Yellowstone National Park Food Web Analysis

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Yellowstone National Park was established on March 1, 1872 and is considered to be the United States' first national park. It is 8,987 km^2 with 96% of Yellowstone located in Wyoming, 3% in Montana and 1% in Idaho. 5% of Yellowstone is composed of rivers and lakes. The remaining area is covered with forests, grasses, mountains, and canyons. Yellowstone is located on the North American plate which has moved across a mantle hotplate causing unique features such as geysers and hot springs. It is not uncommon for small earthquakes to occur although most are not felt by people (Briney, 2018). The average elevation is 2,400 meters above sea level. The highest point in Yellowstone is Eagle Peak with an elevation of 3,466 m. The lowest point in Yellowstone is Reese Creek with an elevation of 1,610 m below sea level (VI Staff, 2020).

Because of the different altitude changes in Yellowstone, the climate varies throughout the park. The higher up you go, the colder it is. The average temperature in the summer during the day ranges from 18-25 ºC and 3-5 ºC at night. Snow can still occur although it is rare. June is the rainiest month with an average precipitation of 5.5 cm. July has an average precipitation of 2.1 cm and August averages 3.3 cm. In the fall, September tends to be warm and dry with an average high of 18 ºC during the day and an average low of -1 ºC at night. Rainfall is only about 3.8 cm with low occurrences of snow. October starts to get colder with a high of 10 ºC and a low of -5 ºC. November is even colder with a high of 1 ºC and a low of -11 ºC with more precipitation averaging 5 cm of rainfall and 58 cm of snow. The winter can be very cold with temperatures not getting higher than -1 ºC. The average snowfall is 76 cm in December, 88 cm in January, and 63 cm in February. In the early spring, winter temperatures are still present with an average of 2 ºC in March. But as you get farther into spring, the temperatures increase to an average of 10 ºC in May. The temperatures can get below freezing of up to -4 ºC. Snowfall is still common in the spring with an average of 66 cm in March and 15 cm in May (Becker, 2019).

Because of the unique geography of Yellowstone, it is home to many different species of plant and animals. There are 1,700 species of trees and plants native to Yellowstone, 60 animal species, 18 fish species, and 311 bird species. This causes a complex food web within Yellowstone. There are 4 trophic levels consisting of primary producers, primary consumers, secondary consumers, and tertiary consumers. The primary consumers include grass and trees such as aspen and willows. The primary consumers include bison, elk, red deer, snowshoe hare, beaver, gopher, and mouse. Secondary consumers include grizzly bears, coyotes, and ravens (Briney, 2018). The tertiary consumer is the grey wolf. This is considered to be the dominant species in the food web and exhibits top-down control. Elk is the dominant primary consumer representing 92% of the wolves' diet with an elk-to-wolf ratio of 166 and a biomass/month of 28.1 kg/month. Wolves are known to kill an average of 1 elk every 15 days on average. 10% of the energy is lost from wolf to elk. Wolves also feed on smaller prey such as rabbits with a biomass/month of .5 kg/month representing .5% of their diet with 10% of energy being lost (Barja, 2009; Smith et al., 2003). They are also known to prey upon berries with a biomass/month of .468 kg/scat/month, but this is very rare, as 28% of energy is lost (Gable et al., 2017). Wolves were removed from Yellowstone in 1943 due to hunting because these species were not protected by the park. Because of the devastating effects caused by this, they were reintroduced back into the park in 1995 by capturing wolves from the Rocky Mountains (Maughan, 2018).

Grizzly bears are the dominant species for the secondary consumers. This is because coyote populations have been reduced due to wolf predation. In 1996-1998, coyote densities declined by 50% to up to 90% in areas with high wolf presence. In the Northern part of Yellowstone, their populations went from 80 to 36 individuals and their average pack size decreased from 6 to 3.8 animals. As a result, their litter size increased, but wolves can easily prey upon the pups. 84% of wolf-coyote interactions are won by wolves.

Wolves are also important because they provide food for other organisms. When wolves die, scavengers such as coyotes, birds, and bears feed on their carcasses. Ravens rely on these for food by following them around until a wolf is killed. They average 29 ravens per wolf kill and the largest ever recorded was 135 ravens per one wolf kill. Grizzly bears often rely on these carcasses as they tend to feed on them as opposed to hunting ungulates. Their large size allows them to successfully drive wolves away from the carcass allowing less energy spent on obtaining food than they would with hunting.

Grizzlies will also scavenge and feed on berries with 28% energy lost from aspen trees. 5-8 year old aspen trees produce the highest fruit biomass/month of 36 kg/ha/month for chokecherries. Aspen trees also produce hazelnuts with a biomass/month of 71,000 nuts/ha/month or 71 kg/ha/month (Noyce and Coy, 1990; Smith et al., 2003). That being said, elk are still an important part of a grizzly bear's diet with 38% of energy being lost. They generally target the calves but are known to kill adult elk and bison. Bison are less likely to be preyed upon by both wolves and bears because of their large size and they stand their ground when attacked. But if elk populations are low, wolves will consume bison. In addition, competition between bears and wolves is high when a bison carcass is present (Smith et al., 2003).

Elk and other ungulates are important for regulating the primary producers. Herbivores have been shown to increase soil moisture when the soil is dry and reduce the moisture when the soil is wet. They increase the nitrogen availability to plants by adding urine and dung to the soil. This helps increase nitrogen mineralization rates in the grazed plants but reduces shoot biomass (Frank et al., 2018). Ungulates have a biomass/month of 228 kg/ha/month and a total biomass/month of 524 kg/month on short grasses. For the coniferous plants, the biomass/month is .273 kg/ha/month and the total biomass/month is 9 kg/month. Ungulates also feed on aspen trees with a biomass/month of .208 kg/ha/month and a total biomass/month of 91 kg/month. They only make up 2% of the park area but are the only trees from a deciduous forest (Miyaki and Koichi, 2004; Romme et al., 1995). Willows also only grow in a small part of the park only making up 1% of the area. They make up less than 15% of elk's diet with grass making up 75% (Singer et al., 1994). Grazing is important for elk because 28% of the energy is lost when it reaches the primary consumers (Wiegert and Fraleigh, 1972). This means that more than 10% of energy is lost between trophic levels.

Yellowstone National Park is considered to be run by top-down control, but there has been evidence of bottom-up control as well. Since wolves are the dominant predator of Yellowstone, they control how the food web is run. Before 1883, hunting was allowed in the park and this caused many of the ungulates to be hunted for their hide and meat. Wolves and coyotes were poisoned so they wouldn't prey upon them. After hunting was banned, wolf populations began to show recovery in 1912. Since wolves preyed upon ungulates, there was concern that they would kill too many of them since the wolf population was continuing to increase. Wolf predation results in a 21% reduction in elk populations and wolves are known to consume an average of 1035 elk per year. From 1914-1926, wolves were removed from the park.

Without wolves to control the elk population, their numbers exploded (Ripple and Larsen, 2000; Varley and Boyce, 2006).

Not only did this affect the elk population, but many of the primary producers were affected as well. Woody vegetation populations such as willow and aspen trees declined by 50% in Northern Yellowstone which is 153,000 ha. This is because the ungulates, such as elk, prey upon these species and stunt their growth; "park officials have stated, 'there remains no question that ungulate browsing is the immediate cause of the decline of aspen on the northern range'" (Ripple and Larsen, 2000; Tercek et al., 2010). In Yellowstone, willow trees can grow in the valley near the river or on the hilly areas. In the presence of wolves, elk tend to feed on the upland willows because they can escape easier from wolves; they can see the wolves better from up higher, there are more escape routes, and they can hide in the nearby conifer forests (Ripple and Beschta, 2006). These willows tend to be shorter than the ones in the valley because the elk prey on them more and they are farther away from the river's water source. Although, they still do feed on the willows in the valley which helps their growth. This is because the elk feed on the older, less healthy branches, which allows for better water flow throughout the tree's healthier branches. This also increases the shoot diameter allowing more water to be obtained. This results in larger leaves with creates a higher photosynthesis rate, making the tree healthier. With the removal of wolves, the elk no longer had to hide from the wolves, so they started to prey upon the valley willows. This resulted in overgrazing and a decline in willow tree populations. Not only does this affect the willow populations, but beaver populations are also affected (Johnston et al., 2007).

Beavers are important organisms in Yellowstone because they build dams using the wood from willow trees. This allows the willows to grow because it filters out the toxins in the water as well as increases the water height. Willows are trees that need lots of water, so the beavers create dams which raises the water level. Beavers also rely on the willows for wood for their dams and they consume the leaves and branches. With the removal of wolves and the overgrazing of willows, the beaver populations declined; by 1988 the beaver population was completely absent in Northern Yellowstone. This caused erosion of the sediment and reduced the water level that is not ideal for willows to grow. Even after the reintroduction of wolves, beaver populations have not been able to reestablish; there have been no documented beaver colonies in Northern Yellowstone since the reintroduction of wolves (Johnston et al., 2007; Smith et al., 2003). This is because the low water levels limit willow height and are not sufficient enough to support the beaver population. Stream erosion has also increased the width of the river, making it too large for beavers to build dams. This caused the beaver population to be regulated by bottom-up control because they are limited by the willow population (Johnston et al., 2007).

Although willow recovery has not been uniform, there are some significant changes when wolves were reintroduced. Before 1995, willow trees averaged < 80 cm in height. After 1995, when wolves returned, not only did some willows return to that size, but some grew over 400 cm. This still allows for elk to graze on smaller trees, but willows larger than 250 cm are too tall for elk grazing which prevents overgrazing of these willow trees. This is an example of how Yellowstone is regulated by top-down control where wolves are the dominant species because they control elk populations to prevent overgrazing (Tercek et al., 2010).

One of the next steps to understanding Yellowstone's ecosystem and trophic levels is to look at the relationship between elk and willows. Ripple and Beschta (2006) thought willow height was originally due to the rate of elk grazing as opposed to how much water the trees were exposed to. They believed that elk graze in higher grounds to avoid predation by wolves. Other studies have combated this by saying that wolves' home range do not overlap with some elk foraging areas. It was also found that wolf predation occurs more in open areas as opposed to in the valley. In addition, elk eat more willows when wolves are present than when they're absent. They also found that snow limits predation on valley willows more than wolves do. It is believed that abiotic factors have a stronger influence on elk grazing behavior than do wolves and the increase of wolves may allow for more grazing. This is interesting to look into because when wolves were absent, the elk populations increased. This causes the assumption that overgrazing will occur because of the increase in elk populations. This is not the case and the next step may be looking into why this is or creating more studies to confirm this (Tercek et al., 2010).

Another step to take to better understand the food web is to study the food web in the rivers and lakes. Besides beavers, lake and river organisms were ignored in this review. Since bears and other species feed on aquatic organisms such as fish, it is important to incorporate the terrestrial food web with the aquatic food web. Before that is possible, the next step is to understand the aquatic food web. Yellowstone Lake is the largest body of water in Yellowstone which covers 87,040 acres and is 120 m deep. It has an elevation of 2,537 m which makes it the highest altitude lake in North America (Briney, 2018). Yellowstone's aquatic food web used to be 3 trophic levels consisting of phytoplankton, zooplankton, and cutthroat trout. The introduction of lake trout caused 4 trophic levels with lake trout feeding on the cutthroat trout. Lake trout are considered to be apex predators and have caused the native trout species to decline (Tronstad et al., 2010).

The addition of the lake trout changed the aquatic ecosystem completely and is regulated by top-down control. The higher the lake trout abundance, the lower cutthroat trout abundance. This had a large effect on zooplankton. With lower abundances of their predator, zooplankton had a longer body length, a longer mean assemblage length, a higher biomass, a higher biomass of larger species, domination of cladoceran, and a decrease in zooplankton production. Without the lake trout, zooplankton had a shorter body length, a shorter mean assemblage length, a lower zooplankton biomass, a lower biomass of larger species, copepod domination, and a higher zooplankton production. Phytoplankton were also affected by the lake trout such that their biovolume was lower, they had a lower chlorophyll a concentration, and the water was less turbid. Without the lake trout, they had a higher biovolume, a higher chlorophyll a concentration, and the water was more turbid (Tronstad et al., 2010).

This example is the opposite of removing the wolves because instead of removing an apex predator, one was added. The next step may be to remove the lake trout to see if the ecosystem will go back to normal. It is also interesting to look into how this affected the terrestrial food web. For example, bears may now prefer fish over land animals because they are larger and can provide more calories for the bear. This could result in an increase of the bears terrestrial prey or allow wolves to kill more terrestrial prey because there is less competition for the same prey species. In addition, it might be interesting to compare the effects of removing an apex predator versus adding one to see how the food web changes.

Another step to understand the food web is to look at microscopic organisms found in the hot springs. Bacterial species and algal species are known to inhabit the hot springs. Eukaryotic green algae is known to inhabit low-temperature (below 40 ºC), acidic (pH of 3.0) thermal springs. These are found to be a food source for insect larvae. The genus *Thermus* comprises of bacterial species that inhabit springs between 55 to 70 ºC (Boyd et al., 2009; Nold and Ward, 1995). It is important to understand this food web because it can relate back to the terrestrial food web. Since insect larvae feed on these microscopic organisms, this food web could affect insect population numbers which would affect insect predators as well as the primary producers that rely on insects for pollination.

It is also important to understand the effects nutrients have on the food web. Mercury is the only known metal that increases in concentration as it travels up the food web through each trophic level. An effect of this is that the higher up the food chain you go, the more likely health problems are to arise. Mercury is more common in aquatic ecosystems and enters the food web through the uptake of primary producers. This is important to understand how Yellowstone's lakes and rivers are affected by mercury and how that impacts the terrestrial food web. But it is also important because mercury has been found in hot springs in toxic concentrations. This affects the algae species *Zygogonium*. This is a type of green algae that appears purple due to a reaction between iron and tannin (a biomolecule). This species is known to take up mercury into its cells. Larval insect species feed on these and the mercury accumulates (Boyd et al., 2009). This is important to see how the mercury builds up in the food web from insects such as when they are consumed. Another important thing is to see how mercury in aquatic ecosystems and mercury in hot spring ecosystems work together. For example, trout could have accumulated mercury from phytoplankton and then accumulated more from eating insects which could pass up to bears. This could increase the mercury concentrations found in organisms which could cause more health problems. In addition, with the decline of beavers, harmful chemicals such as mercury could be taken up by willow trees instead of being blocked by dams, affecting the terrestrial food web.

Another important step to take is to look at how the food web will be altered in the future due to things like climate change. The average temperature has increased by .6 ºC over the last 100 years and is predicted to rise another 1.4-5.8 ºC in the next century. This could cause a shift in trophic structures such as phenology, reproductive success, distribution, and synchrony of plant and animal species. Wolves are important organisms in that they provide carcasses to other animals. In the absence of wolves, many elk species died in the winter due to not being able to find enough food as opposed to wolf predation. This resulted in less animals being able to eat the elk carcass because there was less meat to consume. As temperatures rise, there is predicted to be shorter winters and earlier snow melts. This will result in elk recovering quicker from winter stress, easier access to food, and a decrease in energy required to obtain food. This means that less elk will be killed by wolves as they are able to escape easier and earlier in the year. This affects the scavengers that rely on elk carcasses as a food source. In addition, elk normally die in March and April due to the winter, but an earlier winter may cause them to die in November through February. This can be a problem for species that rely on elk carcasses for survival. For example, coyotes depend on elk carcasses from late-winter to early-spring. If elk are dying earlier, coyote populations may decrease because they rely on elk later in the year. In addition, elk meat will be more concentrated over a shorter window of the year which could cause more competition between scavengers. It is important to understand the effects of climate change on the food web because it can affect how it is controlled. This may change the food web from top-down control to bottom-up control because of the limited access to elk carcasses (Wilmers and Getz, 2005).

All in all, Yellowstone National Park has a complex food web that can and has been altered from factors such as removal or addition of apex predators, climate change, added toxins and metals, and an interaction between microscopic, terrestrial, and aquatic food webs. It is important to further study this ecosystem and its food web components as it is constantly changing. Yellowstone National Park is a unique area with many species of animals and plants so by understanding the food web can help us further protect the diversity of species known to inhabit it.

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