is unsuccessful in eradicating the parasite because the trypanosome parasite has evolved to have over 300 genes which code for variable surface glycoproteins (VSGs) (Gilchrist and Sasaki, 2002, Hamilton et al. , 2007). This offensive mechanism counteracts the immune system by changing the surface protein the immune system makes an antibody for every time the body starts to decrease the parasite population (Gilchrist and Sasaki, 2002, Hamilton et al. 2007).

Once a new VSG is put in place by the parasite, the immune system reacts as if the parasite is an entirely new foreign substance and must construct a new antibody (Gilchrist and Sasaki, 2002, Hamilton et al. , 2007). This process cycles under the Red Queen effect until the cow becomes too weak to continue fighting the parasite and the cow eventually dies (Gilchrist and Sasaki, 2002, Hamilton et al. , 2007). In conclusion, it is evident that both coevolution and escalation act on species and affect how species relationships evolve.

However, it is clear that coevolution is the dominant force as it influences many more inter-species relationships, particularly predator-prey relationships. Coevolution is apparent in animal-animal relations as shown with the cheetah and gazelle, in insect-plant relations shown by the monarch butterfly and milkweed and in parasite-host relations illustrated by the trypanosome parasite and cows. Developing a stronger understanding of how species interact and influence one another today, allows stronger and more accurate predictions of future species population dynamics.