Examining Water Quality and Vegetation Along Cozine Creek
Senior Capstone ENVS 460: Fall 2020

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INTRODUCTION

When examining a satellite image of Earth from outer space, the spherical ball that is home to an array of organisms is predominantly blue. That is because 71% of the planet is covered by water; 96.5% of that is held in the oceans (USGS 2008). Freshwater only takes up 3% of Earth's water; 2.5% is unavailable (stored in ice caps, glaciers, the atmosphere, soil, etc.) and is one of the most valuable resources to plants, humans, and animals (Bureau of Reclamation 2014). The health of a society depends on the health of the water used for irrigation and drinking; furthermore, clean water is an essential component of a healthy ecosystem and requires a range of specific conditions to be conducive to life (Resh and Unzicker 1975). Across the globe, clean drinking water is becoming harder to access and has turned into a major environmental and public health issue (Li et al. 2014).

Increased anthropogenic pressures such as pollution, improper waste disposal, and exploitation of resources is having a significant impact on rivers, lakes, streams, and wetlands. Recognizing this, the United States and other international governments have made public statements and crucial policies that address the importance of safe, clean drinking water for all forms of life (WHO 2004). As years pass, the human population is increasing in tandem with urban sprawl, and waterways are becoming more at risk for contamination. Contamination of freshwater is a concern to humans and the surrounding ecosystems, but it is up to humans to protect and rehabilitate water sources (Dodds et al. 2013).

Water is crucial to the survival of fish and wildlife and provides essential habitat to at-risk species so they can spawn, breed, and rear their young (ODFW 2019). The ability of riparian organisms to survive and reproduce is dependent on the quality of the water in the environment they occupy (Dudgeon et al. 2006). Even slight changes in water quality can have large effects on the ecosystem. Water quality in many ecosystems is suffering as a result of overexploitation and contamination. Poor water quality may result in range reductions and population declines of freshwater species, reducing biodiversity. Water is the foundation for all life however this vital resource is under eminent pressure (UNESCO 2006).

Policy and Water Quality Legislation

Water pollution is one of the United States' leading environmental issues. In 1948, the United States implemented its first law to address water pollution known as the Federal Water Pollution Control Act (FWPCA) that authorized state governments to establish a fund to improve water quality across the country to solve the problem of water pollution. However, sewage and garbage were still being dumped into rivers, resulting in serious environmental problems. In 1962, Rachel Carson wrote "Silent Spring" that warned the public about the dangers of pesticides and the threats posed by human activities to the environment; the book catalyzed a change in attitudes. It provided a voice for the increasingly popular "environmental movement". The Cuyahoga River fire in 1969 further aroused public awareness of environmental protection in the United States. In the 1970s, the United States passed a series of federal laws on environmental protection. The Clean Water Act of 1972 and the Safe Drinking Water Act of 1974 were established as the most important legal means for protecting water resources and controlling pollution in the United States. The Clean Water Act (CWA) required all municipal and industrial sewage to be treated before it could be discharged and set two strict targets: (1) achieving "zero discharge" of pollutants by 1985; and (2) requiring all water meet fishable and swimmable water standards by 1983. The Clean Water Act became the principle of law enforcing pollution control and water quality for the United States’ waterways (EPA 2014).

The Clean Water Act is the foundation of surface water quality protection and the basic framework of water pollution control. The U.S. government intends the bill to “restore and sustain the chemical, physical, and biological integrity of the nation's waters by preventing point and nonpoint source pollution, providing assistance to publicly owned wastewater treatment facilities and maintaining the integrity of wetlands” (EPA 2016a). Currently, the public waters of the United States are regulated by state and federal legislations, though it is not common for the federal government to set water quality standards for a specific in-state waterway. In most circumstances, the state’s water quality standard is influenced by the format provided by the federal government’s requirements. According to federal law, the EPA is to review states’ submitted water quality standards. The EPA works with federal, state, and tribal partners to monitor and ensure proper actions are being taken in compliance to laws and regulations under the Clean Water Act (EPA 2014). The most significant amendment in the Clean Water Act is the control of the discharge of pollutants to any water bodies that are classified into two main types: point source pollution and nonpoint source pollution. Point source pollution is defined as pollution with an identifiable source such as domestic or industrial wastewater with fixed discharge pipes or outlets. Nonpoint source pollution is pollution from unrecognizable sources, such as urban and farm run-off. The implementation of the Clean Water Act changed the water pollution situation and improved the water quality of surface water in the United States. However, there are some problems related to the Clean Water Act. The Act requires states to have water management standards and plans, but the authority of implementation is in the hands of each state (EPA 2018b).

Although the Clean Water Act was fairly successful in controlling point source pollution, nonpoint source pollution was and still is harder to track down and mitigate (EPA 2018b). Examples of nonpoint source contaminants include fertilizers, insecticides, herbicides, oil, and toxic chemicals from industrial, urban, agricultural, and unknown sources. Nonpoint source pollution commonly happens in industrial, agricultural, and urban lands across the globe (EPA 2018a).

In 1972, the Clean Water Act became the principal law enforcing pollution control and water quality for the United States' waterways. Polluted water can carry bacterial, viral, and parasitic diseases. Every day, two million tons of sewage drain into the world's waters, causing unsafe water that kills more people each year than war. Drinkable water is limited, with less than one percent accessible for use (Denchak, 2018). This law gave the EPA the power to implement water quality standards for all contaminants in U.S. surface waters, as well as making it unlawful for anyone to discharge pollutants from a point source into a waterway without a permit (BOEM 2012). In 2015, the EPA Administrator put into place a final rule that updated the key areas of federal water quality standards regulation and helped implement the Clean Water Act (EPA 2016a). This revision defined a more structured pathway for states and tribes to improve water quality, maintain high quality waters, and increase the transparency for more local involvement in keeping waterways healthy (EPA 2018b).

The state of Oregon's general standards for water quality are listed in Chapter 340 Division 41 in the Oregon Administrative Rules. This chapter contains definitions, nutrient values, and specific criteria for the different ecoregions of Oregon. Cozine Creek, the focus of this study, is located within the Willamette Valley and is therefore expected to be suitable for a vast array of uses including irrigation, livestock, fishing, and boating (DEQ 2005). The expectations for Cozine Creek are high, but the reality is that the stream is not conducive to many of these uses. Cozine Creek is listed as a migratory and rearing habitat for salmon and trout but also is classified as an "impaired waterway" under list 303(d). As a part of the Clean Water Act, every two years the EPA is given a list of prioritized waterways that demand change of TDMLs (Total Daily Maximum Loads) of pollutants (EPA 2019). Desired water quality standards for Cozine Creek include having a pH of 6.5-8.5, a seven day average temperature that does not go above 18.0°C, a dissolved oxygen content no less than 8.0 mg/l (ppm), turbidity under 10%, and bacterial levels of no more than 126 *E. coli* organisms per 100ml over a 90 day geometric mean. The list of these standards is included in the state's general water quality standards as well as the basin specific standards (DEQ, 2019). Though the EPA does not have data pertaining to the potential sources for the pollutants, the creek is listed as having unhealthy *E. coli* levels and reduced dissolved oxygen levels (EPA 2014).

Water Quality Variables

The term water quality is an umbrella statement for a variety of factors that are used to estimate the condition of a waterway. Although there are many variables that can be used to examine water quality, some of the most important include temperature, pH, DO (dissolved oxygen), BOD (biochemical oxygen demand), flow, turbidity, nutrient levels (e.g., phosphate, ammonia, and nitrate), and levels of coliform bacteria. A change in one of these factors often results in a change in another. Each factor is reflective of the organisms inhabiting the water source as well as the environmental stresses each system faces. Some of these factors are tested in the field (e.g., pH, flow, temperature, and DO), whereas others are often analyzed in the laboratory (e.g., BOD, nutrient, and bacterial levels) (EPA 2016a).

Temperature is one of the easiest variables to measure, and it can have a significant effect on biological activity. The temperature of water changes with the seasons, the degree of shade from vegetation, the rate of stream flow, the stream depth, and thermal pollution (USGS 2016a). Water temperature has an inverse relationship with dissolved oxygen (DO). The warmer the water, the less dissolved oxygen the water can hold. Temperature also impacts pH; warmer water will have lower pH levels (USGS 2016b). Increasing stream temperatures often can be attributed to human activities including removal of native vegetation that shade the water, dams that heat the water in reservoirs, logging, water withdrawal for irrigation, and runoff from farms that can cause increased turbidity. In Oregon, warmer streams and rivers impede the survival, health, and distribution of native salmonids. For salmon to spawn and hatch, water temperatures of 9-12℃ are required, and they die above 18℃ (EPA 2003). Temperature is one factor affecting salmon over the last few decades as water temperatures have increased due to climate change. As temperatures increase, so do salmon feeding rates, but if the food is not there the fish go hungry. Changing temperatures with the seasons also may delay salmon migration and increase predation. If stream temperatures are high when salmon are spawning, salmon die as they rely on stored energy that can be depleted quicker if the water is too warm. Higher temperatures also reduce the size and number of eggs produced by the female salmon (Sauter et al. 2001).

The pH describes how alkaline or acidic water is and is defined as the negative log of the concentration of hydrogen ions. The scale for pH goes from 0 to 14, where 0 to 6 is acidic, 7 is neutral, and 8 to 14 is alkaline (basic). The more free hydrogen ions present, the more acidic the solution is. The numbers are on a logarithmic scale, so an increase from one number to the next represents a 10-fold change in the pH of the solution. Pollution can affect the pH of waterways due to acid precipitation and dry deposition, toxic waste, run-off, and non-point pollution (USGS 2016a). The pH of water can be influenced by chemicals and is a useful indicator of water quality. pH levels in water systems should range between 6.5-8.5. If the pH drops below 6.5 salmon eggs won’t hatch and adult salmon could die (Sauter et al. 2001).

Dissolved oxygen (DO) is the amount of oxygen present in water and is often measured to assess water quality. DO is measured in parts per million (ppm) or percent (%) and is a direct indicator of a waterway's ability to support aquatic life. Oxygen diffuses into water from the atmosphere and as a result of photosynthesis by aquatic plants; aquatic animals and bacteria use DO during respiration. Organisms require different amounts of DO; levels that are less than 3 milligrams per liter (mg/L or ppm -parts per million) are of special concern. Low oxygen levels are considered hypoxic and can result from eutrophication and excess organic matter. Low oxygen levels usually occur at the bottom of a water column and affect bottom or sediment dwelling organisms. All organisms need oxygen to live, but how they get it varies among species. Fish absorb dissolved oxygen across their gills; this is how they get oxygen to their tissues (Carter 2005). When the levels of DO in streams and creeks decrease, fish survival is threatened. The optimal level of DO in a waterway is above 9 ppm (EPA 2016b). Levels below 4 ppm are fatal for salmonids (Muradian 2016). DO levels below 80% can lead to smaller sized fry, a longer incubation period, and delayed hatching in salmonids (Bjornn and Reiser 1991).

Although DO measures the amount of oxygen present in a waterway, biochemical oxygen demand (BOD) represents the amount of oxygen consumed by animals, bacteria, and other organisms as they respire or decompose organic matter. BOD also is a measure of the amount of oxidizable chemical substances in a water sample that can lower DO (USGS 2016c).

The flow of water is the speed the water is moving and can affect temperature, turbidity, and oxygen levels in the water. Flow can be influenced by seasonal changes, as well as sediment, debris, or physical blockage in waterways. Streams are affected by periods of low flow when the water is stagnant and low. Low flow will cause an increase in the temperature of water and a decrease in DO and turbidity. When flow is low, water becomes heated by the sun, causing the decrease in DO (USGS 2016b). Stream flow is important for salmon migration and needs to be at levels sufficient for salmon to spawn and for eggs to remain until they hatch (Bjornn and Reiser, 1991).

Turbidity is the clarity of the water. It is measured as the amount of light scattered by material in the water when light is shined through the sample (USGS 2016d). Clay, silt, algae, organic matter, and microorganisms are major causes of increased turbidity. Periods of low flow often have water that is a clear, green color with low turbidity. High turbidity is characteristic of waters with high flow and volumes that stir up material from the stream bed. Turbidity has increased over the past 50 years due to human impacts such as logging, agricultural runoff, mining, road construction, and urbanization. Higher turbidity can pose a health concern to humans and wildlife. High levels of turbidity have been known to cause poor phytoplankton productivity in lakes, smother bottom life such as mussels, as well as dilute organic debris (Borok 2014). Because pathogenic bacteria often feed on some of the causes of turbidity, it can lead to waterborne disease outbreaks (USGS 2016d). The length of time that the suspended solids are in the water is a primary factor on how organisms are affected. If the solids are washed through and diluted quickly, the chances of the fish and other organisms have lasting damage are low. As erosion and runoff increase, turbidity in streams can reach lethal levels for salmon. Some of the effects high turbidity can have on salmon include gill trauma, disrupted blood chemistry, stunted growth, damaged redds, increased territorialism and avoidance behavior, and a reduction in spawning habitat (Bolton 2001).

Nutrients such as nitrogen and phosphate are essential for growth of plants however, high levels create problems in water. Nitrogen is found in two biologically accessible forms: nitrate and ammonia. Ammonia often enters waterways as runoff from animal feedlots and agricultural lands and is fairly unstable in waterways. When ammonia levels are high, the compound can build up in the tissue of fish, causing death. Ammonia levels of 2.0 ppm can kill most fish within hours (Brungs et al. 2020).

Nitrate also enters waterways from runoff from farms, as well as from nitrogen oxides emitted by internal combustion engines. It is very stable in natural environments and readily moves through water systems and into the water table (EPA 2017). Because nitrates are short lived in the environment, they have varying effects on fish. The concentration for salmon should be less than 10 ppm (Brungs et al. 2020).

Phosphates are usually present in small concentrations because they are not very water soluble, but they are very mobile once they get into water. Phosphate enters water naturally due to soil erosion and anthropogenically from the use of fertilizer (USGS 2018), animal and human waste, laundry detergents, and industrial effluents (Oram 2020). Phosphates are a limiting nutrient in most streams (Brungs et al. 2020) so a small increase can result in eutrophication and algal blooms leading to low DO (USGS 2017a). The maximum amount of phosphate in a stream should be less than 0.1ppm. If the levels of phosphates rise above 0.1 ppm, oxygen levels will drop and salmon and other aquatic organisms will die (Brungs et al. 2020).

The main problem with excess nutrients is that they cause eutrophication resulting in algal blooms. The algae eventually die as nutrients are depleted and the dead organisms undergo bacterial decomposition. This will deplete the dissolved oxygen in the water, which can lead to dead zones in the oceans, often at deltas of rivers, or in coastal areas that have little to no dissolved oxygen (USGS 2020).

All waterways have bacteria and most are harmless, although some can cause disease and be detrimental to human health. Coliform bacteria are found in the fecal matter of animals and humans. *Escherichia coli* (*E. coli)* is a species of coliform bacteria that is found in the fecal matter of warm blooded vertebrates; it is an indicator of fecal contamination in water. There are many different strains of *E. coli;* most are harmless, but some can be pathogenic and can make people very sick. Pathogenic *E. coli* are usually transmitted through contaminated water or food (CDC 2014). The levels of *E. coli* allowed in recreational freshwater is a mean of 126 organisms per 100 mL over a 90 day period, and no single sample can exceed 406 organisms per 100mL (DEQ 2020).

Salmonella and *Aeromonas* are two other coliform bacteria that are commonly tested for in water. *Salmonella* can cause diarrhea, fever, and abdominal cramps if consumed by humans . It can be found in sources such as private wells that are contaminated by feces of an infected person. It may enter groundwater via sewage overflow, septic system failures, polluted stormwater runoff, or agricultural runoff (CDC 2015b). Some *Salmonella* found in manure can last up to 231 days (Liu et al. 2018).

Aeromonas has similar effects on the human body as *Salmonella.* They are disease causing agents in both fish and humans (Chaix et al. 2017) and can cause gastrointestinal illnesses and other infections. People can be exposed to *Aeromonas* through their skin or ingestion (Salvat et al. 2019). The most common way for humans to acquire *Aeromonas* is by oral consumption of contaminated water, dirt, or seafood (Chen et al. 2017). The maximum allowable level for *Aeromonas* in drinking water is a median of 20 CFU/100 ml over the course of a one year period (WHO 2020).

STUDY AREA - Cozine Creek

Our study was done at Cozine Creek in the Willamette Valley of northwestern Oregon. Our study sites were located in the Greater Yamhill Watershed (GYW), one of the largest watersheds in the Willamette River Valley. The valley was carved out during the last ice age, but the Missoula Floods and Lake Allison formation deposited a variety of fertile soils. The most common soil type in the area is Jory soil. It is a silt and clay soil that formed from weathered basalt bedrock and the deposition material from the Missoula Floods during the last ice age (USDA 2019). The Willamette Valley is characterized by cool, wet winters with warm, dry summers. Moisture throughout the year is abundant but rain mostly falls in winter and spring (Taylor 1993). Yamhill County contains 70 percent of the Greater Yamhill watershed, including approximately 430 miles of streams and rivers, four percent of which are designated as essential for imperiled winter steelhead trout. Our specific research project was done along Cozine Creek, a tributary to the Yamhill River, that runs through the city of McMinnville, Oregon (Figure 1).

Cozine Creek begins in the coastal foothills southwest of McMinnville and flows through agricultural areas before entering the urban region. It then enters into the South Yamhill River in McMinnville. Cozine Creek has been identified as a focus area for water quality pollution and a Class A for invasive weeds by the Oregon Department of Agriculture (ODA) and Oregon Department of Environmental Quality (ODEQ) (GYWC 2018).

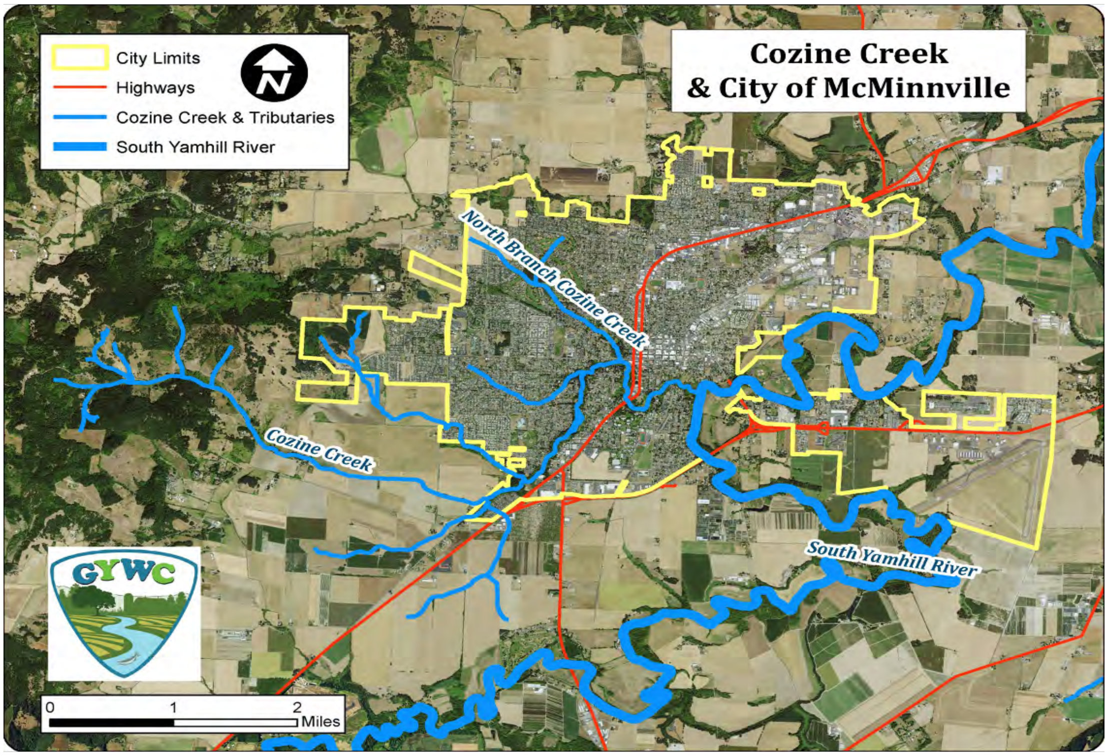

Figure 1. Map of Cozine creek as it flows through McMinnville, OR and into the South Yamhill River. Map provided by Luke Westphal and the Greater Yamhill Watershed Council.

Monitoring projects conducted by the Greater Yamhill Watershed Council (GYWC) have identified Cozine Creek's water quality as impaired due to pollutants, high temperatures, low dissolved oxygen levels, and levels of *E. coli* that exceed human recreational limits. The impaired water quality of Cozine Creek is in part due to pollutants from McMinnville's agricultural fields. The natural landscape in the urban area has been replaced with impervious surfaces such as roads and buildings that have increased runoff into streams. As stormwater flows over urban areas, it picks up sediment, nutrients, bacteria, pesticides, metals, and petroleum by-products. These things impair the water quality of Cozine creek as well as harm the fish and wildlife who rely on Cozine Creek for survival (USGS 2016b).

The city of McMinnville has developed methods to solve resource problems, yet the quality of Cozine creek remains poor. Contributing factors to the poor water quality may be linked to leaks leading to increased pollution. In 1988, a petroleum leak from the football stadium flowed into Cozine Creek. The spill was cleaned but not the residual oil seeped into the soil. (DEQ 1988). In 2019, a developer from Stafford Land Company was fined $17,259 for failing to follow stormwater runoff protocols and polluting Cozine Creek with highly turbid stormwater among other violations (Loew 2019). However, there has been work done to restore the Cozine Creek habitat. In 2002, the Greater Yamhill Watershed Council (G.Y.W.C.) received $45,000 by the State of Oregon to restore Cozine Creek habitat and improve water quality. Work continues to be done annually by the G.Y.W.C. and local volunteers (Westphal 2017).

History of Area

With Cozine Creek being an important landmark for Linfield University, it also is important to recall the creek's rich historical relevance. Before Europeans arrived, Oregon was occupied by over 30 indigenous tribes (Macnaughtan 2012). The Kalapuyans occupied over a million acres with most of their time spent in the Willamette Valley along rivers and streams (Lewis 2019). The Yamel were a small tribe, relatives of the Kalapuya, who had a plant-based diet and harvested camas lily (*Camassia quamash*), wapato (*Sagittaria latifolia*), tarweed seeds (*Madia sp.*), and beaked hazelnuts (*Corylus cornuta*) (YBC 2001). The camas bulb was a staple used extensively by the indigenous people. Other vegetable resources were wapato (*Sagittaria latifolia*), a marsh plant whose tubers were harvested during the fall, tarweed seeds (*Madia* spp) found in burned-over prairies, and hazel-nuts, dried in the sun and beaten to remove their husks before being stored (Zenk 2020). Camas was abundant and provided nutrition to a diverse group of animals including the camas pocket gopher (*Thomomys bulbivorus*). The Yamel tribe managed the land and would annually burn multiple acres at a time. This promoted the annual regrowth of native species (Lewis 2019). They often set low intensity and slow burning fires that removed the vegetation on the forest floor preventing wildfires and helping maintain the savannas and grasslands. Oregon white oaks (*Quercus garryanna*), with their thick bark and strong root systems, were resistant to fire damage (Johannessen et al. 1971).

With the arrival of increasing numbers of Europeans in the 1840s, the landscape began to change, reflecting the newcomers' elimination of Kalapuyan burning techniques and the introduction of cultivated agriculture (Robbins 2020). Today more than 95 percent of the white oak are gone, and the remaining ones are threatened by urban expansion, land conversion, and fire suppression management (YSWCD 2015).

Historically, the Willamette River overflowed in the winter and spring, flooding low-lying areas of the valley. The annual floodwaters produced up to 40-50 inches of water leaving behind rich soil deposits and an abundance of aquatic, plant, and animal life. The natural occurrences of the Willamette River overflow replaced the local tribes' burnt vegetation with lush green grasses producing a considerable harvest the following year (Robbins 2020).

In the 1840s ships began coming up the Columbia and Willamette Rivers and through the Tillamook, Yaquina, Coos, and Umpqua River basins. By 1851, Europeans had claimed the Willamette Valley as their own. They called for the removal or genocide of all native people in the area (Lewis 2019). By 1900, less than 5% of the original native population was left in Oregon (Meengs and Lackey 2005). The gold rush in California and in parts of Oregon had led to a huge population increase in the Willamette Valley. In 1925, there were 2,864 farms in Yamhill County, many of them growing wheat. The Willamette River was looked upon as the transportation route needed for moving wheat and other products to Portland and other markets. The federal government funded the construction of a steam-powered "snag-puller" in 1869 to remove obstructions from the river. The operation and the construction of a canal at Willamette Falls in Oregon City in 1873 was the beginning of efforts to reshape the waterway to meet commercial and industrial needs for expansion (Robbins 2020).

By the 1940s, much of the resources in the area had been overutilized. Timber based on Douglas-fir (*Pseudotsuga menziesii*) accounted for the majority of the forest industry. Overharvesting of timber was so extreme the Department of Interior classified the forests of modern day Yamhill County as “extremely depleted.” All sewage was dumped directly into the Yamhill River until the first modern sewage system was built in 1951. Water quality is presumed to have been unhealthy for the town of McMinnville that had relied on the river as a source of drinking water (YBC 2001).

In Oregon, the camas lily is now used in programs to help reintroduce native species to wetlands and prairies in restoration projects. Protecting and conserving camas populations has become increasingly critical because oak savannas and wetlands have been converted to agriculture, housing, and commercial development (Kephart 2020).

Fish

The Willamette Valley has many fish populations that inhabit the local rivers and streams. Winter steelhead and Coho salmon are important and essential fish species in the area. Coho salmon reproduce and return in their natural migration patterns in the waters of the Willamette Valley due to their ability to find natal streams from the chemical distinction of the water (Fondriest 2014). Historic salmon populations in the Pacific Northwest have been estimated at upwards of five million salmon per year coming into rivers and streams from the ocean. Coho salmon made up 1.5-2.5 million, and Chinook salmon were over 500,000. Current Coho populations are believed to be between 11 and 19% of historic levels. Salmon populations began to decline beginning in the mid 1870s partly as a result of a salmon cannery that was founded on the Columbia river that produced 25,000 cases annually by 1890 and up to 140,000 cases by 1922. Another cause of decline in salmon populations was mining and dams that were put in in the Willamette Valley. Beginning in the 1850s, hydraulic mining began in Oregon that used pressurized water to blast entire hillsides away and wash the sediment into streams and rivers. This smothered and killed salmon and their eggs and destroyed the habitat in these areas. Diversion dams were built to support the hydraulic mining; these were fish barriers that stopped salmon from reaching spawning grounds. The dams also killed salmon by the intake pipes that supplied the water for the hydraulic mining (Meengs and Lackey 2005).

Vegetation

Streamside and aquatic vegetation are integral to water systems and water quality. Plants provide food and shelter for animals, buffer inputs of things such as nutrients into streams by filtering pollution, and preventing streamside erosion. Streamside vegetation also provides shade that cools water and helps keep dissolved oxygen levels high. Riparian vegetation is integral to maintaining and improving water quality along with the health of the stream-related biotic community. As humans have become dominant ecosystem engineers it is up to individuals and governments to support the supply of clean water and improve the chemical quality for human consumption and greater ecosystem use (Tristin 2013). Current human needs frequently have usurped ecosystem needs with demand for agriculture and urban expansion. The removal of vegetation around streams fragments forests and natural lands as well as provides non-native species a chance to invade; this invasion correlates with a drop in biodiversity (YBC 2001).

Native vegetation is defined as species present before European settlement, whereas non-native or exotic plants are those that are from other areas of North America or elsewhere and were brought in post-European settlement (OSU 2020). These non-native plants often classified as weeds (unwanted pests) are a great danger to biodiversity and the restoration efforts to increase the abundance of native species in Yamhill County (YBC 2001).

The four main habitat types in the Greater Yamhill Watershed include riparian forest, wet and dry prairie, woodlands, and oak savanna. The vegetation of the Willamette Valley is about 30% grass and oak savannah habitats (GYWC 2018). Currently, the Willamette Valley is mostly covered by agricultural lands - most notably wine grape vineyards, filbert orchards, and grass seed fields (Towle 1982). Due to the mild winters and dry summers, the climate is suitable for grass seed and grapes, which is why the Willamette Valley produces two thirds of the United States' total cool-season grasses (Jessie 2018). Europeans filled many of the wet prairies and tilled them for agricultural purposes. Riparian forests were cleared for agricultural use except for small habitat patches alongside streams in an attempt to naturally stop the meandering of streams. Oak woodlands and savannah, home to the native Oregon white oak, is one of the most endangered habitat types and is found in isolated pockets as agricultural and residential areas expand across the Willamette Valley. Historical habitat now covers less than 5% of the valley and less than 6% of the neighboring Coast Range. Habitat loss combined with fire suppression, have allowed invasive species and Douglas-fir trees to encroach on the open oak habitat (OSU 2020), further threatening the oak savanna. In addition, the introduction of a non-native fungus that causes 'sudden oak death' also endangers native oaks as it moves into Oregon from California (YBC 2001).

Native tree species found in the study area of Cozine Creek include red alder (*Alnus rubra*), Douglas-fir, and Oregon ash (*Fraxinus latifola*). Ash and alder are dominant along stream banks, providing shade and habitat and acting as natural biofilters for nutrients and pollutants that can enter into waterways. Uptake of nutrients by the roots of the trees have a direct influence of soil nutrients flowing into nearby streams and into the water table (Allan et al. 2010).

Invasive species found in the Cozine area include reed canary grass (*Phalaris arundinacea*), Himalayan blackberry (*Rubus discolor*), and English ivy (*Hedera sp.*). These plants outcompete native shrubs and herbaceous vegetation and prevent recruitment of new trees

(Oregon Conservation 2018). The Oregon Conservation Strategy recommends implementation of early detection methods for invasive species followed by rapid control methods (chemical, physical, or biological controls vary with effectiveness) along with promoting plantings of native vegetation during restoration projects (Oregon Conservation Strategy 2019).

In 2016, students in Linfield's Environmental Problem Solving class (ENVS 470) completed an inventory and assessment of the vegetation in the Cozine Creek area on campus and reported that the two most dominant tree species in that area were Oregon white oak (28.2%) and Oregon ash (38.2%), along with scattered Douglas-fir (9.7%) and Northwest willow (*Salix sessilifolia*) (5.8%) (Gernhart et al. 2016). The dominant shrubs included creek dogwood (*Cornus sericea*) and Himalayan blackberry. The latter has been a target of invasive species control during the Cozine restoration project. Within the creek itself, duckweed (*Lemna sp.*) has prolifically spread during times of warm water and low flow. Native camas that still thrive on the site have been harvested, replanted, and spread with the removal of the blackberry (GYWC 2020). Dominant herbaceous cover includes non-native, invasive reed canary grass and Italian arum (*Arum italicum*) that are targets of removal, and the native trailing blackberry (*Rubus ursinus*) and camas (Gernhart et al. 2016).

Past Research at Linfield

In 2011, students in Linfield's Research Methods classes (ENVS 385 and 460) began conducting annual water quality testing in Cozine Creek as it runs through the campus. The original purpose of that study was to compare the water quality in urban and rural creeks; therefore, the students compared Cozine Creek to Gooseneck and Mill Creeks in Polk County. In 2012 poor water quality in Cozine Creek was attributed to agricultural and urban runoff (Bailey et al. 2012). In 2015, the students concluded that of the three nearby creeks examined, Cozine Creek had the worst water quality. This conclusion was supported by data for pH, temperature, flow, turbidity, BOD (biochemical oxygen demand), DO (dissolved oxygen), nutrient levels, macroinvertebrate diversity, and bacterial counts (Blanco et al.2015).

In 2016, the students decided to examine only Cozine Creek at several McMinnville locations to more closely study the effects of urbanization. The water quality in Cozine Creek is affected by its flow through both agricultural and urban settings. The students that year concluded water quality was declining due to runoff (Cowell et al. 2016). In 2018 students found slight improvement in the water quality as evidenced by declines in bacteria and turbidity; however, the dissolved oxygen levels and temperatures were still not within the range to support salmon (Schmidt et al. 2018). In spring 2018 students in Linfield's Environmental Studies Senior Capstone class (ENVS 470) wrote a grant for a restoration project and received $14,500 from the Oregon Watershed Enhancement Board (OWEB).The grant funded an ecological restoration experiment to compare various techniques to control non-native, invasive species such as Himalayan blackberry. The techniques compared using herbicides, mowing, and hand removal. The bulk of the money was used to pay the restoration contractor (Upshot LLC) for spraying and mowing efforts on the property; with hand pulling done by volunteers. The grant also funded the purchase of native plants that are being planted by Linfield students and volunteers. The restoration project should eventually improve the quality of water and riparian habitats in the Cozine Creek area on Linfield's campus by enhancing the vegetation in the surrounding area, increasing habitat, and decreasing runoff (Berg et al. 2018).

In 2019, the students in the Research Methods class (ENVS 460) again examined water quality in areas of Cozine Creek, and included a site in the Michelbook Meadows subdivision, upstream from the Michelbook Country Club. The students concluded the water at Michelbook Meadows had significantly lower levels of DO and water temperature and higher levels of BOD, turbidity, phosphate, and *Aeromonas* than the water at the College or Library sites. They attributed this to a low water flow at the site (Allen et al. 2019).

Purpose of Our Study

This fall, our class again examined and compared water quality at several sites along Cozine Creek. We also measured the vegetation in the area on campus and compared it to previous years in an attempt to determine the success to date of the restoration project on native plant cover. We hypothesized the restoration work being done in Cozine Creek area might decrease water quality by exposing the stream to more direct sunlight after the removal of invasive vegetation, affecting both stream temperature and dissolved oxygen. The removal of invasive plant species may also increase turbidity due to the reduction in ground cover. Although we did not believe we would see an improvement in water quality this year, we hope to find with proper urban planning, community involvement, and the continuation of Cozine Creek restoration projects, water quality will improve to the point that the creek will become viable for salmonids in the future.

DESCRIPTION OF STUDY SITES

We collected our data at three locations on Cozine Creek as it flows through McMinnville, Oregon: behind the McMinnville City Library (the “Library” site), on Linfield University’s campus (the “Campus” site), and along the creek by Shady Street (the “Shady Street” site), located just before the creek flows into the South Yamhill River. We took locational coordinates at each site using a hand-held Garmin Extrex GPS (Table 1). The McMinnville City Library site and the Shady Street site each had three subsites where sampling was conducted; the Linfield University site had 4 subsites (Figure 2).

Table1. GPS coordinates for each subsite at each site location.

Site Name	Subsite	Latitude	Longitude
Campus	1	45.20301	-123.19795
Campus	2	45.20218	-123.19831
Campus	3	45.20350	-123.19953
Campus	Side Stream	45.20529	-123.19990
Library	1	45.20988	-123.20155
Library	2	45.21033	-123.20197
Library	3	45.21059	-123.20208
Shady Street	1	45.20557	-123.18925
Shady Street	2	45.20544	-123.18965
Shady Street	3	45.20597	-123.18943

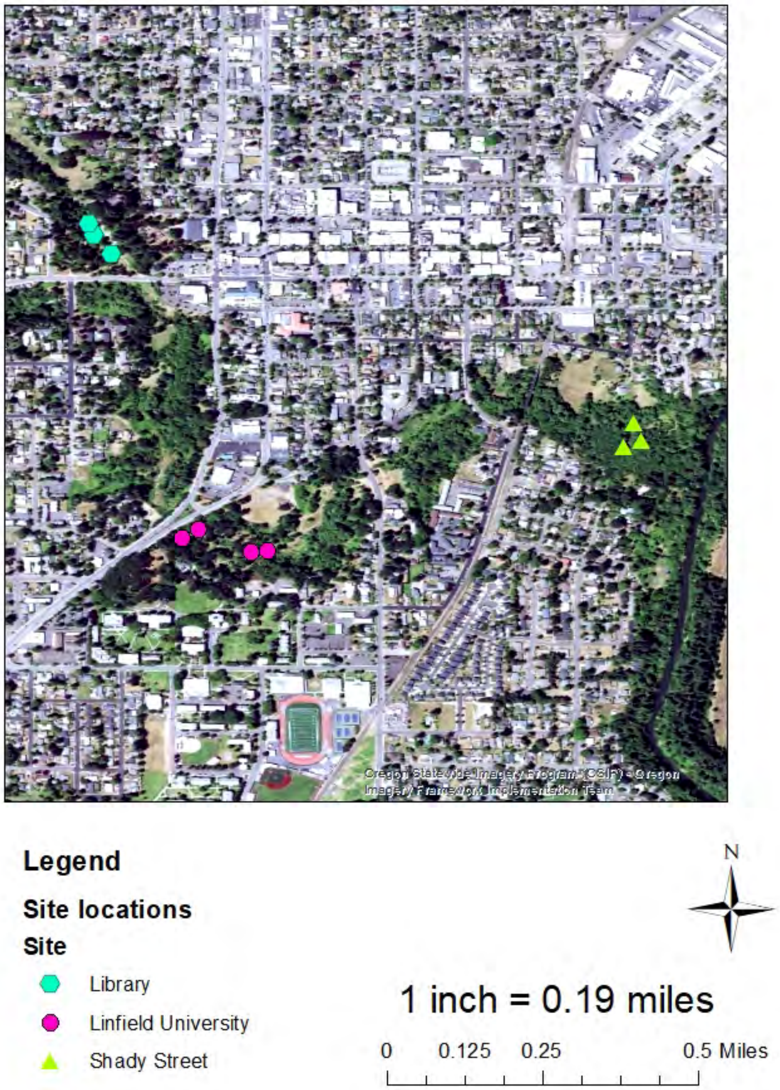

Figure 2. Map showing the subsites at each of the three site locations in McMinnville, Oregon. Map made using ArcGIS by Lily Hulsman.

Linfield University (Campus) Site

The site at Linfield University (called "Campus" in this study) was located along Cozine Creek as it flows through the north end of the campus (Figure 3). The Campus site has been tested annually by senior ENVS students since Spring 2011. There were three subsites along Cozine Creek (selected in 2011) with a fourth site (the sidestream) that was added in 2017 (Figure 3).

Figure 3. Linfield University (Campus) showing subsite locations. Each subsite is marked in the dot location on the map with the number noting the subsite name; S is the side stream. Map made using ArcGIS by Lily Hulsman.

Campus Subsite 1

The creek at subsite 1 was approximately 10 feet wide with no flow due to downed woody debris downstream. The lack of flow allowed large quantities of duckweed to cover most of the surface of the water. The bottom of the creek was predominantly mud. This subsite was the most downstream of the sampling areas for this site (Figure 3). The vegetation at this subsite included many Oregon ash trees that shaded the creek. Shrubs found at the subsite included creek dogwood and ninebark (*Physocarpus capitatus*) (Figure 4). Herbaceous plants included trailing blackberry, reed canary grass, and lemon balm (*Melissa officinalis*).

Figure 4. Photo taken at the Campus subsite #1 by Jordan Leis on 09/23/20.

Campus Subsite 2

The creek at this subsite was about eight feet wide and had many large rocks and pieces of woody debris present on the muddy substrate. This subsite was upstream from subsite 1 (Figure 3). The stream width was about 8ft in this section. The second subsite also had low flow but was covered by less duckweed. Oregon ash trees shaded the creek. Shrubs included creek dogwood, ocean spray, Himalayan blackberry, and ninebark. A few sedges and grasses were scattered above the creek along with some dead camas stalks. We noticed some trash scattered along the creek and observed water striders.

Campus Subsite 3

This subsite was the most upstream of the three main subsites (Figure 3) and was located as the creek flowed onto the campus below the culvert that runs under Baker Street. The culvert separated the stream into two separate rectangular tunnels that rejoined into a narrow stream as they entered campus. This section of the creek was only two feet wide and had a higher flow, less shade, and a mud substrate. Trees present included black cottonwood, Oregon ash, and red alder. The shrubs consisted of Himalayan blackberry and Douglas' spiraea (*Spiraea douglasii*). A large amount of reed canary grass covered much of the south side of the bank (Figure 5).

Figure 5. Photo taken at Campus subsite #3 by Jordan Leis on 09/23/20.

Campus Side Stream Subsite

This site is on a small side stream that empties into Cozine Creek at subsite 3 (Figure 3). The stream appears on the hill between Baker Street and the President's house. This site was added in 2017 to determine how it impacted the Campus site's water. It still is unclear what the source of the water is. The stream was about 2 feet wide. Trees included vine maple (*Acer circinatum*) and Oregon ash, as well as an ornamental birch tree (*Betula sp.*). The understory included sword fern (*Polystichum munitum*), bittersweet nightshade (*Solanum dulcamara)*, snowberry (*Symphoricarpos albus*), trailing blackberry, and invasive Italian arum (Figure 6). The sidestream substrate was mostly mud with some rocks scattered along the stream bank.

Figure 6. Photo taken at the Cozine Creek University Side-stream Subsite by Jordan Leis on 09/23/20.

The Library site

The Library Site was located upstream of the Campus Site in Lower City Park adjacent to the McMinnville City Library (Figure 2). This site had 3 subsites (Figure 7). The site differed from the Campus Site in that it is in a public park and the surrounding area includes lawns, picnic tables, many ornamental non-native species, and parking lots.

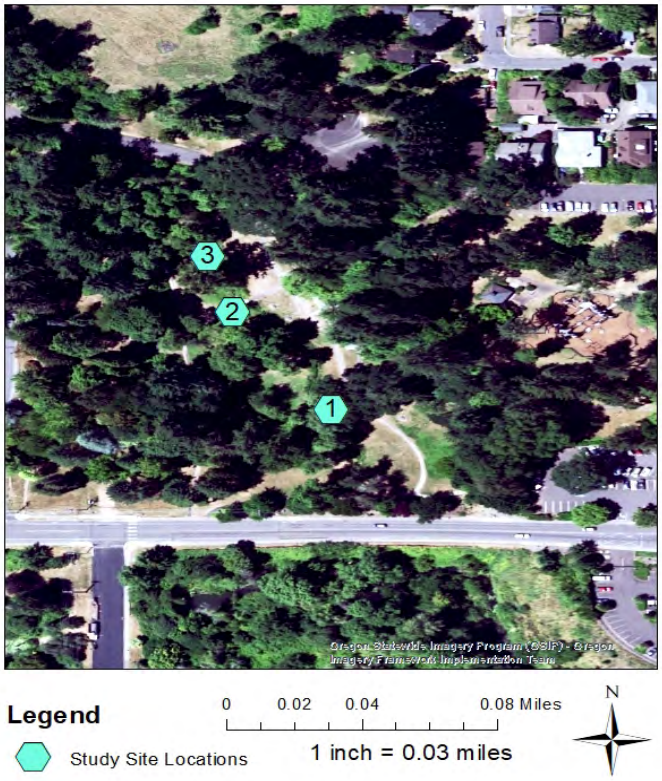

Figure 7. Library Site in City Park showing subsite locations. Each subsite is marked in the dot location on the map with the number noting the subsite name. Map made using ArcGIS by Lily Hulsman.

Library Subsite 1

The creek at this site was approximately 5 feet wide and was the most downstream sampling area at this site (Figure 7). The substrate was mud with scattered pebbles and chunks of concrete. Overstory trees included Oregon ash, a non-native poplar (*Populus sp*), a willow, and Douglas-fir. The understory consisted of many invasive species including yellow flag iris (*Iris pseudacorus*), lemon balm, bittersweet nightshade, creeping buttercup (*Ranunculus repens*), and Himalayan blackberry. Native species included trailing blackberry (Figure 8).

Figure 8. Photo taken of the Library Subsite 1 by Jordan Leis on 09/30/20.

Library Subsite 2.

The second subsite was upstream from the first and approximately 4 feet wide (Figure 7). The stream ran beneath a foot bridge immediately upstream from this site (Figure 9). There were several non-native popular trees in the area that shaded the creek, along with Himalayan blackberry. Other tree species included non-native English hawthorne (*Crataegus monogyna*) and Port Orford cedar (*Chamaecyparis lawsoniana*). Groundcover included wild blackberry, reed canary grass, and rush.

Figure 9. Photo of Library subsite #2 taken by Jordan Leis on 09/30/20.

Library Subsite 3

The third subsite was approximately 8 feet across and was the most upstream sampling location (Figure 7). The creek substrate was a mixture of mud and silt with large rocks and concrete slabs scattered in the muck. The flow appeared to be faster at this subsite. Trees in the area were all ornamental species of poplar and alder. Groundcover included yellow flag iris, bittersweet nightshade, and Himalayan blackberry (Figure 10). We also found *Ludwegia sp*, a particularly bad aquatic species at this site.

Figure 10. Photo of Library Subsite 3 taken by Jordan Leis on 09/30/20.

Shady Street Site

The Shady Street site was located in the area just above where Cozine Creek empties into the South Yamhill River (Figure 11). The area was surrounded by a riparian forest of native Oregon ash trees. This site had three subsites (Figure 11). The creek here was more deeply incised than at the other two sites, resulting in steep banks. The substrate was very muddy. This area has historically attracted transient populations that leave behind trash and debris.

Figure 11. Shady Street Site showing subsite locations. Each subsite is marked in the dot location on the map with the number noting the subsite name. Map made using ArcGIS by Lily Hulsman.

Shady Street Subsite 1

The first subsite was located down a steep slope and was the most downstream of the three sampling locations here (Figure 11). The creek was about 4 feet wide and there was woody debris in the creek upstream of our sampling area that reduced the flow of the stream. Many Oregon ash trees were located in the riparian forest above the creek that shaded the water. The understory vegetation included Himalayan blackberry, English hawthorn, wild rose (*Rosa multiflora*), and ninebark (Figure 12). The creek bed was very muddy with areas with small pebbles.

Figure 12. Photos of Shady Street Subsite 1 taken by Jordan Leis on 10/07/20.

Shade Street Subsite 2

Subsite 2 was located upstream from subsite 1 (Figure 11). A small rivulet with incised banks and a copper colored bottom flowed into Cozine Creek here (Figure 13). The creek was about 4 feet wide and had a very muddy bottom. The area above the creek had Oregon ash trees that shaded the bank. The bank itself was covered with Himalayan blackberry, reed canary grass, snowberry, evergreen blackberry (*Rubus laciniatus*), and unidentified herbs. Trash was found at this site.

Figure 13. Photo of Shady Street Subsite 2 showing the side stream taken by Jordan Leis on 10/07/20.

Shady Street Subsite 3

This subsite was the most upstream site sampled at this location (Figure 11). It was located upstream of a large debris dam that resulted in very low flow. The creek was approximately 10 feet wide with a muddy substrate. Trees found above the creek included Oregon ash and English hawthorne. The understory included Himalayan blackberry, creek dogwood, snowberry, and wild rose (*Rosa multiflora)* (Figure 14).

Figure 14. Photo of Shady Street Subsite 3 taken by Jordan Leis on 10/07/20.

METHODS

Methods in the Field

At each site we noted what vegetation was present, how wide the creek was, the weather, the general stream condition and substrate, and took GPS coordinates using a handheld Garmin Etrex 22x GPS. We then collected two water samples. The first sample was collected in a sterile 250 mL Nalgene bottle that was put on ice until we returned to the Environmental Science Lab, where it was placed in a freezer. The second sample was collected in a 250 mL glass BOD bottle that was fully filled with water and the stopper inserted ensuring no air bubbles or pockets were present in the container. This sample was immediately wrapped in foil and put in the ice cooler until we returned to the Environmental Science Lab, where it was put in a dark cabinet at room temperature for five days, after which time it was then used to determine BOD in the lab. The depth of the creek at the locations where these water samples were taken was measured.

After we collected the water, we measured four water quality variables at each subsite: DO, temperature, pH, and flow. Five readings of each were taken at each subsite of each variable. All equipment was calibrated prior to going into the field.

Dissolved Oxygen (DO) was measured in parts per million (ppm) and percent (%) using an Oakton DO6+ DO meter. The DO probe was placed in the stream so the probe was fully submerged but not touching the bottom of the stream. Measurements were taken after the reading had stabilized; the probe was removed from the creek between each of the five readings. Temperature was taken using the same DO meter. It was recorded five times, and the probe was taken out of the creek between readings.

pH was measured using a Hanna pHep probe. The probe was placed in the water until it was fully submerged. The measurement was taken after the meter had stabilized. It was recorded five times with the probe being taken out of the creek between readings.

Flow was measured with a Flowatch meter. The probe was placed in the stream with the propeller facing upstream ensuring it was not touching the bottom or moving for any reason other than flow. The probe was left in the stream for at least ten seconds and the average flow was recorded. It was recorded five times with the probe removed from the stream between readings.

Methods in the Laboratory

Five days after we collected the BOD water sample, we measured the dissolved oxygen (DO) in the sample. We carefully poured about 40ml of each sample into 5 beakers. We then measured the dissolved oxygen (DO) as percent and ppm in each beaker using the same DO meter we had used in the field. BOD was calculated by subtracting the DO measured in each beaker from the average DO measured at the subsite in the field (Delzer and McKenzie 2003).

The frozen water samples in the Nalgene bottles were slowly thawed, and those water samples were used to test for turbidity, coliform bacteria, and nutrients.

Turbidity was measured in the lab using a HANNA Instruments turbidity meter (model: HI93703). The bottle was gently inverted about three times to mix the contents and resuspend any particles. We then poured a sample of water into the cuvette provided with the machine and capped it. After wiping the outside with a cloth, the cuvette was placed in the reader and the turbidity was measured. Five measurements were taken for each sample, with the cuvette gently mixed between each reading. Turbidity readings were given in Formazin Nephelometric Units (FNU), which are similar to Nephelometric Turbidity Units (NTU) (USGS 2017b).

To test for coliform bacteria in the water samples we pipetted 1-3 ml of each water sample into a bottle of ECA Check Easygel using sterile technique. We made five plates from each water sample following the directions for the kit. Plates were placed in the dark at room temperature for 48 hours. After that time two students counted the number of colonies on each plate. The kit results in different bacteria being different colors: red/pink were *Aeromonas*, teal were *Salmonella*, dark blue were *E coli*, and gray or other shades of blue were other coliforms. The raw colony counts were converted to colonies per 100 ml (Micrology Laboratories, 2008).

We measured the levels of nutrients (nitrate, ammonia, and phosphate) in 5 subsamples from each water sample for each nutrient test. We tested each sample five times for nitrate by following the directions in the LaMotte nitrate kit (test kit 3354). The values were multiplied by 4.4 to convert to parts per million (LaMotte 2010). We tested each sample five times for ammonia by following the directions given with the LaMotte Ammonia kit (test kit 5864). Ammonia nitrogen was recorded as ppm after converting the reading by 1.3 (LaMotte 2009).We tested each sample five times for phosphate using the directions from the LaMotte Low Range Phosphate Water Test Kit (test kit 3121-01). This test gave readings in ppm (LaMotte, 2011).

Vegetation Sampling Methods

Vegetation was examined in the Cozine creek area on Campus at locations that had been set up prior to the start of the restoration project: on Newby Hill, on the South Side of the creek, and on the North Side of the creek. These transects allow us to observe changes in plant cover after the restoration project. We measured vegetation at each location by running transects starting from known GPS coordinates. The transects were run toward the designated compass heading to ensure we were measuring the same land as previous years. Ground cover was measured by noting what percent of each plant species (or ground) was located under each meter increment.

RESULTS

Water Quality Results Among Sites in 2020

We found that DO (%) and ppm were significantly lower at the Campus site than at any of the other sites, and that turbidity and water temperature were significantly higher at the Campus site than the others (Table 2). pH and flow were significantly higher at Shady Street than any other site. BOD (%) was significantly higher at the Library site than the Shady Street site, which was higher than at the Campus and Sidestream sites. Nitrate and ammonia were significantly higher in the Sidestream than at the other sites, whereas phosphate was significantly higher at the Sidestream and Shady Street than at the Library site.

Table 2. Mean (standard deviation) and probability of water quality variables among locations in Cozine Creek in fall 2020 based on ANOVA. Means with different letters are significantly different based on a Tukey HSD post hoc test.

Variable	Library	Campus	Sidestream	Shady Street	Probability
Air Temp (F)	70.0 (0) C	85.3 (2.6) A	86.0 (0) A	77 (0) B	<0.0001
DO %	63.4 (2.57) A	47.5 (23.9) B	79.5 (2.44) A	65.1 (3.59) A	<0.0001
DO ppm	6.08 (0.27) A	4.26 (2.23) B	7.37 (0.25) A	6.33 (0.39) A	<0.0001
Water Temp (C)	17.15 (0.31) BC	20.49 (3.17) A	19.46 (0.32) AB	16.57 (0.73) C	<0.0001
pH	7.04 (0.08) B	6.47 (0.18) C	7.08 (0.25) B	7.35 (0.18) A	<0.0001
Flow (cm/sec)	4.87 (1.68) B	0.4 (0.82) B	0 (0) B	12.2 (10.0) A	<0.0001
BOD%	57.73 (1.11) A	9.36 (13.24) C	13.3 (0.81) C	39.38 (18.50) B	<0.0001
Turbidity (FTU)	3.07 (1.07) B	9.03 (4.55) A	2.28(0.40) B	1.27 (0.51) B	<0.0001
Nitrate ppm	0.29 (0.77) BC	0 (0) C	4.4 (0) A	0.7 (1.03) B	<0.0001
Ammonia ppm	0.23 (0.13) B	0.27 (0.18) B	3.12 (1.16) A	0.11 (0.09) B	<0.0001
Phosphate ppm	0 (0) B	0.21 (0.22) AB	0.40 (0) A	0.23 (0.35) A	0.0048

We found significantly more *E coli* in the Library water sample than in the Campus or Shady Street water samples (Table 3). There were significantly more *Salmonella* in the Sidestream site than the other sites. There were significantly more *Aeromonas* in the Sidestream than the Library site, and both sites had more than at the Campus or Shady Street sites.

Table 3. Mean (standard deviation) and probability of the number of coliform colonies per 100mL of water at different sites on Cozine Creek in fall 2020 based on ANOVA. Means with different letters are significantly different based on a Tukey HSD post hoc test.

Variable	**Library**	**Campus**	**Sidestream**	**Shady Street**	**Probability**
E. coli	173.3(174.3) A	0 (0) C	150.0 (108.0) AB	41.1 (96.2) BC	<0.0001
Salmonella	4.4 (14.5) B	1.1 (6.1) B	20.0 (42.2) A	0 (0) B	0.0051
Aeromonas	622.4 (583.1) B	74.5 (156.0) C	1110.0 (375.5) A	316.5 (483.0) C	<0.0001
Other coliforms	425.9 (393.2) A	15.6 (23.4) B	410.0 (506.5) A	103.3 (147.1) B	<0.0001

Water Quality Variable Results For the Campus Site By Year

Percent DO was significantly higher in 2018 than all other years except 2017 and was significantly lower in 2013 and 2015 (Table 4). Temperature was significantly higher in 2012 than the other years; flow was low in 2012-2016 and in 2020. Nitrates were significantly higher in 2018 than the other years, and phosphate was significantly higher in 2011, 2015, 2017, and 2020 than in 2012 and 2019.

Table 4. Mean (standard deviation) and probability of water quality variables at the Linfield Campus site by year based on ANOVA. Means with different letters are significantly different based on a Tukey HSD post hoc test.

Water Variables	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**P Value**
DO %	69.49 (2.9) (BC	58.3 (1.0) BCD	43.5 (8.6) DE	52.43 (10.07) CD	33.99 (12.16) E	63.09 (3.73) BC	72.16 (9.09) AB	83.46 (10.87) A	58.6 (2.49) CD	47.51 (23.99) D	<0.0001
DO ppm	-	-	4.67 (0.89) CD	5.09 (1.15) CD	2.92 (1.00) E	6.20 (0.35) BC	7.08 (1.08) B	8.42 (1.56) A	5.59 (0.28) CD	4.26 (2.23) DE	<0.0001
Water Temp (C)	12.3 (0.1) E	9.5 (0.3) F	13.3 (0.7) DE	13.4 (1.2) DE	16.6 (0.6) BC	15.9 (0.6) BC	16.2 (1.1) BC	15.0 (2.7) CD	17.5 (0.6) B	20.5 (3.1) A	<0.0001
pH	6.84 (0.23) BC	6.49 (0.26) CD	6.32 (0.53) D	6.30 (0.31) D	7.17 (0.04) AB	7.30 (0.12) A	7.17 (0.15) AB	7.16 (0.44) AB	7.08 (0.10) AB	6.47 (0.18) CD	<0.0001
Flow (cm/sec)	8.8 (6.3) ABC	10.5 (8.56) ABCD	0.4 (0.9) CD	-	3.0 (4.4) CD	7.0 (7.6) BCD	26.0 (30.5) A	14.6 (8.3) ABC	17.9 (13.8) AB	0.4 (0.8) D	<0.0001
BOD%	-	3.68 (3.76) C	9.84 (6.01) BC	16.23 (7.58) ABC	24.9 (14.2) A	12.2 (6.23) BC	22.4 (5.73) AB	18.5 (6.09) AB	24.7 (12.6) A	14.3 (13.4) ABC	<0.0001
Turbidity (FTU)	-	-	9.12 (5.55) AB	5.04 (0.65) BCD	9.49 (4.04) A	5.94 (0.86) ABCD	6.42 (4.92) ABC	3.77 (1.28) CD	2.42 (1.99) D	9.03 (4.55) AB	<0.0001
Nitrate ppm	0 (0) BC	0 (0) BC	0 (0) BC	1.95 (3.19) BC	2.64 (3.91) B	2.49 (2.48) B	0.82 (1.04) BC	5.84 (2.19) A	1.47 (2.0) BC	0 (0) C	<0.0001
Ammonia ppm	-	-	0.12 (0.05) A	0.15 (0.06) A	0.15 (0.13) A	0.19 (0.09) A	0.14 (0.89) A	0.30 (0.43) A	0.25 (0.06) A	0.28 (0.17) A	0.1181
Phosphate ppm	0.2 (0) ABC	0 (0) D	0.06 (0.05) BCD	0.11 (0.18) BCD	0.311 (0.18) A	0.07 (0.05) BCD	0.19 (0.19) AB	0.08 (0.09) BCD	0.04 (0.05) CD	0.21 (0.22) AB	<0.0001

There were significantly more *E coli, Salmonella, Aeromonas,* and other coliform colonies in the creek at the Campus site in 2011 than in any other year (Table 5).

Table 5. Mean (standard deviation) and probability of the number of coliform colonies per 100mL of water at Campus site by year based on ANOVA. Means with different letters are significantly different based on a Tukey HSD post hoc test.

Year	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**p-value**
E. Coli (#/100mL)	577.8 (635.9) A	51.1 (28.5) B	44.4 (68.2) B	0 (0) B	15 (40.4) B	2.4 (6.6) B	47.4 (76.0) B	2.8 (11.1) B	2.2 (10.4) B	0 (0) B	<0.0001
Salmonella (#/100mL)	800 (447.2) A	0 (0) C	138.9 (92.8) B	0 (0) C	25 (43.7) C	5.6 (17.6) C	43.7 (67.7) C	4.6 (9.8) C	0 (0) C	1.11 (6.1) C	<0.0001
Aeromonas (#/100mL)	27288.9 (5210.7) A	1133.3 (487.1) B	-	22.2 (44.1) BC	30 (135.7) C	5.2 (12.0) C	52.6 (90.0) C	5.11 (11.5) C	66.7 (66.6) C	74.4 (156.0) C	<0.0001
Other coliforms (#/100mL)	4977.8 (2307.5) A	80 (49.0) BC	-	155.6 (187.8) BC	126.7 (257.7) BC	10.4 (27.5) C	123.7 (206.3) BC	8.0 (16.0) BC	276.7 (164.7) B	15.6 (24.3) BC	<0.0001

Water Quality Variable Results For the Sidestream Site By Year

pH and flow were significantly greater in 2017 in the Sidestream than in the other years it has been tested, and BOD, ammonia, and phosphate were significantly greater in 2020 than other years (Table 6).

Table 6. Mean (standard deviation) and probability of water quality variables in the Linfield Campus Sidestream by year based on ANOVA. Means with different letters are significantly different based on a Tukey HSD post hoc test.

Water Variables	**2017**	**2018**	**2019**	**2020**	**p-value**
DO %	88.02 (1.45) A	79.46 (9.23) A	77.76 (2.60) A	79.46 (2.43) A	0.0634
DO ppm	8.35 (0.20) A	7.47 (0.26) B	7.19 (0.23) B	7.37 (0.25) B	<0.0001
Water Temp (C)	17.3 (0.43)	18.15 (4.08)	19.04 (0.05)	19.46 (0.32)	0.585
pH	8.39 (0.20) A	7.64 (0.09) B	7.71 (0.08) B	7.08 (0.25) C	<0.0001
Flow (cm/sec)	11.8 (1.32) A	2.8 (0.76) B	0 (0) B	0 (0) B	<0.0001
BOD%	-	25.9 (0.72) B	19.0 (0.72) C	66.2 (0.81) A	<0.0001
Turbidity (FTU)	6.42 (0.75) AB	5.83 (0.72) B	9.11 (1.03) A	2.16 (0.16) C	<0.0001
Nitrate ppm	0.88 (0.37) D	7.04 (0.37) A	2.64 (0.62) C	4.4 (0) B	<0.0001
Ammonia ppm	0.13 (0) B	0.17 (0.09) B	0.10 (0.03) B	3.12 (1.16) A	<0.0001
Phosphate ppm	0 (0) C	0.12 (0.11) B	0.05 (0) BC	0.4 (0) A	<0.0001

We found significantly more *E. coli* in 2019 than in 2018 in the Sidestream, but significantly more *Salmonella* and *Aeromonas* in 2020 than in any other year (Table 7).

Table 7. Mean (standard deviation) and probability of the number of coliform colonies per 100mL of water at Linfield Campus Sidestream by year based on ANOVA. Means with different letters are significantly different based on a Tukey HSD post hoc test.

Bacteria	**2018**	**2019**	**2020**	**p-value**
E. coli	35.8 (42.4) B	308.9 (457.7) A	108.0 (34.2) AB	0.0035
Salmonella	2.5 (7.6) B	0 (0) B	20 (42.2) A	0.0216
Aeromonas	55(56.6)B	120(163.4)B	1110(375.5)A	<0.0001
Other coliforms	53.4 (55.6) B	383.4 (503.1) A	410 (506.5) A	0.0021

Water Quality Variable Results For the Library Site By Year

We found significantly higher BOD and lower turbidity in 2020 than in other years, but significantly higher DO in 2017 than in 2020 at the Library Site (Table 8).

Table 8. Mean (standard deviation) and probability of water quality variables at Library site by year based on ANOVA. Means with different letters are significantly different based on a Tukey HSD post hoc test.

Water Variables	**2017**	**2018**	**2019**	**2020**	**P-value**
DO %	77.76 (0.78) A	66.94 (1.73) B	64.25 (4.57) BC	63.40 (2.57) C	0.0001
DO ppm	7.40 (0.08) A	6.53 (0.21) B	6.07 (0.39) C	6.08 (0.27) C	0.0001
Water Temp (C)	16.14 (2.45) B	16.35 (0.42) B	17.98 (0.42) A	17.15 (0.31) AB	0.0008
pH	7.40 (0.04) A	7.08 (0.12) B	6.96 (0.13) B	7.04 (0.08) B	0.0001
Flow (cm/sec)	2.60(0.60) B	3.53(3.33)AB	3.26(2.40)AB	4.86(1.68)A	0.0647
BOD%	21.7 (0.82) C	20.4 (0.42) C	32.4 (1.94) B	57.7 (0.28) A	0.0001
Turbidity (FTU)	7.81(2.21)A	-	7.60(1.92)A	3.06(1.06)B	0.0001
Nitrate ppm	0.29(0.31) B	3.73 (1.14) A	1.32(0.62) AB	0.29(0.77) B	0.0001
Ammonia ppm	0.19(0.09)A	0.31(0.19)A	0.24(0.09)A	0.23(0.12)A	0.1321
Phosphate ppm	0.21(0.22)A	0.08(0.08) BC	0.12(0.07)AB	0 (0) C	0.0002

There were significantly more *E. coli*, *Aeromonas*, and other coliform colonies in 2020 at the Library site than in the other years but significantly more *Salmonella* in 2017 (Table 9).

Table 9. Mean (standard deviation) and probability of the number of coliform colonies per 100mL of water at Library site by year based on ANOVA. Means with different letters are significantly different based on a Tukey HSD post hoc test.

Bacteria Types	**2017**	**2018**	**2019**	**2020**	**p-value**
E. coli	30.4 (36.1) C	91.1 (41.3) B	0 (0) C	173.3 (174.8) A	<0.0001
Salmonella	92.6 (90.4) A	17.2 (20.5) B	0 (0) B	4.4 (14.4) B	<0.0001
Aeromonas	10.3 (18.5) B	61.6 (56.3) B	18.8 (37.3) B	622.3 (583.1) A	<0.0001
Other coliforms	22.9 (33.9) B	78.8 (82.9) B	73.3 (85.0) B	425.9 (393.1) A	<0.0001

Vegetation Results

We found the percent of coverage by English ivy and total invasive species was significantly lower in 2020 than in 2017 (Table 10).

Table 10. Mean (standard deviation) and probability as per ANOVA of percent cover by plant species and total invasive species on Newby Hill. Means with different letters are significantly different based on a Tukey HSD post hoc test.%

Ground Cover	**2017**	**2018**	**2019**	**2020**	**p-value**
Bare ground	18.8 (11.8)	25.8 (20.6)	18.1 (10.8)	21.4 (20.1)	0.8788
Creeping buttercup	4.4 (2.7)	1.5 (1.8)	7.1 (4.5)	3.0 (3.0)	0.0789
English ivy	24.1 (4.4) A	13.7 (4.5) AB	21.6 (5.7) A	7.7 (8.9) B	0.0026
Reed canary grass	0 (0.04)	0 (0.04)	0 (0.04)	0.08 (0.04)	0.3756
Himalayan blackberry	10.3 (5.7)	5.6 (3.8)	6.4 (5.0)	8.4 (10.1)	0.6881
Wild blackberry	11.7 (8.9)	23.9 (15.1)	16.7 (7.7)	7.4 (8.8)	0.1244
Grass	16.9 (4.5)	10.9 (9.1)	13.0 (5.6)	7.3 (8.5)	0.2207
Snowberry	4.2 (4.3)	5.6 (7.7)	4.2 (6.0)	0.2 (0.4)	0.439
Invasive species	43.5 (3.6) A	26.5 (6.6) AB	41.5 (4.8) AB	21.0 (21.2) B	0.0166

We found no significant differences in plant cover between 2019 and 2020 in the South Side cleared site (Table 11).

Table 11. Mean (standard deviation) and probability as per ANOVA of percent cover by different plant species along the South cleared site. Means with different letters are significantly different based on a Tukey HSD post hoc test.

% Ground Cover	**2019**	**2020**	**p-value**
Bare ground	46.9 (34.1)	9.9 (19.9)	0.1477
Creeping buttercup	1.4 (1.7)	7.9 (7.1)	0.2033
English ivy	0.7 (0.5)	0.2 (0.5)	0.5614
Reed canary grass	3.8 (5.8)	2.3 (3.2)	0.715
Himalayan blackberry	9.2 (7.0)	23.1 (7.0)	0.2341
Wild blackberry	0.5 (0.8)	0.6 (0.6)	0.8512
grass	12.5 (9.1)	29.5 (29.3)	0.3917
Invasive species	15.51 (8.5)	33.96 (18.8)	0.1969

We found the percent bare ground at the North Bridge site was significantly higher in 2017 than in 2020, and that the percent cover by Himalayan blackberry and invasive species were greater in 2020 than in 2017 (Table 12).

Table 12. Mean (standard deviation) and probability as per ANOVA of percent cover by different plant species along North Bridge site. Means with different letters are significantly different based on a Tukey HSD post hoc test.

% Ground Cover	**2017**	**2019**	**2020**	**p-value**
Bare ground	75.1 (12.72) A	28.2 (23.4) B	13.4 (26.8) B	0.002
Creeping buttercup	1.0 (1.5)	1.3 (1.9)	3.6 (3.1)	0.1897
Reed canary grass	0 (0)	0.4 (0.9)	4.0 (6.8)	0.2507
Himalayan blackberry	1.1 (1.3) B	16.7 (22.4) AB	30.4 (19.5) A	0.0575
Wild blackberry	0.8 (1.9)	3.3 (6.1)	1.9 (2.9)	0.6753
Grass	15.3 (8.8)	30.9 (38.7)	40.4 (44.7)	0.5272
Invasive species	3.7 (3.0) B	34.9 (22.7) AB	47.8 (27.7) A	0.016

In 2018, restoration project grant money was used to plant native species on Newby hill. These species included Oregon grape, snowberry, Indian plum, and sword fern. More plantings were done in 2019. We found survivorship in fall 2020 ranged from 8 to over 76% for different species (Table 13).

Table 13. Percent survivorship of restoration project native species plantings on Newby Hill.

Plant Species	Number planted in 2018	Number Planted in Spring 2019	Number surviving Fall 2018	Number surviving Fall 2019	Number surviving Fall 2020	Percent Survivorship (2018)	Percent Survivorship (2019)	Percent Survivorship (2020)
Oregon Grape	72	24	26	9	8	36.1	12.5	8.3
Snowberry	29	66	35	10	73	120.7	34.5	76.8
Indian Plum	35	10	10	5	7	28.6	14.3	15.6
Sword Fern	-	37	-	-	11	-	-	29.7

DISCUSSION

Cozine Creek By Site in Fall 2020

This year, our class found that water quality appeared to be the poorest at the Campus site compared to the other sites we sampled. We found DO was significantly lower and turbidity was significantly higher at the Campus site than at the Sidestream, Library, or Shady Street sites. Warmer water holds less DO, therefore, warmer streams often have lower DO than colder streams. There are several reasons why temperature may have been higher at the Campus site. The campus was measured on the hottest day we sampled water quality (86°F), so the low DO at the Campus site may have been related to recent weather. There also had been no precipitation for over a month (Anonymous 2020) resulting in low to no flow. Water heats up as it fails to flow so this also could have contributed to the difference between the Campus and other sites. In addition, due to the ongoing restoration project, removal of Himalayan blackberry and other invasive species that had shaded the stream may also have been a contributing factor to higher temperatures and lower DO. The Campus site also had the highest turbidity; higher levels of turbidity also can increase water temperature (SOURCE). The DO at the side stream was significantly higher than any of the other three sites, this could be a result of the source of water in the Sidestream. The Sidestream has unknown origins and enters the site from a culvert below

Baker and has about a two foot drop that could oxygenate the water. This could contribute to the higher levels of DO at the Sidestream site.

The pH was significantly lower at the Campus site than any of the other sites. Warmer water tends to have lower pH, so it could have simply been related to the weather. pH can also be affected by the amount of dissolved carbon dioxide and nutrient pollutants in the water by lowering pH value making the water more acidic. Pollution can also affect the pH of waterways due to acid precipitation, dry deposition, toxic waste, run-off, and nonpoint-source pollution (USGS 2016b).

Coliform bacterial levels in Cozine creek were significantly lower at the Campus site than any other sites tested. We found levels of *E. coli* in the Library site water sample were much higher than at the other sites. The higher level of *E. coli* at the Library site could have been contributed to an increase in fecal waste from pets, birds and other wildlife (CDC 2015a). or due to the golf course upstream where many there are many geese. *E. coli* colonies in Cozine are still well below recreational limits of 126 to 406 CFU (DEQ 2020).

Campus site Changes over the Years

When we examine the water quality on the Campus site where we have been sampling the water for ten years, we see some interesting trends. Water temperature at the Campus site has been above levels where salmon can spawn and hatch for the entire time, we have been sampling (Figure 15). Temperature was significantly lower in 2012 than the other years, but still not within the limits required for salmon. Temperatures below 9°C are required for salmon to spawn, and they die above 18°C (EPA 2003).

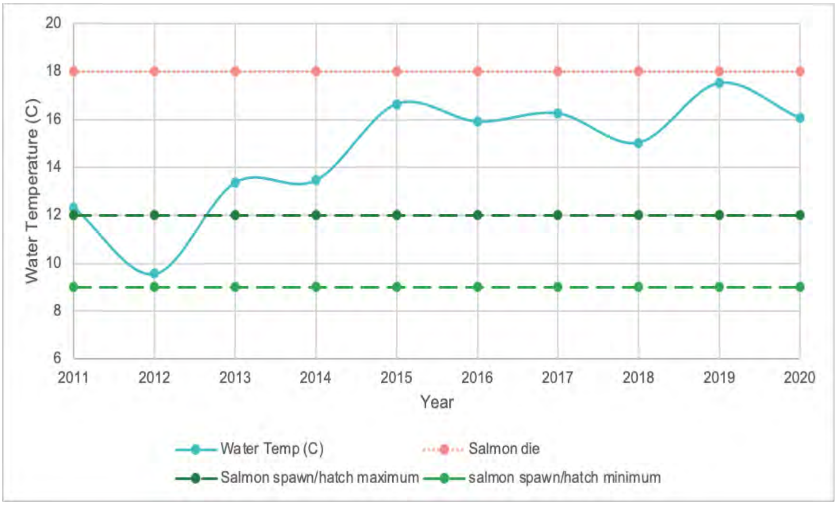

Figure 15: Mean temperature (°C) at the Linfield Campus site fall 2013 to 2019. The dotted line represents the maximum temperature for salmon to live, 18°C (EPA 2003).

Percent DO was significantly higher in 2018 than all other years except 2017 and was significantly lower in 2013 and 2015 (Figure 16). The higher stream temperature and lower dissolved oxygen content in the last two years could be a result of the restoration project removing invasive species that have been shading the stream. Salmon prefer DO above than 9 ppm and will not spawn until it is above 11 ppm (EPA 2016b). The Campus site DO levels have been below what salmon require every year we have tested it.

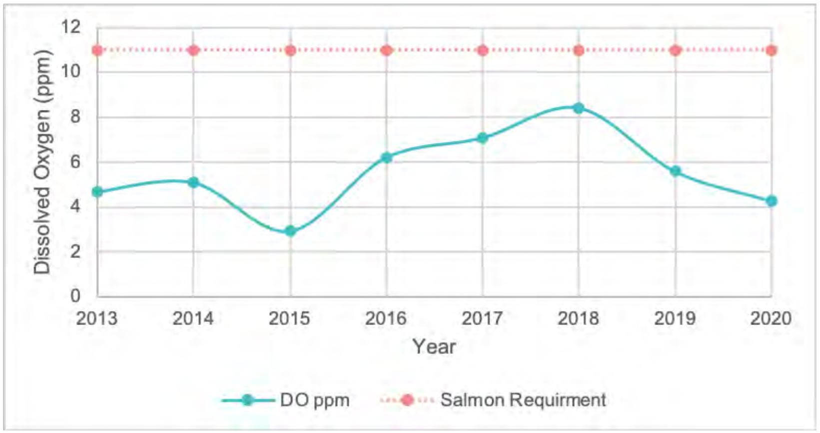

Figure 16: Mean oxygen (ppm) at the Linfield Campus site fall 2013 to 2019. The dotted line represents the minimum amount of DO that salmon prefer (EPA 2016b).

pH at the Campus site has fluctuated (figure 17). The level between 2015 and 2019 was in the acceptable range for salmon but dropped close to the level unfit for them this year (Sauter et al. 2001).

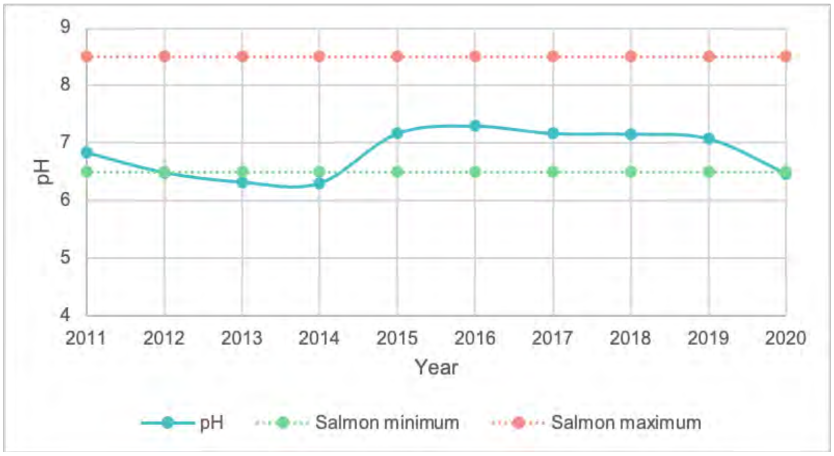

Figure 17. Mean pH value of Linfield Campus site fall 2011 to 2020. Dotted lines represented maximum and minimum values where salmon and trout can live (Sauter et al. 2001).

The levels of *E coli* at the Linfield Campus site were high in 2011 but dropped in 2012 and have remained low (Figure 18). This means the amount of fecal contamination is low, which is a promising trend toward higher water quality.

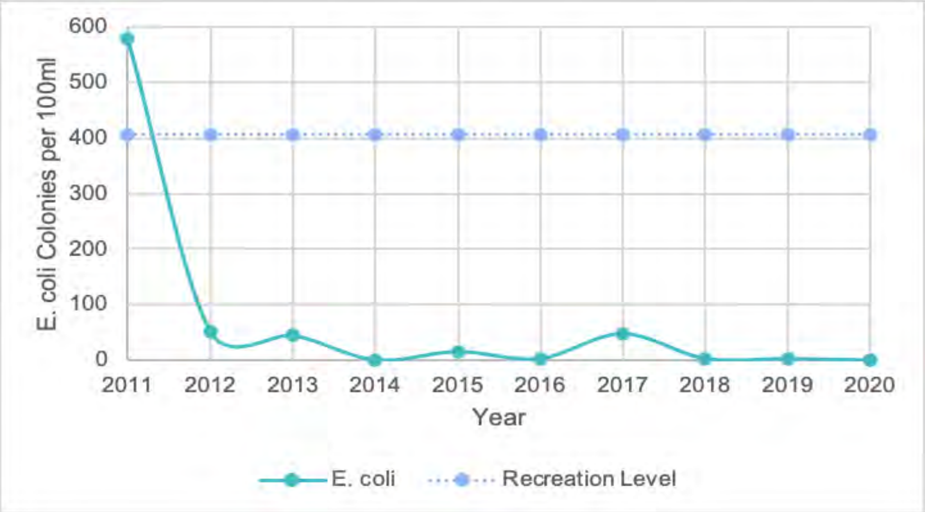

Figure 18. Mean *E. coli* colonies found at the Linfield Campus site from fall 2011 to 2020. The dotted line represents human recreational use limit (DEQ 2020).

Library Site Changes over the Years

The senior capstone classes began testing water at the Library site in fall 2017. The level of dissolve oxygen (DO ppm) was significantly lower in 2020 than 2017 and has constantly stayed below the salmon spawning requirement of 11 ppm (Figure 19). The low level of DO is consistent with what we see at the Campus site.

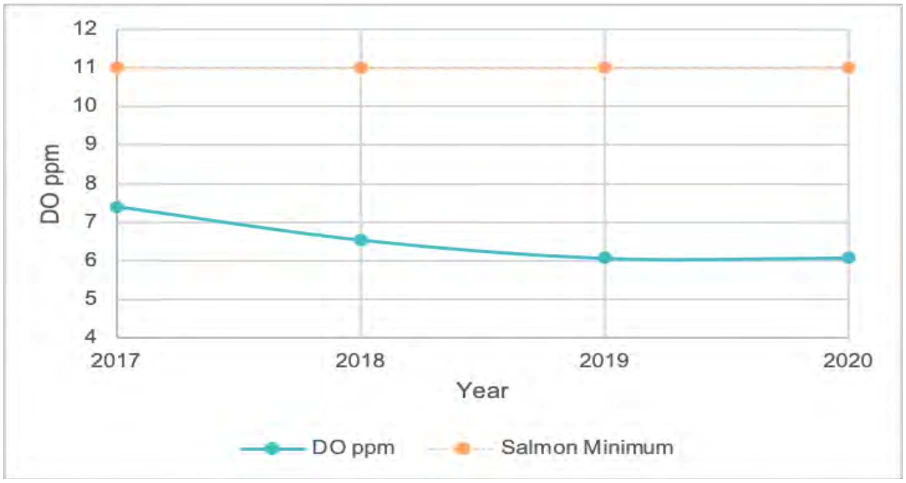

Figure 19. Mean DO (ppm) at the Library site from fall 2017 to 2020. The dotted line represents the minimum amount of DO that salmon prefer (EPA 2016b).
The water temperature at this site has fluctuated (Figure 20).

The temperature has been with a level where salmon can survive but it above the level where they can spawn (EPA 2003).

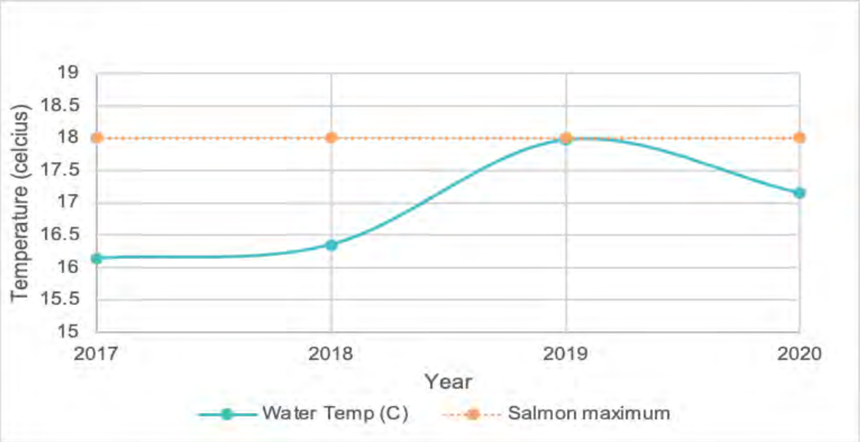

Figure 20. Mean temperature (°C) at the Library site fall 2017 to 2020. The dotted line represents the maximum temperature for salmon to live, 18°C (EPA 2003).

Levels of *E. coli* have also fluctuated (Figure 21) but at their highest in 2020. In all years, the level has been below the recreational limit for human use in streams. The level found this year could be from an increase amount of people taking their dogs to the public park and not cleaning up or to the geese that live upstream at the Michelbook Golf Course.

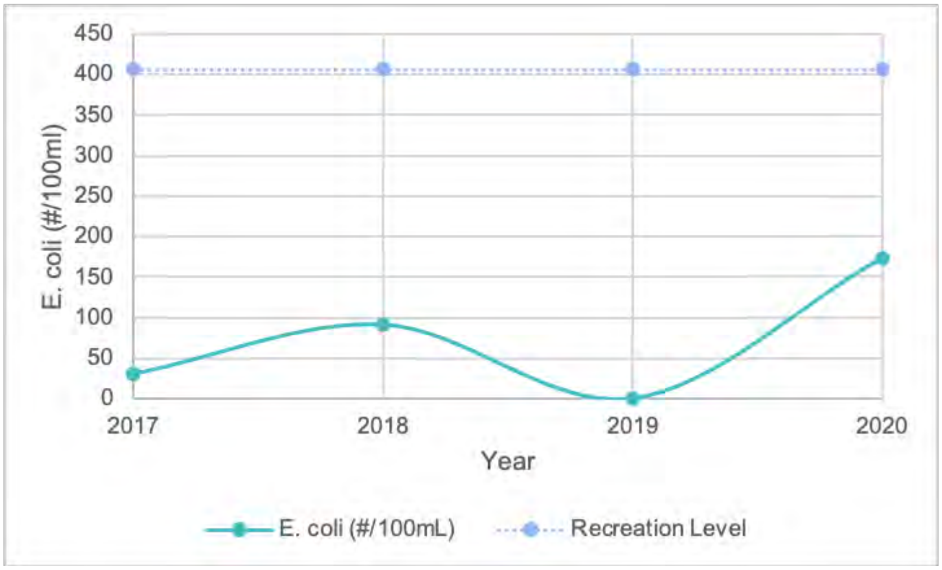

Figure 21. Mean *E. coli* colonies at the Library site fall 2017 to fall 2020. The maximum amount allowed for human recreational use is represented by the dotted line (DEQ 2020).

Vegetation Survey and Restoration Project

Vegetation is important for streams; native plants provide shade, which helps keep the water cool, prevents erosion, and filters pollutants, preventing them from entering waterways. The Cozine restoration project has focused on removing invasive vegetation and replacing it with native trees, shrubs, and ground cover. Students first started measuring vegetation on Newby Hill in 2017, a year after hand removal began. This year we found percent cover by invasive species on Newby Hill had significantly decreased from 2017 to 2020 (Figure 22). This suggests the restoration work of hand removal in this area of campus is having a positive impact on native plant restoration by decreasing the number of invasive species that out-compete and reduce native biodiversity (OSU 2020). Though the overall percentage is decreasing we did find small increases in abundance of invasive species like Italian arum and reed canary grass, which are harder species to control. We also found that the planting of native species is helping, and the snowberry, which was planted on Newby hill in 2018 and 2019, has increased in number and appears to be reproducing on its own.

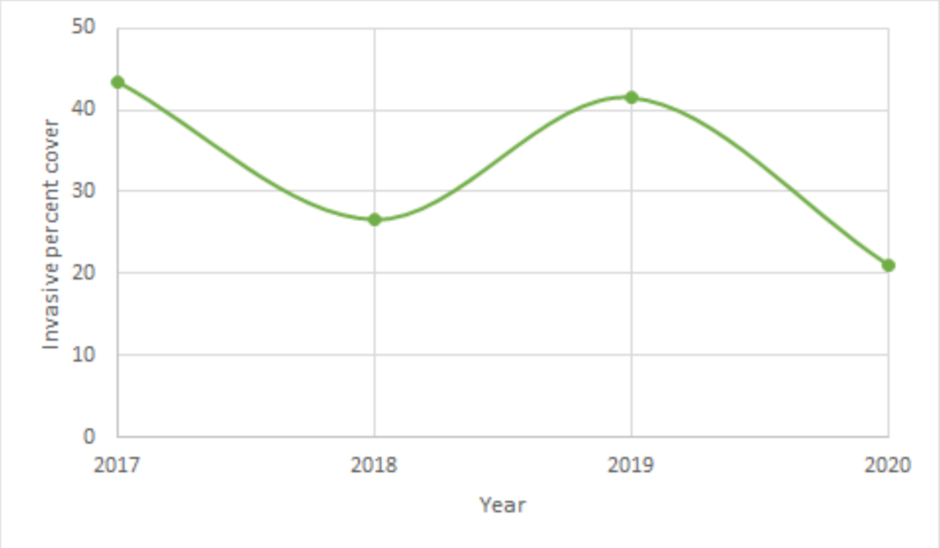

Figure 22. Mean percent total invasive species cover on Newby hill from 2017 to 2020.

CONCLUSIONS

In 2011 the Environmental Studies Senior Capstone class found that the water quality of Cozine Creek was impaired due to low oxygen levels, high water temperatures, and levels of *E. coli* (Allen et al. 2019). This was the first year that the Environmental Studies Capstone classes began to test the water quality in Cozine Creek; this has continued until this year. This year like in the past we found that most of the water quality variables exceeded levels required for salmonids to survive in the creek. It is hoped that the restoration project on our campus, as well as other areas along Cozine Creek will lead to a gradual improvement in the water quality.

The restoration project is removing nonnative vegetation at the Campus site and replanting native species. We have seen a decline in cover by invasive species on Newby Hill where hand pulling started before the grant funding. We also have seen a regeneration of native vegetation in the study area, with Camas returning to areas soon after blackberry removal. The Camas is now healthy enough that we are harvesting seed to help with restoration in other areas. We hope the restoration project will ultimately result in improved water quality and a healthy ecosystem with restored native biodiversity.

Limitations

While performing any type of research there will be errors in the collection of data as well as in executing lab procedures. Many sources of error stem from small mistakes made by the persons collecting or recording data. Errors that can occur in the field include incorrectly reading the value from a piece of equipment, not waiting for readings to stabilize, contamination of the water prior to taking a reading, or incorrectly recording data. Many of these human errors can be reduced by having multiple people test, read, record, and re-check the data.

Recommendations

In the future, if the class that is large enough, we would recommend splitting the students into groups so all the sites could be tested on the same day. Changing weather from one week to the next may have resulted in temperature and flow issues.

Acknowledgments

This project was successful with the help and encouragement of several people. We would like to thank Nancy Broshot who oversaw the project and helped with data collection in Cozine Creek. We also want to thank Barbara Van Ness for helping set up and run labs, as well as for calibrating all equipment prior to lab. Thanks to Bill Fleeger for his support and helping with restoration planning. Thank you to the head of the Greater Yamhill Watershed Council, Luke Westphal. Luke provided lots of information about the area and the restoration work. Lastly, we would like to thank the Shady Street land owners for granting us access to their property. It is because of you that we were able to do this project and contribute to the restoration of Cozine Creek.

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