Water Quality and Vegetation Study
Senior Capstone ENVS 460: Fall 2019

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INTRODUCTION

Many, if not all, societies around the world utilize freshwater to provide nutrients for their people, from harvesting aquatic organisms from streams or lakes to crops grown with irrigated water. Thus, fresh water is one of the most important aspects of a healthy society. The ecosystems in and by freshwater will continue to host resources for societies. However, freshwater ecosystems are fragile, relying upon a consistent range of conditions to sustain life (Resh and Unzicker, 1975). This fragility makes these ecosystems especially prone to human interaction, as active or passive interaction with water can incur detrimental effects to the ecosystems on which aquatic life depends. With increasing human populations, urban sprawl, and increasing recreational and agricultural use, freshwater resources are susceptible to contamination (Dodds et al., 2013). With increased anthropogenic pressure, regular water quality testing becomes increasingly important. If the water quality diminishes to a point where it cannot sustain life, the resource within the water that society depends upon die (Nellemann et al., 2008).

Freshwater ecosystems rely on the quality of the water in which they exist. The quality of the water will not only determine the health of what lives there, but also what species of fish, amphibians, insects, plants, and other forms of life are present (Wentz et al., 1998). The quality of the water will determine how successful certain species are in all aspects of life, from reproduction to survivability. A high quality freshwater aquatic system can provide essential habitats for at-risk species and can function as spawning and rearing habitat for species such as salmonids, amphibians, freshwater mussels and other invertebrates (ODFW, 2019). Low water quality, however, may result in population declines and range reductions of freshwater species and the biodiversity in that water system (Schmidt et al., 2018).

Many freshwater systems are susceptible to declines in water quality. Overexploitation, destruction and degradation of habitat, flow modification, water pollution, and invasion by exotic species often occur due to human interaction and are the cause of many of these declines (Dudgeon et al., 2006). Water systems in closer proximity to agricultural, residential, or industrial lands will experience greater anthropogenic impacts. Lands with different uses will contribute varying degrees and types of water contaminants based on the methods of land upkeep and the usage of that land. (Taylor et al., 1992). Identifying anthropogenic impacts can help identify the causes of changing water quality.

Beginning in 2011, students in Linfield College's Research Methods classes (ENVS 385 and ENVS 460) have conducted annual water quality tests in Cozine Creek, a small stream that runs through McMinnville, Oregon and Linfield College's Campus. This creek flows through agricultural, forested, and urban areas. The Research Methods' classes between 2011 and 2015 determined that Cozine Creek had the poorest water quality of the three local creeks they examined. To ascertain the quality of water, Research Methods students analyzed the biochemical oxygen demand (BOD), dissolved oxygen levels (DO), pH, water temperature, flow, turbidity, nutrient levels, bacterial counts, and macroinvertebrate diversity (Cowell et al. 2016).

Water Quality Legislation

Public waters in the United States are regulated by both state and federal legislation. Federal legislation is generally written to set a format for the state's water quality requirements. In most cases, the federal government does not set the water quality standards of an individual waterway. Federal laws require that states submit specific water quality standards for review to the Environmental Protection Agency (EPA). In Oregon, water quality standards are monitored and assessed by the Department of Environmental Quality (DEQ) (DEQ, 2019a)

The main federal law that applies to Cozine Creek is the Clean Water Act (CWA). The CWA is the foundation for the regulation of public water quality standards (EPA, 2019e). It requires that states implement and enforce water quality standards appropriate for their ecological situation. These standards are approved by the EPA. The CWA was originally passed to address point source pollution and enables the federal government to require permits and licensing for release of any contaminants that might jeopardize water quality. It since has been amended several times with the purpose of preserving water quality (Anonymous, 2019b)

Oregon's general water quality standards are under Oregon Administrative Rules Chapter 340 Division 41. This law is designed to comply with the CWA. Because Cozine Creek lies within the Willamette basin, it is expected to be suitable for a wide range of beneficial uses under OAR 340-041-0340. These uses include contact recreation, fishing, boating, irrigation, livestock watering, and even public and domestic water if properly treated (DEQ, 2005). Cozine Creek is also designated as salmon and trout rearing and migration habitat (DEQ, 2003). However, Cozine creek is also listed as an impaired waterway under the state's 303(d) list. A 303(d) list is a list of waterways that is given to the EPA every two years, per CWA requirements, to prioritize and organize the implementation of Total Daily Maximum Loads (TDMLs) of pollutants (EPA 2019g). The creek is listed as having impaired temperature, dissolved oxygen, and *E. coli* levels (ODA, 2015). The EPA has no data relating to the sources or probable sources of the impairments and has no listed TMDLs for the creek (EPA 2019f).

The regulations that apply to Cozine Creek are found under both the state general water quality standards and basin specific standards. The acceptable pH range is 6.5 to 8.5 according to OAR 340-041-0345. Temperature, which is taken as a seven-day average, may not exceed 18.0°C under OAR 340-41-0028. For a contact recreation waterway such as Cozine Creek, bacterial levels are not to exceed a 90-day geometric mean of 126 *E. coli* organisms per 100 ml, and no one sample may be above 406 *E. coli* organisms per 100 ml. The state general water quality standards do not allow the presence of any harmful bacteria that may interfere with any of the designated uses of a waterway, but only gives *E. coli* thresholds. Dissolved oxygen content must not be below 8.0 mg/l (ppm). Turbidity is only regulated if an anthropogenic source of turbidity is found in the water, such as from construction. In such a case, turbidity should not exceed 10% of the background (DEQ, 2019b).

History

When Samuel Cozine settled along Cozine Creek in 1845, it would have looked very different than it does today. Prior to European settlement, the area surrounding the creek was mainly prairie and oak savanna with many grasses and wildflowers. The area was inhabited by the Yamel tribe, a subset of the Kalapuya people of the lower Columbia (Personal Communication, Luke Westphal, November 6th). For at least 4,000 years, the Yamel regularly burned large sections of the area. This had the effect of suppressing brush and small tree growth while encouraging grassland habitat. Grassland habitat was vital for the indigenous population because it supported their main food plants, particularly camas (*Camassia quamash*). Unlike other Pacific Northwest indigenous groups, the diet of the Kalapuya was primarily plant based (YBC, 2001). The riparian area surrounding Cozine Creek was dominated by large deciduous trees such as Oregon ash (*Fraxinus latifolia*), Oregon white oak (*Quercus garryana*), and cottonwood (*Populus trichocarpa*) (GYWC, 2019).

As the Willamette Valley became settled by Europeans, McMinnville grew around Cozine Creek. The prairie's grasses and wildflowers were plowed to make way for agriculture. The oak savanna was logged to clear space for the expanding farms and city. In the Willamette valley, less than five percent of oak savanna habitat remains (Oregon Conservation Strategy, 2019c). About 70 percent of the land in the Yamhill watershed is currently agricultural (YBC, 2001).

In 1988 a leak in the Linfield College football stadium boiler room discharged fuel oil into Cozine Creek. The spill was cleaned up, but residual oil in the soil was not cleaned (DEQ, 1988). In 2008 *E. coli* levels became so elevated that the City of McMinnville warned people not to touch the water (Paysinger, 2008). In February 2019, a sewage line spill dumped about 4,000 gallons of sewage into the creek. The spill occurred upstream of the McMinnville library and Lower City Park was posted with signs to warn the public against coming into contact with the creek (KLYC, 2019).

Water Quality Variables

Many factors are involved in determining the quality of water. Although many aspects of water can be tested to determine the quality of a water source, some of the most important are dissolved oxygen (DO), biochemical oxygen demand (BOD), flow, pH, water temperature, turbidity, phosphate levels, nitrate-nitrogen levels, ammonia-nitrogen levels, and coloform bacterial contents. Each of these factors are important in their own way with regard to how they affect the health of a water source - different organisms that live in the water have different requirements for these variables. Changing one can alter the entire. Factors such as pH, temperature, DO, and flow can all be tested using equipment in the field, whereas factors such as BOD and bacteria require analyzing water in the laboratory (Lower Colorado River Authority, 2019).

Dissolved oxygen (DO) is the measure of how much oxygen is available for aquatic organisms. Oxygen most commonly enters water systems through aeration from riffles, waterfalls, and water with high flow, but it can also enter water from the photosynthesis of plants and underground discharge from springs (USGS, 2014). Aquatic animals, bacteria, and decomposing plant matter consume DO. Additionally, water temperature and DO levels are inversely correlated as warmer water can hold less dissolved oxygen. A lack of available DO can result in water becoming uninhabitable by organisms (Connolly et al., 2004). DO readings below 3 mg/L (ppm) are considered a concern for aquatic life, and any reading below 1 mg/L is considered hypoxic and unable to sustain most life (EPA, 2019d). Ultimately, the availability of DO critically affects the composition of freshwater communities, which will vary with DO, making this aspect of water quality important in maintaining ecosystems (Connolly et al., 2004). The mean DO level that is acceptable for adult salmon is >11 ppm and levels lower than 6 ppm are considered lethal. (Kidd, 2011).

The biochemical oxygen demand (BOD) is the amount of dissolved oxygen consumed by organisms and chemical oxidation reactions in a sample of water kept in the dark at room temperature for five days. Decomposition and aerobic processes increase biochemical oxygen demand (Jouanneau et al., 2013). A high BOD level negatively correlates with a lower dissolved oxygen as there will be less oxygen available in the water if it is being utilized. The BOD is also impacted by a number of variables including temperature, pH, abundance and function of microorganisms, and the presence and type of organic and inorganic material in the water (EPA, 2012a).

Flow, or stream discharge, directly influences the DO in a water system. Flow is the total volume of water that passes through a fixed point over a fixed time period and is directly related to the amount of water flowing from the watershed into the stream channel. Flow will increase in wetter seasons and decrease in drier seasons and when vegetative water demand is high (EPA, 2012b). Flow can be impacted by water withdrawals for agricultural, municipal, or industrial purposes. A higher water flow allows faster discharge of pollutants, provides higher levels of DO, and generally provides better water quality. Waterways with lower levels of flow are more susceptible to water pollution and often have lower DO. The flow also determines the kinds of organisms inhabiting the waterway both directly as a result of the force of the water and indirectly through the relation of flow to other water quality criteria (USGS, 2016a).

The pH, the negative log of free hydrogen ion concentration (H^+), indicates acidity or basicness. It can influence the level of chemical and environmental pollution in water. pH determines the solubility and biological availability of chemical compounds including nutrients and heavy metals. Changes in the pH can increase the solubility of phosphorus, potentially causing a eutrophic environment given the right nutrient levels, flow, and DO levels (USGS, 2016b). pH should be in the range of 6.5 to 9.0 for most freshwater organisms, and higher levels reduce offspring hatch rates and reduce survival rates of adults and offspring. Salmon, for example, prefer a pH between 7 and 8 and will become distressed and suffer physiological damage from absorbed metals at levels below 6. Changing pH often results from runoff, carbon dioxide sequestration, respiration by aquatic organisms, decomposition, and increased temperature (Fondriest Environmental, 2013).

Similar to pH, temperature is another variable affecting water quality. As water temperature increases, the biological activity of aquatic organisms also increases, raising BOD and decreasing DO (USGS, 2016c). As water warms, the rate of chemical reactions increases, dissolving more minerals from surrounding rocks and raising the toxicity of organic and inorganic chemical compounds and metals (Fondriest Environmental, 2014b). As climate change increases the atmospheric temperature, water temperatures will increase with potentially dramatic consequences to aquatic life (Whitehead et al., 2009). It is important to measure the temperature of water because it directly affects many water quality parameters (USGS, 2016c). The optimal temperature for salmon to be able to spawn is between 6 and 15°C, and the optimal temperature for salmon egg survival is 8-12°C (Bergendorf, 2002). The 7-day moving average maximum for salmon is 18°C (Kidd, 2011).

Turbidity is an indication of how many suspended solids are in the water. These solids include organic matter such as leaf detritus, plankton, and algae, as well as inorganic matter such as minerals and sediments (Fondriest Environmental, 2014a). Suspended solids can have negative effects on organisms as sediments block light, diminishing photosynthesis that produces DO. Suspended solids also smother aquatic organisms and carry contaminants throughout the water (Denby, 1987). A higher turbidity level usually indicates excessive microbiological growth, high levels of erosion, or the presence of chemical pollutants. Higher water flow in a stream often increases the turbidity of the water (USGS, 2016a).

Nutrient testing provides an indication of pollutants in the water. Nutrients (phosphate and nitrogen) can impact the quality of water. When large amounts of nutrients are present, eutrophication can result. (EPA, 2019b). Eutrophication is caused by an increase in the productivity of photosynthetic organisms as a result of elevated nutrient levels. The increase in photosynthetic organisms results in a larger foundation of the ecosystem’s food chain. Photosynthetic organisms contribute oxygen to the water system, but when they die, the bacteria involved in their decomposition uses oxygen. Nutrient pollution that leads to eutrophication can lead to a drastic shift in aquatic communities, habitat conditions, and species in affected water. (Anonymous, 2008).

Phosphate is an element that makes its way into the environment through the weathering of rocks. Inorganic phosphorus from rocks ends up in the soil where it is taken up by plants, converted to organic forms, and used in biological compounds such as ATP, phospholipids, and nucleic acids. Animals assimilate phosphorous when they consume plants and excrete it in urine or fecal matter. When animals and plants die and decompose, residual phosphates can make their way into soils. Phosphorus in the soil can make its way into waterways through erosion or leeching (Anonymous, 2019a). Because plants require phosphate to grow, it is one of the main ingredients in many fertilizers. Excess fertilizer use and runoff can result in large amounts of phosphate entering waterways. Other sources of phosphate can be attributed to human sewage, pet waste, fruit or vegetable processing, and chemical manufacturing. Phosphate is often a limiting nutrient in waterways. Eutrophication due to excess amounts of phosphorous results in algal blooms that can be harmful to aquatic species (USGS, 2019a). Areas that experience eutrophication as a result of excess levels of phosphorous tend to be less habitable for salmonids due to not only the reduced levels of DO, but also because of raised water temperatures resulting from the high phosphate levels. The raised water temperatures are a result of algal blooms decreasing albedo of the water and increasing the amount of sunlight absorbed (Salmon and Trout Conservation, 2019)

Nitrogen is another element that plays a critical role in water quality. In waterways, nitrogen is measured in two primary forms: nitrate and ammonia. Nitrate (NO_4) is often found in fertilizers and manure but can also come from bacterial processes in soil and sewage (DOH, 2019). Nitrates in soil often make their way into water through runoff. The EPA has set a MCL (maximum contaminant level) for nitrate at 10 mg/L in drinking water (EPA, 2019c). Levels of nitrate above the EPA's MCL are particularly harmful to babies and pregnant women and can result in infants developing a potentially fatal condition known as blue baby syndrome (DOH, 2019). When ingested by animals, nitrate is reduced to nitrite, which is then further reduced to nitric oxide. This process has been observed to increase under hypoxic conditions and can result in vasodilation and modulation of cellular respiration (Lundberg et al., 2008). Fish are affected by nitrates due to increased levels of photosynthetic plankton, which results in lower levels of DO. Cold water fish tend to be more sensitive to nitrate levels than fish that reside primarily in warm water; the recommended minimum levels of nitrate for salmon are 0.06 mg/l (McGlynn, 2019).

Nitrogen in the form of ammonia also comes from fertilizer runoff but can also come from household cleaning products, refrigerants, chemical and pharmaceutical manufacturing processes, and bacterial processes in soils. The EPA has not yet set an MCL for ammonia found in drinking water, although environmental limits throughout the United States for surface water range from 0.25 to 32.5 mg/L. Excessive levels of ammonia in waterways are toxic to fish and other aquatic organisms. Humans and other larger animals tend to be not as severely affected by ammonia in waterways as fish and other smaller creatures (ODHS, 2019). For some fish, lethal levels of ammonia can be as low as 0.2-2.0 mg/l. Other factors such as pH and temperature play a role in the levels of ammonia that fish are able to tolerate. Salmon and trout are among the most sensitive to ammonia levels in water, with salmon fingerlings being reported to experience hyperplasia in their gill linings at sustained exposures of 0.002 mg/l. Additional symptoms fish can experience from higher levels of ammonia in water include reduction in growth rate and damage to organs such as the liver and kidneys (Oram, 2019).

We also tested the level of chlorine at each of the study locations. Residual chlorine in surface waters can be toxic to many aquatic species. Fish and invertebrates will be affected at a concentration above 1 mg/l. There are no natural sources of chlorine in surface waters. A common source of chlorine comes from municipal drinking water, chemical treatment facilities, food and paper industries, pools and irrigation, thus the presence of chlorine at our sites could indicate the input of municipal water (AGI, 2000).

Bacteria are natural in aquatic systems; many are beneficial, and some are required in ecosystems. However, water can become contaminated with bacteria that can harm organisms and/or cause disease. Coliform bacteria such as *Escherichia coli* (*E. coli*) are only found in the fecal waste of warm-blooded vertebrates (CDC, 2015). The presence of coliform bacteria in water is indicative of fecal contamination. Agricultural runoff of manure from farms often leads to large amounts of coliform bacteria in water (Dufour, 1984). Although most *E. coli* bacteria do not cause human illness, harmful pathogens can co-occur with indicators of fecal contamination. The presence of *E. coli* in water also may indicate a sewage leak or malfunctioning sewage system upstream. No freshwater sample may exceed 200 fecal coliform per 100 mL and no colonies are allowed in drinking water samples. Ingestion of *E. coli* can cause serious digestive system upsets, leaving an infected individual weak and dehydrated, and one strain, *E. coli* O1757, can cause kidney failure and death (EPA, 2016b).

We also tested for the bacterial coliform, *Aeromonas*. It is a rod-shaped bacterium that affects the gastrointestinal systems of the infected individuals. Although no current level is set by the EPA in drinking water, in 1985 health officials in the Netherlands suggested 20 EC (10,000 ppm) as a safe level in drinking water. The potential danger these bacteria cause is unclear (WHO, 2005). It is not possible to predict if a strain of *Aeromonas* will induce diarrheal illness, but it is known that *Aeromonas* can cause diarrhea, and wound infections. Diarrheal cases in which *Aeromonas* are considered the cause are 1.5 times more common in the summer than in the winter and occur more commonly in children. (Morris and Horneman, 2019).

Salmonella is the third bacterial coliform we examined. The genus *Salmonella* encompasses a group of facultatively anaerobic bacteria that are a part of the Enterobacteriaceae family. *Salmonella* are rod-shaped and gram-negative. Most frequently, *Salmonella* are found in the intestinal tracts of humans and other animals. Not all species of *Salmonella* cause disease, but *S. typhi* is known to cause typhoid fever, and variants of *S. enteritidis* are known to cause paratyphoid fever (CDC, 2019). *Salmonella* enters water in the feces of infected warm-blooded vertebrates, sewage overflows, and agricultural runoff. This bacterium is very common in areas that experience frequent flooding or water table contamination (UGA, 2009).

Another water quality variable we examined was the abundance and diversity of macroinvertebrates. Macroinvertebrates are organisms that are large enough to see without a microscope but lack the skeletal system to be classified as a vertebrate. They can be found in fast moving streams, slow-moving waters, and stagnant bodies of water. Macroinvertebrates are studied because a high diversity of organisms usually signifies a healthy waterway, and low diversity or the presence of pollution tolerant organisms indicates the waterway is unhealthy (EPA, 2016a). Macroinvertebrates live in the water for up to a year and thus reflect long term water quality. Legislative measures have been proposed to create a criterion for macroinvertebrates that would help to put streams on the EPA's list of damaged waters. All 50 states are either developing or implementing a macroinvertebrate biomonitoring program (Miller, 2011).

Macroinvertebrates have known pollution tolerances, allowing for the calculation of the Pollution Tolerance Index for a waterway. Collected macroinvertebrates are categorized as pollution tolerant, somewhat intolerant, or pollution intolerant. Pollution tolerant organisms include snails, midge larva, and aquatic worms. Somewhat tolerant species include clams, dragonflies, and crayfish. Pollution intolerant species include mayflies, caddisflies, and stoneflies (Anonymous, 2019c). PTI is calculated by counting the number of taxa in each of the three categories and then multiplying the total by 1 for pollution tolerant taxa, 2 for somewhat intolerant taxa, or 3 for intolerant taxa. The quantities when summed give the PTI, which indicates the overall water quality of a stream (Table 1) (IDEM, 2017).

Table 1. PTI values and their corresponding water quality categories (IDEM, 2017)

PTI	**Stream Quality**
>23	Excellent
17-22	Good
11-16	Fair
<10	Poor

Vegetation

Healthy waterways support a healthy environment and are vital for our social and economic well-being (NRM South, 2014). In a similar manner, a healthy environment is needed to support healthy waterways. Included in a healthy environment is high quality riparian vegetation. Protecting the land from erosion and retaining sediment, vegetation buffers and filters nutrients from runoff. Native vegetation such as dogwood (*Cornus sericea)* provides cover for the watershed, as well as improved habitat for aquatic organisms. Invasive species such as Reed canary grass (*Phalaris arundinacea),* Himalayan blackberry *(Rubus armeniacus*), and English ivy (*Hedera sp.*) outcompete the native species (Oregon Conservation, 2018). Invasive species have no predators, diseases, or other controlling factors in their new ecosystem and hence exhibit rapid growth at the expense of the native species (Oregon Conservation Strategy, 2019a).

The Oregon Conservation Strategy recommends prevention, early detection, and quick control of the invasive species in the Willamette Valley. If they become established, multiple site-appropriate tools (mechanical, chemical, and biological) can be utilized to manage most species. It also is beneficial to promote restoration and revegetation by native species (Oregon Conservation Strategy, 2019b).

The inventory and assessment that was conducted by the ENVS class in the Spring of 2016 concluded the Cozine Creek Natural Area is combination of oak savanna and wetland/riparian habitats. The two most dominant tree species in the area were Oregon white oak and Oregon white ash, both of which are native. An additional tree species was Douglas-fir (*Pseudotsuga menziesii*), which made up 10% of the tree species. All three of these trees are native. Shrubby vegetation found around the creek included native species like creek dogwood and invasive species such as Himalayan blackberry. The latter was targeted for removal by the restoration project and has decreased in abundance. Among herbaceous species, the invasive reed canary grass has become an especially prevalent pest in recent years. On the other hand, Cozine Creek has begun to experience a resurgence of camas lily, a native plant that was a mainstay in the diet of local Native Americans (Berg et al., 2018).

Restoration Project

In 2018, students in Linfield's Environmental Study's Senior Capstone class (ENVS 470) successfully wrote grants that led to the acquisition of $19,000 from the Oregon Watershed Enhancement Board (OWEB), the Yamhill Watershed Stewardship Fund, and the Associated Students of Linfield College (ASLC) for a restoration project in the area where Cozine Creek flows through Linfield's campus. The grant was designed to compare different methods of invasive species removal: completely manual removal, no treatment, mechanical removal then chemical application, and chemical application and then mechanical removal (Figure 1). This grant payed a restoration contractor from Upshot LLC to spray and mow designated areas of Cozine Creek; other areas were cleared by hand by volunteers. The grant also will fund the acquisition and planting of native tree and shrub species in the area after invasive species removal. The restoration plan is expected to impact the quality of water and riparian habitats in the Cozine Creek area on Linfield's campus by improving the area's surrounding vegetation, increasing habitat for macroinvertebrates, and decreasing runoff and turbidity (Berg et al. 2018).

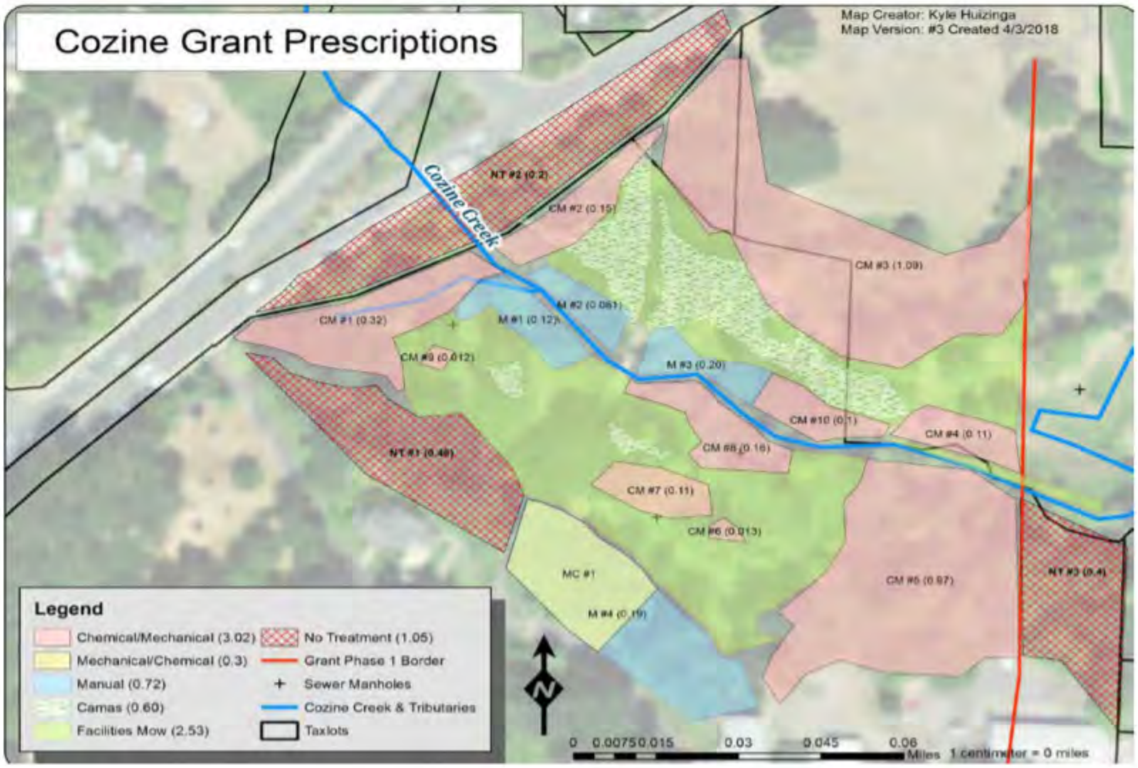

Figure 1. Prescription of treatments for Cozine Creek area restoration project in 2018 (Map created by Kyle Huizinga).

The first area restoration work was done in was on the Newby Hill area. After the removal of invasive species by volunteers, planting of native species such as snowberry (*Symphoricarpus alba*), Oregon grape (*Mahonia aquafolium*), and Indian plum (*Oemleria cerasiformis*) began. The first planting was in February 2019 by both Linfield volunteers and members of the Greater Yamhill Watershed Council. Native species were only planted in areas that were 75% weed free and would not impede any further restoration projects (Berg et al., 2018). We have been determining the survivorship of what we have planted to help evaluate the progress of the restoration project. In fall 2018, we found the percent cover by invasive species on Newby Hill to be significantly lower than in 2017, suggesting the restoration work there had been successful (Berg et al., 2018).

Purpose of Our Study

We gathered water quality data for Cozine Creek by measuring BOD, DO, flow, turbidity, pH, water temperature, nutrient levels, chlorine levels, coliform bacteria, and macroinvertebrates. Besides examining the water in the section of the creek on the Linfield

College campus, we examined water quality at two additional sites on Cozine Creek upstream from Linfield College: one in Lower City Park near the McMinnville library and the other in the Michelbook Meadows subdivision (Figure 2). We predicted the Linfield College site would have the lowest water quality because of its location downstream from the other two sites. The Michelbook Meadows subdivision site was expected to have the best water quality because it is furthest upstream and above the golf course, which was a suspected source of nutrients.

Figure 2. Map detailing location of all study sites on Cozine Creek (Map created by William McCuen with ArcGIS software).

Water quality data from our sites was used to examine current water quality in Cozine Creek at several locations. Our data was also compared with previous year's data to determine changes of water quality over the years. Our data will be shared with the Greater Yamhill Watershed Council to aid in their continued monitoring of water quality in Cozine Creek. The GYWC may potentially utilize our data and analysis to determine courses of action in regard to the improvement of Cozine Creek's water quality. Our hypothesis was that the Michelbook Meadows site would have the cleanest water quality because it is the furthest upstream site and above the golf course, followed by the library site, which is below the golf course, and that the Linfield college site would have the worst water quality as it would be accumulating pollutants from upstream sources.

This data also may be used to determine short-term effects, if any, of the Cozine Creek restoration project on Linfield College's portion of the campus. Besides examining water quality, we reran vegetation transects that previous classes set up to examine the impact of the restoration work on percent cover by invasive plant species, as well as to compare the effectiveness to date of the different types of invasive species removal. We hypothesized that because the major plant removal efforts only finished this summer, too little time will have passed to see a noticeable change in water quality, although we hope to see a decrease in invasive plant species cover. With the removal of invasive species, the turbidity of Cozine Creek on the Linfield College sites could increase due to an increase in sediment from runoff.

Previous Findings

Water quality studies on Cozine Creek have been done by previous ENVS research methods classes since 2011. Students in the 2012 ENVS class theorized the reason the water quality was so poor in Cozine Creek was because there was both agricultural and urban runoff (Bailey et al., 2012). According to the latest Oregon Department of Environmental Quality (ODEQ) assessment of Cozine, the creek has been designated a category 5 stream, meaning that the waterway is not fit for use or any type of recreation due to pollution (DEQ, 2014). The ENVS class in fall 2016 found that Cozine Creek at Linfield College had high levels of nitrate, a common problem most likely because nitrogen fertilizers are heavily used (Cowell et al., 2016). In fall 2017 and 2018, students also found poor water quality in Cozine Creek. Areas of concern were water temperature and DO levels that were unable to support salmon (Berg et al., 2017), although a decline in coliform bacteria such as *E. coli* was noted (Schmidt et al., 2018). The Greater Yamhill Watershed Council (GYWC) state funded water quality monitoring has shown

Cozine Creek has impaired water quality as a result of historic and current land use. Stream temperatures are above levels that support fish, and dissolved oxygen (DO) levels are too low for most aquatic life. The GYWC also found that in the summer, *E. coli* concentrations frequently exceed the limits for human recreational water use (GYWC, 2019).

STUDY AREA

Our study took place in the Greater Yamhill Watershed. This watershed is 529,510 acres and ranges from the crest of the coast range to the Willamette River. Approximately 70% of the greater Yamhill watershed lies in Yamhill county, with the rest in Polk, Washington, Lincoln, and Tillamook counties. All our study locations are located on Cozine Creek in McMinnville, Oregon. Cozine Creek's main branch has headwaters in the coastal foothills approximately five miles west of McMinnville. The creek passes through about seven miles of forest, farm, and urban areas before dumping to the South Yamhill River. The only named tributary is the North Fork, which enters the main branch near the Police Station. Several other unnamed tributaries enter the main branch or the North Fork from the north, south, and west (GYWC, 2018).

Study Locations

We conducted our research at three locations on Cozine Creek: where is runs through Linfield College, in Lower City Park near the McMinnville Library, and at the Michelbook Meadows subdivision. The location of each site was noted using a hand-held Garmin Extrex GPS (Table 2).

Table 2. GPS coordinates for each sampling location.

Location	Subsite	Latitude	Longitude
Linfield College	1	45.20302	-123.19798
Linfield College	2	45.20304	-123.19843
Linfield College	3	45.20345	-123.19953
Linfield College	SS	45.20344	-123.19956
Library	1	45.20999	-123.20162
Library	2	45.21029	-123.20184
Library	3	45.21059	-123.20202
Michelbook Meadows	1	45.22066	-123.21844
Michelbook Meadows	2	45.22022	-123.21918
Michelbook Meadows	3	45.22101	-123.21971

Linfield College Site

The first location we sampled was where Cozine Creek runs through Linfield College's campus (Figure 3). The site is located at the northern side of the campus and is the most downstream location of the three areas we tested. This site originally was established in spring 2011 and has been tested annually. This location originally was selected because it is located on college property and represented an urban setting for the ENVS 360 spring 2011 study examining the impact of urbanization on water quality. Three subsites were randomly (Colahan et al., 2011). We also sampled a fourth subsite (the side stream) that was added in fall 2017. The side stream is believed to be water from of overflow storm drains and lawn runoff potentially from across Baker Street; it was tested to compare its water quality to that in the main channel and to determine if it could be a source of nutrients (Schmidt et al., 2018). We tested the water at this site on two dates due to the omission of BOD measurements for the first date; we tested on September 4 and September 25, 2019.

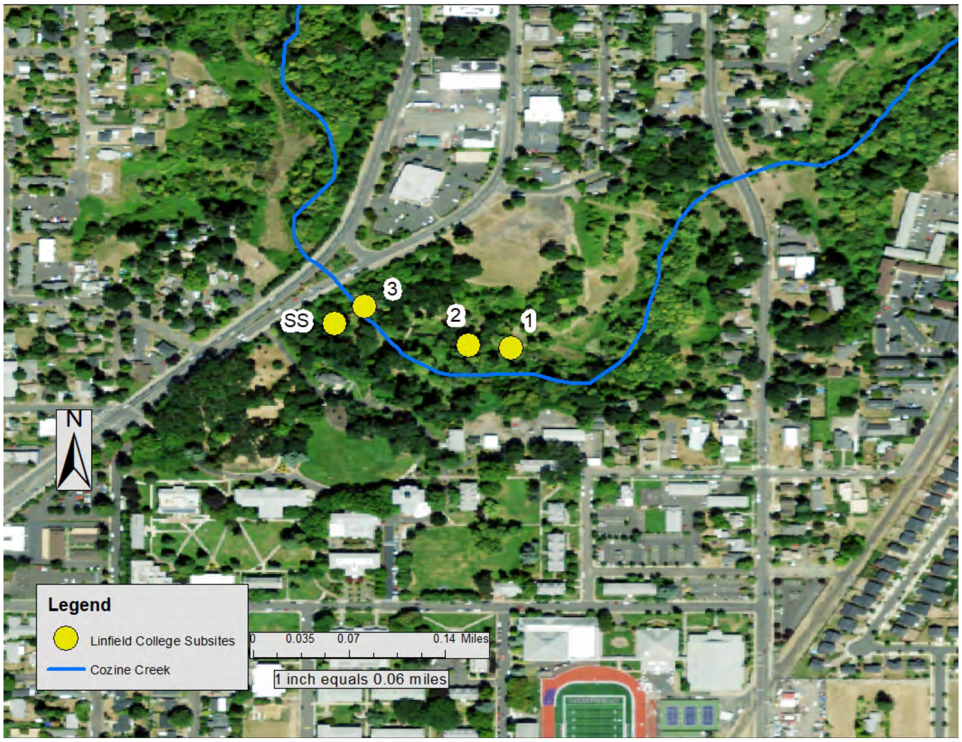

Figure 3. Map detailing location of the four Linfield College subsites on Cozine Creek (Map created by William McCuen using ArcGIS software).

Linfield College Subsite 1

Subsite 1 was the most downstream of the subsites at the Linfield College location; it was tested first to avoid contamination of the other subsites. The creek at this location was about eight feet wide with scattered rocks on a muddy streambed. The north side of the creek was lined with stones whereas the south side of the creek was mud. There was medium canopy cover from Oregon ash trees and several dead trees had fallen across the creek upstream and downstream of the site. Creek dogwood (*Cornus sericea*) was the dominant shrub but trailing blackberry (*Rubus ursinus*) and reed canary grass were also observed on the banks. We also observed large green dragonflies.

Linfield College Subsite 2

The creek at this location was about 10 feet wide with very slow-moving water. The muddy creek bottom had scattered rocks that were covered with a thin layer of algae. Both the north and south sides of the creek were muddy and had steep slopes. One large and several small Oregon ash trees, as well as ninebark *(Physocarpus capitatus),* creek dogwood*,* and snowberry*,* Himalayan blackberry, reed canary grass, and tansy ragwort (*Jacobaea vulgaris*) were present. Across from the site, a pipe, believed to carry runoff from the college, was observed. We also noticed many water striders among the duckweed.

Linfield College Subsite 3

Subsite 3 was the most upstream of the subsites at this location. Just upstream from where we sampled was a culvert that runs under Baker Street. This concrete culvert has two sections, each about six feet tall and eight feet wide. The site itself consisted of a small stream about 3 feet wide with a shallow pebble riverbed that dumped into a larger pool about 11 feet across. A few trees provided some shade. Oregon ash and willow trees (*Salix* sp.) lined the bank and a large dead cottonwood tree was on the other side. Ninebark, reed canary grass, Himalayan blackberry, tansy ragwort, poison hemlock *(Conium maculatum),* trailing blackberry, and clover (*Trifolium sp*.) were on the bank (Figure 4). A small side stream flowed into the main channel here; this is the side stream we tested and will discuss next. We also heard and saw many bushtit birds at this location.

Figure 4. Cozine Creek and streamside vegetation at Linfield College Subsite 3 (Photo taken by Benjamin Whiting).

Linfield College Side Stream

This stream was narrow, with a width of about three to four feet. The bottom of the slow-moving stream was muddy with a thick layer of algae. The creek had woody debris on the bottom. Neither side of the stream had any significant slope (Figure 5). The side stream is sectioned off from the area where the main channel of Cozine Creek is by a two-foot-tall rock retaining wall covered with wire. Trees in the area included Oregon white oak, Oregon ash, Douglas-fir, cascara (*Rhamnus purshiana*), vine maple (*Acer circinatum*), and an ornamental birch *(Betula sp*.). Bittersweet nightshade (*Solanum dulcamara*), sword fern (*Polystichum munitum*), and Himalayan blackberry also were observed. It is important to note that the side stream is very close to Baker Street, which is a heavily trafficked road. The side stream is probably water from the overflow of storm drains and runoff from lawns near the 7/11 convenience store just off campus across Baker Street (Personal communication, Javier Mendoza, November 25th, 2019).

Figure 5. The side stream subsite we tested at Linfield College (Photo taken by Benjamin Whiting).

Library Site

The second location we tested was near downtown McMinnville where the North Fork of Cozine Creek flows through Lower City Park near the McMinnville Public Library. This site is located upstream of Linfield College and downstream of Michelbook Golf Club. The site was selected by the research methods (ENVS 460) class in 2017 because it was between the college site and the more rural (Old Sheridan Bridge) site they studied. The area consists predominantly of grassy lawn areas with scattered trees. There are picnic tables and paths. The location had three subsites that were randomly selected by the 2017 class (Berg et al., 2017) (Figure 6).

Figure 6. Map detailing location of the three Library subsites on the North Fork of Cozine Creek (Map created by William McCuen using ArcGIS software).

Library Subsite 1

The creek at Library Subsite One was about three feet wide and had a muddy bottom with scattered pebbles and stones. It had very low flow. This subsite was the most downstream site at this location and was slightly upstream of 2nd Street in McMinnville. Both sides of the stream had steep slopes (Figure 7). The area had scattered Oregon ash, Oregon white oak, and willow. Other plant species included Himalayan blackberry, horsetail (*Equisetum arvense*), bittersweet nightshade, yellow-flag iris (*Iris pseudacorus*), dock (*Rumex occidentalis*), and reed canary grass. We also noticed waterstriders on the surface, dragonflies in the air, and small fish and crayfish in the creek.

Figure 7. Photo of Cozine Creek where it flows through our Library Subsite 1 (Photo taken by Benjamin Whiting).

Library Subsite 2

At Library Subsite 2 the creek was about three feet wide and had a muddy, silty bottom with a few scattered rocks. The flow here was very low, possibly due to the large amount of vegetation in the creek. This subsite is just downstream of a small footbridge over the creek (Figure 8). There was some canopy cover from mostly ornamental trees including Norway maple (*Acer platanoides*), quaking aspen (*Populus tremuloides*) and arborvitae (*Thuja occidentalis*). Other plants included Himalayan blackberry, dock, English ivy*,* and non-native hawthorne *(Crataegus monogyra)* We also observed water striders and a clam shell in the creek.

Figure 8. Subsite 2 showing vegetation and the footbridge at the Library site (Photo taken by Benjamin Whiting).

Library Subsite 3

The creek at this site was about three and a half feet wide with a muddy bottom and some larger rocks. The bottom of the creek had some woody debris. We noticed a pipe that might be for runoff about 20 feet upstream. Quaking aspen, red alder (*Alnus rubra*), Port Orford cedar (*Chamaecyparis lawsoniana*), and Oregon white oak trees provided shade. Other vegetation on the bank included lemon balm (*Melissa officinalis*), yellow-flag iris, Himalayan blackberry, and bittersweet nightshade. We also observed many sculpins in the creek, along with some trash.

Michelbook Meadows Site

The third location where we tested water quality was where the North Fork of Cozine Creek flows through the Michelbook Meadows subdivision. This location was the furthest upstream of our sites and was located just above the Michelbook Country Club. It was chosen this year to test water quality above and below the golf course. Our class randomly selected three subsites to become our sampling locations (Figure 9). The site was very different from our other locations in that it was mostly wetland rather than a distinct creek. It also was surrounded by homes that lay just outside of the wetland area.

Figure 9. Map detailing location of the three Michelbook Meadow subsites on the North Fork of Cozine Creek (Map created by William McCuen using ArcGIS software).

Michelbook Meadows Subsite 1

The width of the wetland area here was approximately 30 meters; the actual creek channel was not visible. This was the most downstream location at this site. Both sides of the wetland area were lined by nearby homes (Figure 10). The area was relatively flat with little to no bank sloping from the surrounding houses to the water. The area was very muddy with little to no flow. Slightly uphill of the wetland area were many Oregon white oak, Oregon ash, and willow trees. The vegetation in the marsh area included broadleaf cattails (*Typha latifolia*), bittersweet nightshade, duck weed (*Lemna minor*) and reed canary grass. Many red-winged blackbirds and a few killdeer were using the site while we were there. We also noted an abundance of spiders.

Figure 10. Michelbook Meadows Subdivision subsite 1 showing vegetation and the collection of water samples by Benjamin Whiting (Photo taken by Nancy Broshot).

Michelbook Meadows Subsite 2

The area at subsite 2 was approximately 30 meters wide in a marshy area with a very muddy bottom. This site also was very flat with a very gradual slope from the surrounding homes to the water. The water at this subsite was extremely shallow; this site was the hardest for us to sample due to deep mud and an abundance of duckweed. The shore had Oregon ash, Oregon white oak, and willow trees that were covered in lichen (*Ramalina subleptocaupha*). The plants in the marsh included cattails, duckweed, reed canary grass, rushes (*Juncus sp.*), sedges (*Carex sp.),* and sword ferns (*Polystichum munitum*) (Figure 11). The red-winged blackbirds were also numerous here.

Figure 11. Michelbook Meadows Subdivision subsite 2 showing the marsh, nearby homes, and vegetation (Photo taken by Nancy Broshot).

Michelbook Meadows Subsite 3

At this subsite, the marsh was approximately 20 meters wide and there were areas of open water. The location, while still flat, had slightly steeper muddy slopes to the water's edge. Oregon ash and willow were on the bank; cattails, sedges, duckweed, and reed canary grass were in the water (Figure 12). Other creek vegetation included spirea (*Spiraea douglasii*), sedges, Canada thistle (*Cirsium arvense*), snowberry, and rushes. We observed small fish (appeared to be redside shiners) in the open water. The red-winged blackbirds occupied this area as well.

Figure 12. Photo of Garrett Scales measuring dissolved oxygen at subsite 3 at the Michelbook Meadows Subdivision. Photo shows shoreline and marsh vegetation (Photo taken by Nancy Broshot).

METHODS – Field Procedures

We collected water quality data beginning with the most downstream subsite at each creek location to minimize contamination. We began by taking notes on the ecology, vegetation, stream visual characteristics, weather conditions (including air temperature), and other potentially important information. Coordinates for each site were taken with a Garmin Etrex GPS.

We began water quality testing at each subsite by collecting two water samples: one in a sterile 250 ml Nalgene bottle and one in a 250 ml BOD bottle. These samples were collected in areas of the stream deep enough to fully submerge the bottles. We measured the depth of the water where we collected the water using a ruler. After the BOD bottle was filled, the stopper was placed so that it displaced all air bubbles in the sample. The bottle was then wrapped in aluminum foil. Both bottles were placed in an ice chest until we returned to the environmental science laboratory. In the lab, the BOD bottle was placed in a dark location at room temperature for five days (Delzer and Mckenzie 2003). The sterile sample was placed in the freezer.

Dissolved oxygen (DO) was measured at each subsite in an undisturbed area upstream from where water had been collected. Five readings were taken using an Oakton DO 6+

dissolved oxygen meter with the probe removed from the water between individual readings. Readings were recorded after the meter stabilized. Percentage of DO, DO in parts per million, and the temperature of the water were recorded.

pH was measured at each subsite using a pHep Hanna pH meter (model: HI 98128). The probe was placed in the water in such a manner that it was not touching the stream bottom. Five readings were taken after the reading stabilized with the probe removed from the water between each reading.

Stream flow was measured at each subsite in an area with representative flow using a JDC Flow Watch flow meter. The probe was placed in the creek so that the propeller faced into the flow and could freely turn. We took five readings with the probe removed from the water between readings.

We sampled macroinvertebrates only at subsite one at the Linfield Campus location. Five macroinvertebrate sample locations at this subsite were randomly selected. To collect macroinvertebrates, two D nets were used: one net was placed facing upstream with the bottom edge of its frame flush with the streambed. The second D net was held out of the water upstream by another team member. We rubbed rocks on the bottom of the stream, allowing detached macroinvertebrates to flow into the downstream net. Then the streambed was scraped with the second D net into the downstream net. This ensured that macroinvertebrates in the sediment would be captured. The contents of the nets were emptied into basins, and the nets were the rinsed to remove all material. Each tub was surveyed by at least two people. All macroinvertebrates were captured using plastic dropper pipettes and forceps and placed in jars containing 70% isopropyl alcohol (Helgen, 2002). The jars were taken back to the lab to be identified, sorted, and counted at a later date.

The levels of chlorine were measured from one sample per study location although we ran five subsamples of each water sample. Free available chlorine and total residual chlorine were measured using the Lamotte chlorine test kit. We used the procedure in the test kit's directions; the combined chlorine was calculated from the previous two measurements (LaMotte, 2019).

METHODS – Vegetation Transects

To determine the effectiveness of the different methods of removing invasive species done in the restoration project, we reran transects that had been established by previous classes. Newby hill transects were initially established by the ENVS 470 capstone class in spring 2016; the other transects (north side of creek and south side cleared area) were established the following fall by ENVS 460 students. Using the previously recorded GPS locations, we reran the transects and measured the percentage plant species along each meter. We analyzed data by percent cover by individual species as well as by the total percent cover by invasive species (Percent cover by invasive species includes clematis, crabapple (*Malus sylvestris*), creeping buttercup (*Ranunculus repens*), creeping Jenny (*Lysimachia nummularia*) , English ivy (*Hedera sp.*), English laurel (*Prunus laurocerasus*), hawthorn (*Cratageus monogyna*), herb Robert (*Geranium robertianum*), Himalayan blackberry (*Rubus armeniacus*), yellow-flag Iris (*Iris pseudacorus*), Italian arum (*Arum italicum*), lemon balm (*Melissa officinalis*), plum (*Prunus sp.*), reed canary grass (*Phalaris arundinacea*), Canada thistle (*Cirsium arvense*), and periwinkle (*Vinca major*).

To determine survivorship of native species planted in spring of 2018 on Newby Hill by ENVS 470 students and the GYWC, we combed the hillside and counted all snowberry, Oregon grape, and Indian plum plants that we could find. The number of individuals of each species was compared to the number of individuals planted in spring of 2018. Survivorship of each species was calculated in terms of the percentage remaining since planting.

METHODS - Lab Procedures

Biochemical oxygen demand was measured from water in the BOD bottles. Five days after the water had been collected, allotments from the BOD bottles were carefully poured into five 50 ml beakers in such a manner as to avoid air bubbles. The DO was measured in each beaker using the same Oakton DO meter we used in the field. Percent DO and ppm were recorded for each aliquot. BOD was calculated by subtracting the DO measured in each beaker from the average DO measured at the site in the field (Delzer and McKenzie 2003).

The sterile Nalgene bottles with water samples were removed from the freezer, thawed at room temperature, and the water then used to test turbidity, nutrient levels, and bacterial counts.

Turbidity was measured in the lab using a HANNA Instruments field turbidity meter (model: HI937037C). The bottle was inverted gently to mix the contents. Once mixed the sample was poured into the turbidity meter cuvette. The cuvette was capped, and the outside wiped with a lint free cloth. The cuvette was placed in the reading cell of the turbidity meter and the resulting turbidity recorded. Five measurements were taken for each sample with the cuvette inverted to mix the sample between readings. Readings are given Formazin Turbidity Units (FTU). Turbidity readings also can be collected as NTU (Nephelometric Turbidity Units) or FAU (Formazin Attenuation Units); these units are equivalent to one another with a 1:1:1 ratio of measurement (Daly, 2007).

The levels of the nutrients (ammonia, nitrate, and phosphate) were measured in five subsamples of water from each site. Ammonia nitrogen level were tested using the LaMotte ammonia-nitrogen test kit. Tests were done using the procedure in the test kit's directions. The resulting values were multiplied by 1.3 to convert to parts per million (LaMotte 2011a). Testing for nitrate was done with the LaMotte nitrate nitrogen test kit using the procedure in the directions. Values were multiplied by 4.4 to convert to parts per million (LaMotte 2011b). Testing for phosphate was done using the LaMotte phosphate test kit using the procedure in the directions. No conversions were needed. The kit gave readings in parts per million (LaMotte 2011c).

Coliform bacteria (*E. coli, Salmonella, Aeromonas,* and other coliforms) were measured. Two milliliters of water were pipetted into bottles of ECA Check Easygel using sterile technique. The bottles were gently inverted to mix, and the contents poured into labeled petri dishes. Five petri dishes were made for each water sample. The petri dishes were placed into a dark area at room temperature for 48 hours. Colonies were counted by color. Colonies that appeared dark blue were *E. coli,* colonies of *Aeromonas* appeared as pink/red, colonies of *Salmonella* were teal green, and blue/blue gray were other coliform bacteria. These colony numbers were then converted to colonies per 100 ml by multiplying the number of colonies of each bacterium by 50 (Microbiology Laboratories, 2008).

Macroinvertebrates were identified in lab to the most specific taxa possible under a dissecting microscope using keys and web sites (SWRC 2017; NW Nature 2015). Each jar was counted by two people who ensured they got identical data. The counts allowed for the pollution tolerance index to be calculated.

Statistical Analysis of data was performed using JMP Pro 14. Water variables were compared among the different study sites using a one-way ANOVA; a Tukey Kramer HSD post hoc test was performed to show which sites were significantly different from each other. We also used one-way ANOVA and Tukey HSD to compare the water quality variables among years. A one-way ANOVA test is used to determine if there is a significant difference in means and the Tukey Kramer HSD test compares among pairs of means. All statistical analyses in were considered significant with a p-value <0.05. The Tukey Kramer HSD test provided a connecting letters report. A connecting letters report shows significant differences by assigning a number to each category in the ANOVA; significant differences are denoted by different letters (JMP 2019a and JMP 2019b).

RESULTS

September 4, 2019 vs. September 25, 2019 Linfield College Site Water Quality

DO%, DO (ppm), and pH on both dates were significantly greater in the side stream than for the main channel of the creek as it flows through Linfield College, but it was higher there on September 4 than on September 25 (Table 3). Temperature was significantly higher at the Linfield College on September 4 than on September 25.

Table 3: Mean (standard deviation) of water quality variables at the Linfield College location (main creek and side stream) on the different dates based on ANOVA analysis. Means with different letters are significantly different based on Tukey HSD post hoc test. LC refers to Linfield College SS refers to side stream.

Variable	LC 9/04	LC 9/04 SS	LC 9/25	LC 9/25 SS	p-value
DO%	65.8 (4.0) b	78.8 (1.4) a	57.1 (4.0) c	77.8 (2.6) a	<0.0001
DO (ppm)	5.95 (0.41) b	7.25 (0.07) a	5.59 (0.24) c	7.20 (0.24) a	< 0.0001
Temp (C)	19.8 (0.3) a	19.8 (0.0) ab	17.5 (0.6) b	19.0 (0.1) c	<0.0001
pH	7.36 (0.1) c	7.98 (0.04) a	6.89 (0.32) d	7.71 (0.08) b	<0.0001
Flow (cm/sec)	12.7 (8.3) ab	0 (0) b	17.9 (2.6) a	0 (0) b	0.0012
BOD %	-	-	24.7 (12.6) a	19.0 (2.60) a	0.3342
Turbidity (FTU)	3.5 (1.5) bc	39.8 (12.6) a	9.1 (2.3) c	2.4 (1.99) b	<0.0001
Nitrate (ppm)	5.0 (5.7)	4.4 (0)	1.5 (1.9)	2.6 (0.6)	0.088
Ammonia (ppm)	0.21 (0.10) ab	0.18 (0.14) ab	0.25 (0.06) a	0.10 (0.03) b	0.0179
Phosphate (ppm)	0.06 (0.1)	0.1 (0.07)	0.03 (0.05)	0.13 (0.08)	0.1727

There were significantly higher levels of *Aeromonas* in the mean channels of Cozine Creek mainstream on September 2 and the side stream than in the main channel on September 4 (Table 4). *E coli* was only present in small numbers in the main channel on September 25 and no *Salmonella* were detected.

Table 4. Mean (standard deviation) and probability as per ANOVA of bacterial colonies per 100ml for Linfield College on 9/4/19 versus 9/25/19. Means with differing letters indicate significant differences based on a Tukey HSD post hoc test. LC refers to Linfield College; SS refers to Side Stream

Variable	**LC 9/04**	**LC 9/04 SS**	**LC 9/25**	**LC 9/25 SS**	**p-value**
E. coli per 100 ml	0.0 (0.0)	0.0 (0.0)	2.22(10.4)	0.0 (0.0)	0.3424
Salmonella per 100 ml	0.0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	-
Aeromonas per 100ml	6.67 (20.2) b	83.3 (72.4) a	66.7 (66.6) a	120 (163) a	<0.0001

Linfield College macroinvertebrate pull 3 had the highest total PTI score and the greatest species diversity (Table 5**)**. The average PTI for this year was 8.2.

Table 5. Pollution tolerance index (PTI) scores with the number of total species and the number of taxa in each PTI category.

Pull #	**Total # Species**	**# PTI 1**	**# PTI 2**	**# PTI 3**	**PTI Score**
LC 1	7	1	1	7	12
LC 2	4	0	1	3	5
LC 3	10	1	2	7	14
LC 4	5	0	0	5	5
LC 5	4	0	1	3	5

Cozine Creek 2019 Sites Compared

Michelbook Meadows had significantly lower levels of DO and water temperature and higher levels of BOD, turbidity, and phosphate than the water at the College or Library sites (Table 6). pH was significantly higher at Michelbook Meadows and the Library site than is was at the college or in the side stream. Ammonia was significantly lower in the sidestream. We only found a small amount of chlorine at the Michelbook Meadows site and none elsewhere.

Table 6. Mean (standard deviation) of water quality variables among locations in Cozine Creek in fall 2019 based on ANOVA. Means with different letters are significantly different based on a Tukey HSD post hoc test. LC refers to Linfield College, SS refers to side stream, and MM refers to Michelbook Meadows.

Variable	**LC (09/25)**	**LC SS (09/25)**	**Library**	**MM**	**p-value**
DO%	57.1 (3.9) c	77.8 (2.6) a	64.3 (4.6) b	40.8 (4.6) d	<0.0001
DO (ppm)	5.48 (0.34) c	7.20 (0.24) a	6.07 (0.40) b	3.90 (0.48) d	<0.0001
Temp (C)	17.3 (0.8) bc	19.0 (0.1) a	17.9 (0.4) b	17.2 (0.1) c	<0.0001
pH	7.08 (0.10) b	7.71 (0.08) a	6.97 (0.13) c	6.97 (0.03) c	<0.0001
Flow (cm/sec)	17.93 (13.8) a	0 (0) b	3.3 (2.4) b	0 (0) b	<.00001
BOD %	24.7 (12.6) bc	18.98 (2.56) c	32.37 (7.53) ab	37.23 (4.29) a	<0.0001
Turbidity (FTU)	2.42 (1.99) b	9.11(2.31) b	7.60 (1.92) b	182.93 (16.23) a	<0.0001
Nitrate (ppm)	1.5 (2.0) ab	2.6 (0.6) a	1.3 (1.6) ab	0.4 (0.9) b	0.0417
Ammonia (ppm)	0.2 (01) a	0.1 (0.0) b	0.3 (0.1) a	0.21 (0.07) ab	0.002
Phosphate (ppm)	0.03 (0.05) b	0.05 (0.00) b	0.13 (0.08) b	0.43 (0.37) a	<.0001
Chlorine (ppm)	0 a	0 a	0 a	0.08 a	0.0829

Levels of *Aeromonas* were significantly higher at Michelbook Meadows than at Linfield College or the Library (Table 7). Neither *E. coli* not *Salmonella* were significant, although the mean level of *E. coli* at Michelbook Meadows was high.

Table 7. Mean (standard deviation) and probability for bacterial colonies per 100ml among locations as per ANOVA. Means with differing letters indicate significant differences based on a Tukey HSD post hoc test.

Variable	**LC (09/25)**	**LC SS (09/25)**	**Library**	**MM**	**p-value**
E. coli per 100ml	2.2 (10)	0.0 (0.0)	0.0(0.0)	441.4 (2010)	0.1766
Salmonella per 100ml	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	114.6 (761.2)	0.5015
Aeromonas per 100ml	66.7 (66.6) b	120 (163) ab	18.9 (37.3) b	277 (433) a	<0.0001

2011-2019 Linfield College Water Quality Over Time

Percent DO was significantly higher in 2013-2015 than it was in 2016-2019 (Table 8). Temperature was significantly higher in 2018 than previous years and pH was significantly higher in 2015-2019 than from 2012-2014. Nutrient levels were variable, but ammonia was significantly higher in 2018 than all other years, and phosphate was lower in 2019 than 2017.

Table 8. Mean (standard deviation) of water quality variables at the Linfield College site from fall 2011 to fall 2019 class. Probability among the years from ANOVA. Means with differing letters signify the order based off the Tukey HSD post hoc test.

Variable	**F11**	**F12**	**F13**	**F14**	**F15**	**F16**	**F17**	**F18**	**F19**	**P-Value**
DO%	69.4 (2.9) ab	58.1 (1.0) cd	43.5 (8.6) ef	52.4 (10.1) de	34.0 (12.2) f	63.1 (3.7) bc	72.2 (9.1) a	74.3 (7.7) a	62.2 (4.9) bc	< 0.0001
DO PPM			4.66 (0.89) e	5.09 (1.54) de	2.92 (1.00) f	6.20 (0.35) bc	7.08 (1.08) a	7.00 (0.71) ab	5.77 (0.38) cd	< 0.0001
Temp (C)	12.3 (0.1) d	9.6 (0.4) b	13.4 (0.7) d	13.5 (1.2) d	16.6 (0.7) c	15.9 (0.6) c	16.3 (1.2) c	17.7 (0.6) b	18.7 (1.3) a	< 0.0001
pH	6.84 (0.23) cd	6.49 (0.26) de	6.32 (0.53) e	6.30 (0.31) e	7.18 (0.04) abc	7.30 (0.12) a	7.17 (0.15) abc	6.95 (0.49) bc	7.22 (0.17) ab	< 0.0001
Flow	8.83 (6.28) ab	10.5 (8.57) ab	0.44 (0.89) b		3 (4.41) b	7.00 (7.63) b	26.00 (30.51) a	8.33 (6.24) b	15.33 (11.47) ab	< 0.0001
BOD %		3.68 (3.76) c	9.84 (6.01) bc	16.23 (7.58) abc	24.85 (14.16) a	12.16 (6.23) bc	22.41 (5.73) a	18.53 (6.09) ab	24.70 (12.58) a	< 0.0001
Turbidity (FTU)			9.12 (5.55) ab	5.04 (0.65) bcd	9.49 (4.05) a	5.95 (0.87) bc	6.43 (4.92) abc	4.44 (1.44) cd	2.96 (1.80) d	< 0.0001
Nitrate	0(0) b	0(0) b	0(0) b	1.96 (3.20) ab	2.64 (3.92) ab	2.49 (2.48) ab	0.8 (1.04) b	5.28 (2.97) a	3.23 (4.58) ab	0.0001
Ammonia			0.12 (0.05) b	0.15 (0.07) b	0.15 (0.13) b	0.20 (0.10) b	0.14 (0.10) b	0.48 (0.62) a	0.23 (0.08) b	0.0027
Phosphate	0.20 (0.0) ab	0 (0) d	0.07 (0.05) bcd	0.11 (0.18) bcd	0.31 (0.18) a	0.07 (0.05) bcd	0.20 (0.20) ab	0.15 (0.05) bc	0.05 (0.05) cd	< 0.0001

There was significantly more *E. coli* in 2011 than any other year (Table 9). *Salmonella* levels were significantly higher in 2011 than in 2013 and both those years had significantly more colonies than in 2015-2019. There were significantly more *Aeromonas* in 2011 than in 2012; and more in both those years than in 2015-2019.

Table 9. Mean (standard deviation) and probability of bacterial colonies per 100ml at the Linfield College site among the years based on ANOVA of sampling. Means with differing letters indicate significant differences based on a Tukey HSD post hoc test. PTI score is also reported.

Variable	**F11**	**F12**	**F13**	**F14**	**F15**	**F16**	**F17**	**F18**	**F19**	**P-Value**
E. coli per 100ml	577.8 (635.9) a	51.1 (28.5) b	44.4 (68.2) b	0 (0) b	15.0 (40.4) b	2.4 (6.6) b	47.4 (76.0) b	0.0 (0) b	1.1 (7.4) b	<0.0001
Salmonella per 100ml	800.0 (447.2) a	0 (0) c	138.9 (92.8) b	0 (0) c	25.0 (43.7) c	5.6 (17.6) c	43.7 (67.7) c	1.6 (6.1) c	0 (0) c	<0.0001
Aeromonas per 100ml	27288.9 (5210.7) a	1133.3 (487.1) b	-	22.2 (44.1) bc	30.0 (135.7) c	52.0 (12.0) c	52.6 (90.0) c	3.5 (10.8) c	36.7 (57.5) c	<0.0001
PTI Score	-	-	7.1	5.4	9.2	8.4	9.8	-	8.2	NA

Changes in Vegetation

We found significantly higher percent invasive species on Newby Hill in fall 2017 and fall 2019 than in spring 2018 (Table 10). There was significantly greater cover by English ivy in fall 2017 than in spring 2018.

Table 10: Mean (standard deviation) and probability of the percent cover by selected plant species on Newby Hill in fall 2017, spring 2018 and fall 2019 as well as percent cover by invasive species.

Vegetation	**Fall 2017**	**Spring 2018**	**Fall 2019**	**p-value**
% Invasive	42.3 (5.4) a	25.1 (5.5) b	42.4 (5.4) a	0.0003
Bare ground	18.8 (11.8)	25.8 (20.6)	18.1 (10.8)	0.6803
Creeping buttercup	4.4 (2.6)	1.6 (1.9)	7.1 (4.5)	0.0586
English ivy	24.1 (4.5) a	13.7 (4.5) b	21.6 (5.7) ab	0.0154
Grass	17.0 (4.6)	10.9 (9.2)	13.0 (4.6)	0.3554
Himalayan blackberry	10.3 (5.7)	5.6 (3.9)	6.4 (5.1)	0.3156
Snowberry	4.2 (4.4)	5.6 (7.7)	4.2 (6.0)	0.9196
Vinca	2.1 (2.9)	2.3 (3.3)	3.7 (4.7)	0.7813
Wild blackberry	11.7 (9.0)	23.9 (15.1)	16.7 (7.7)	0.2574

When we examined how many of the seedlings planted in YEAR were still present on Newby Hill, we found low survivorship of Oregon grape, Indian plum, and snowberry (Table 11).

Table 11: Survivorship of native seedlings planted on Newby Hill by ENVS students and the GYWC.

Species	Number Planted in Spring 2018	Number Surviving in Fall 2018	Number Surviving in Fall 2019	Percent Survivorship (Fall 2018)	Percent Survivorship (Fall 2019)
Oregon Grape	72	26	9	36.1	12.5
Snowberry	29	35	10	120.7	34.5
Indian Plum	35	10	5	28.6	14.3

DISCUSSION

September 4, 2019 vs. September 25, 2019 Linfield College Site Water Quality

This fall we had to test water at our Linfield College site on two dates due to the fact Dr. Broshot forgot we needed to measure BOD five days after we did the September 4 water sampling. The mistake did allow us to analyze the water on two different dates after different weather conditions. We found dissolved oxygen, water temperature, and pH to be significantly higher in the creek on September 4 than on September 25. Nitrate was also higher on September 4, but was not significant. In addition, the creek depth rose from 9.3cm to 10.9cm in that intervening time span. Interestingly, the number of *Aeromonas* colonies (a coliform bacteria) were significantly higher on September 25.

We wondered if the weather could help explain the differences. We examined the weather data from the 19-day span before each sampling date. McMinnville received 0 inches of rain in the 19 days before September 4, but 2.77 inches of rain before September 25 (Weather Underground, 2019). The rain had resulted in a slightly deeper water level and could have been the reason for the reduction in water temperature, pH, and nitrate levels. It also could have accounted for the increase in *Aeromonas* if the bacteria were entering from runoff, which would have increased with the rain.

This year we only examined macroinvertebrates in Cozine Creek as it flows through campus. Although one pull had the highest PTI score ever seen in the creek (14), the mean PTI for the area was 8.2, which is an indicator of poor water quality. Macroinvertebrates are studied because a high diversity of organisms usually signifies a healthy waterway. In addition, because they live in the water for up to a year, they reflect long term water quality and are frequently a better overall indicator for year-round water quality as opposed to the one-day data collection we do (EPA, 2016a).

Comparing the main channel of the creek as it flows through campus to the side stream also was interesting. It was added it to the study in 2017 to see if or how that water could be impacting the water in the main channel. The side stream most likely contains runoff from the college as well as from lawns and roads from the neighborhoods across Baker Street (Personal communication, Javier Mendoza, November 25th, 2019). The water in the side stream had significantly higher levels of DO, pH, and turbidity on both dates than the main channel of the creek. It also had higher levels of *Aeromonas* on September 4 and higher levels of ammonia on September 25. The side stream emerges from a storm pipe and then drops from a short waterfall before it enters Cozine Creek. The waterfall could account for the increased DO. The fact that it is runoff from lawns and road may be why it has higher turbidity, ammonia, and *Aeromonas*, although until we know more about the exact source of the side stream, we cannot say with certainty. However, since there was no chlorine found in either the main channel or the side stream, it does not appear to be coming from municipal water (AGI, 2000).

Cozine Creek 2019 Sites Compared

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. We had hypothesized that Michelbook Meadows would have the best water quality because it was the most upstream site and was upstream of the Michelbook Country Club golf course, a suspected source of nutrients. However, we found that Michelbook Meadows had the poorest water quality of all three sites based on the low oxygen level and high levels of BOD, turbidity, phosphate, and *Aeromonas*.

There are several possible explanations for our findings. All three sites at the Michelbook Meadows location were wetland areas that had very shallow water with virtually no flow and high turbidity. The lack of flow at the Michelbook site likely contributed to the low DO, high BOD, and turbidity, as well as the high level of phosphate. Another factor may the large number of birds that were present. When field work was being done, we saw many red wing blackbirds even though breeding season was over. The increase is bacteria as well as the high amount of phosphate may be due to the bird feces (USGS, 2019a). Michelbook Meadows did have a small amount of chlorine though, suggesting that some municipal water may be getting into the stream here (AGI, 2000).

2011-2019 Linfield College Water Quality Over Time

Although some of the variables we tested appear to indicate that water quality may be improving at the Linfield College site over the years (e.g., turbidity, nutrients, and bacteria) the creek is still not habitable for salmon. Temperature, one of the main limiting factors for salmon, has been significantly increasing since fall 2012 and has been over the salmon 7-day moving average maximum for the last two years. DO, another of the limiting factors, has been decreasing over the last few of years but the levels are still too high for salmon survivability (Kidd, 2011).

Looking at dissolved oxygen in more detail, we can see it was significantly lower in 2013 to 2015 than it was in 2016 to 2019 (Figure 13). Even though oxygen levels have risen since fall 2015, they are still below the acceptable minimum level for salmon, which is 11 ppm. Levels below 6 ppm, which we found this fall, are lethal to salmon (Kidd, 2011). Besides salmon, DO is an important factor in all aquatic ecosystems because it affects the composition of freshwater communities (Connolly et. al., 2004). One reason Cozine Creek likely has such low levels of DO is that the flow, a factor that correlated positively with DO, is also low (USGS, 2014). Another reason could be that temperature, a variable that has a negative correlation with DO, is high in the creek (Connolly et al., 2004).

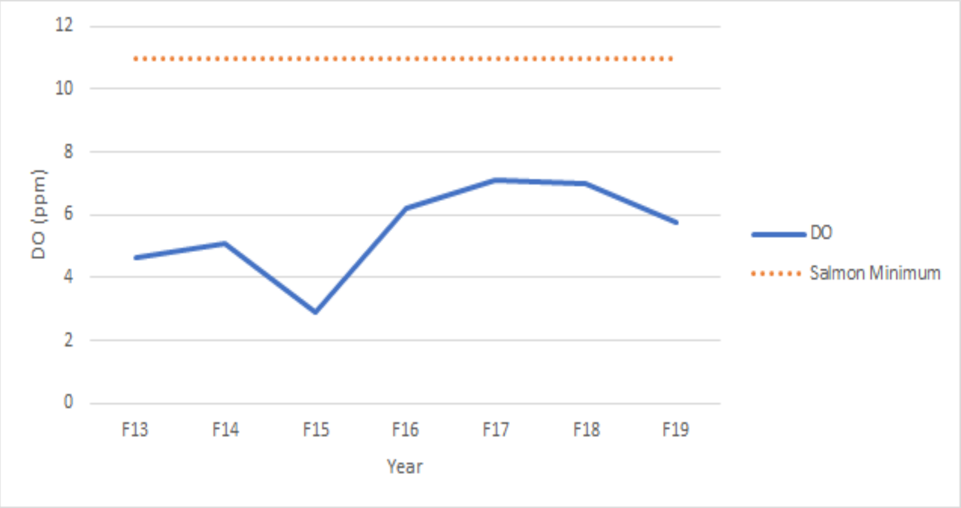

Figure 13. Mean dissolved oxygen (ppm) at the Linfield College site in fall 2013 to 2019. The dotted line represents the acceptable minimum DO (ppm) level for salmon at 11 ppm (Kidd, 2011).

BOD rose steadily from less than 5% in 2012 to 25% in 2015 (Figure 14). Since that time, it has fluctuated but has never fallen below 12%. This rise in BOD indicates that there is less available oxygen in Cozine Creek because BOD is negatively correlated with DO (EPA, 2012a). Low levels of oxygen in a waterway can result in the death of organisms that were previously able to live in the stream (Connolly et al., 2004). High levels of nutrients or bacteria, as well as the decomposition of organic material (Jouanneau et al., 2013). BOD can also increase as temperatures rise, which may explain the increase in correlation with increasing water temperature in Cozine Creek over the years (EPA, 2012a).

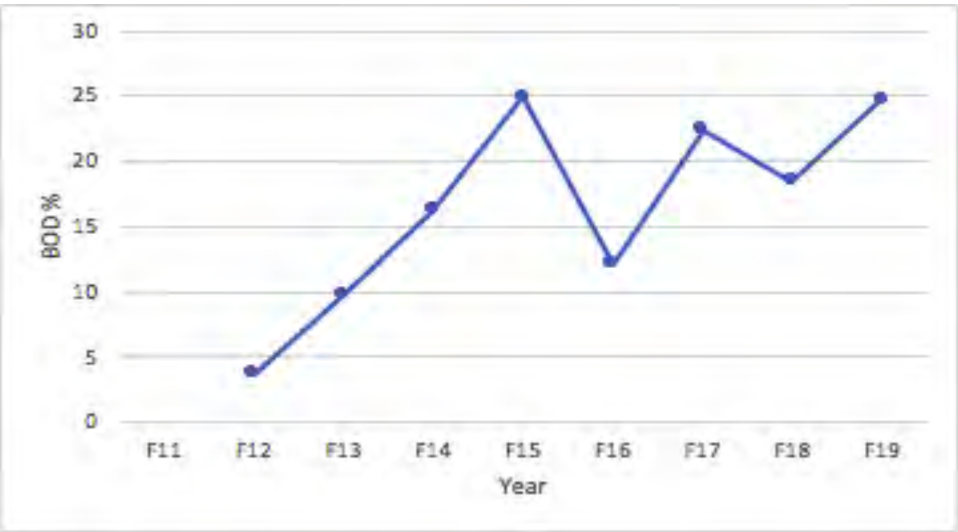

Figure 14. Mean %BOD at the Linfield College site in fall 2013 to 2019.

Flow was at its highest in 2017, but has fluctuated over the years with no real trend (Figure 15). High flow increases the amount of DO in a water system by incorporating oxygen from the air into the water. (EPA, 2012b). Furthermore, high levels of flow allow for faster discharge of pollutants, which is why waterways with low flow are more susceptible to pollution (USGS, 2016a). One potential explanation for why flow levels in Cozine Creek are low is because we took these measurements in September. During drier seasons, flow tends to decrease (EPA, 2012b). Another reason why flow is low in Cozine Creek could be blockages from the many culverts located in the waterway that slow down the rate at which water is flowing (USGS, 2016a).

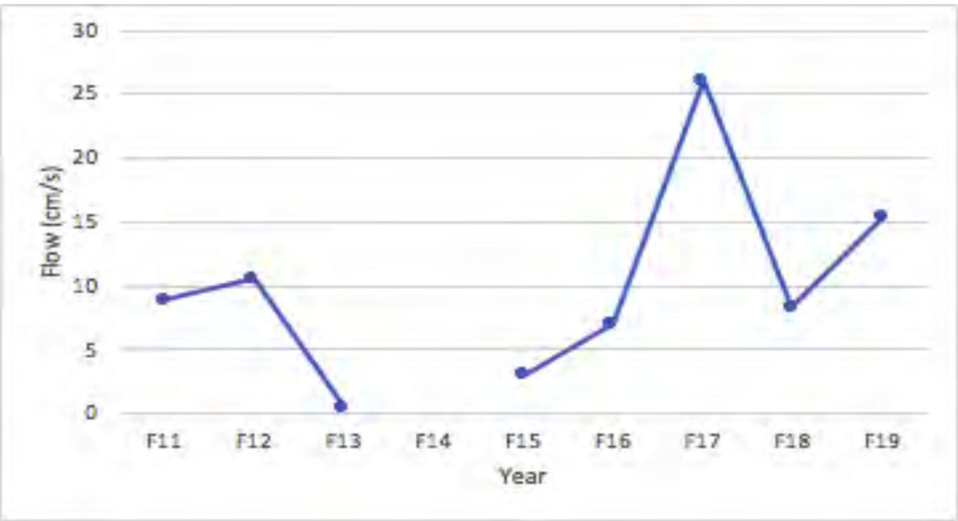

Figure 15. Mean flow (cm/s) at the Linfield College site in fall 2013 to 2019.

pH was significantly higher in 2015 to 2019 than in 2012 to 2014 (Figure 16). The acceptable range for salmon is between 6.5 and 8.5 (Fondriest Environmental, 2013). Since 2015, the pH in Cozine Creek has been in the acceptable range. The pH of water can create a toxic environment for aquatic organisms by becoming too acidic or basic to support biological processes. pH also dictates the biological availability and solubility of chemicals in the water, including nutrients and heavy metals (USGS, 2016b). A pH too acidic or basic will burn a fish's skin and could cause damage to their gills and internal organs, making fish vanish from the waterway. A change in pH can be caused by any number of reasons including runoff, carbon dioxide sequestration, as well as an increase in temperature (Fondriest Environmental, 2013).

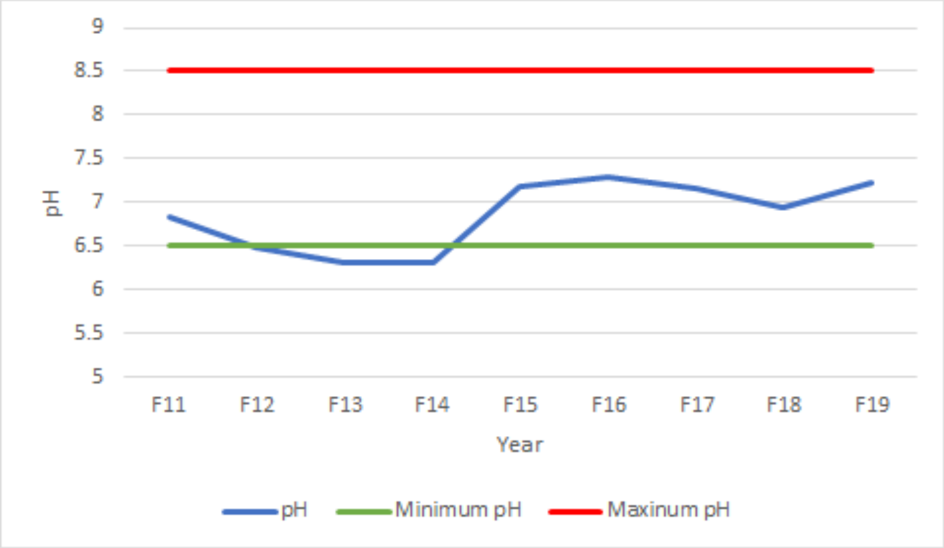

Figure 16. Mean pH at the Linfield College site in fall 2013 to 2019. The red line represents the DEQ acceptable maximum level for salmon at a pH of 8.5, whereas the green line represents the minimum level for salmon health at a pH of 6.5 (Fondriest Environmental, 2013).

Water temperature was significantly higher in 2019 than in all other years and significantly higher in 2018 than in 2015 to 2017 (Figure 17). Last year, the water temperature rose to the 7-day moving average maximum (7dMaM) for salmon, and this year it rose beyond that level (Kidd, 2011). Just as atoms become more active with higher temperature, an organism's biological activities tend to increase in warmer water, which can lead to an increase in BOD and a decrease of DO (USGS, 2016c). Water with warmer temperatures can lead to increases both in turbidity due to minerals dissolving faster and the toxicity of organic and inorganic chemical compounds and metals (Fondriest Environmental, 2014b). One implication of the elevated water temperatures at Cozine Creek is that it could be reducing DO levels, because warmer waters can not hold as much DO as to colder waters (Connolly et al., 2004).

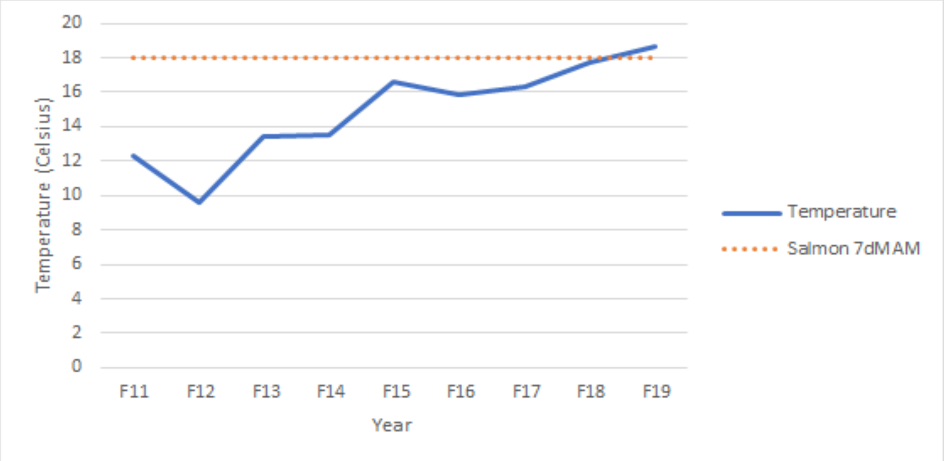

Figure 17. Mean temperature (°C) at the Linfield College site in fall 2013 to 2019. The dotted line represents the maximum temperature for salmon to live, 18°C (Kidd, 2011).

Turbidity has fluctuated since 2013 but has always been relatively low (<10FTU) in Cozine Creek (Figure 18). Turbidity correlates with large amounts of microbiological growth, high levels of erosion, and the presence of chemical pollutants. Due to Cozine's muddiness, we believe erosion of the mud found in the banks and creek bottom to be the likeliest source of overall turbidity. (USGS, 2016a). One implication of higher turbidity levels is that it could result in higher water temperatures due to decreasing the albedo of the water and absorbing more light (Fondriest Environmental, 2014a). Another implication is that higher turbidity levels could result in lower levels of DO due to its ability to reduce levels of photosynthesis within the water (Denby, 1987). The relatively low level does suggest the restoration has not increased the amount of runoff though.

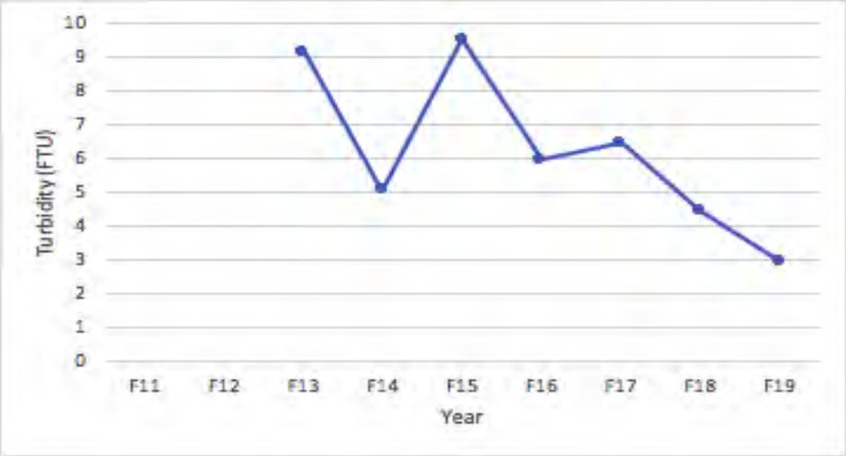

Figure 18. Mean turbidity (FTU) at the Linfield College site in fall 2011 to 2019. We did not begin to measure turbidity until 2013

To determine nutrient levels in Cozine Creek, we measured phosphate, nitrate, and ammonia levels. High nutrient levels cause eutrophication, that often results in low DO and high BOD levels (EPA, 2019b).

We found that phosphate levels in Cozine Creek were significantly higher in 2016-1019 (Figure 19). Because phosphate is often a limiting nutrient in waterways, it is important to avoid excess phosphate due to its ability to cause eutrophication that creates algal blooms. Algal blooms are harmful to species that call the waterway home (USGS, 2019a). High levels of phosphate make the waterway less habitable for salmonids due to increased BOD and reduced DO that result from eutrophication (Salmon and Trout Conservation, 2019). The likeliest source of phosphate in the Linfield College Cozine Creek site is fecal contamination from animals in the area. We do not believe it to be due to fertilizer runoff because the facilities department at Linfield utilizes fertilizers that are primarily nitrogen-based (Personal communication, Javier Mendoza, November 25th, 2019) .

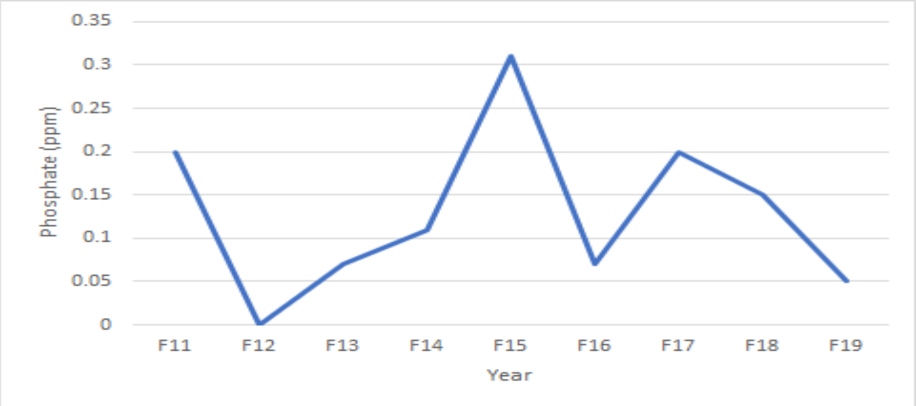

Figure 19. Mean phosphate (ppm) at the Linfield College site in fall 2011 to 2019.

Nitrate levels were significantly higher in 2018 than in 2019 or 2015 to 2016 (Figure 20). The levels fluctuate over the years, which may be due to runoff from recent rainfall events (EPA, 2019c). All the recorded values are well below the acceptable maximum nitrate levels for salmon, which is 10 ppm. High levels of nitrate can result in eutrophication and an increase in algae in the waterway, which increase BOD and reduce DO (McGlynn, 2019). Since 2011, the Linfield College site has exhibited an increased tendency f to become eutrophic. Nitrates commonly enter waterways as a result of fertilizer runoff. We believe this may be the main source of nitrates in Cozine Creek (Personal communication, Javier Mendoza, November 25th, 2019).

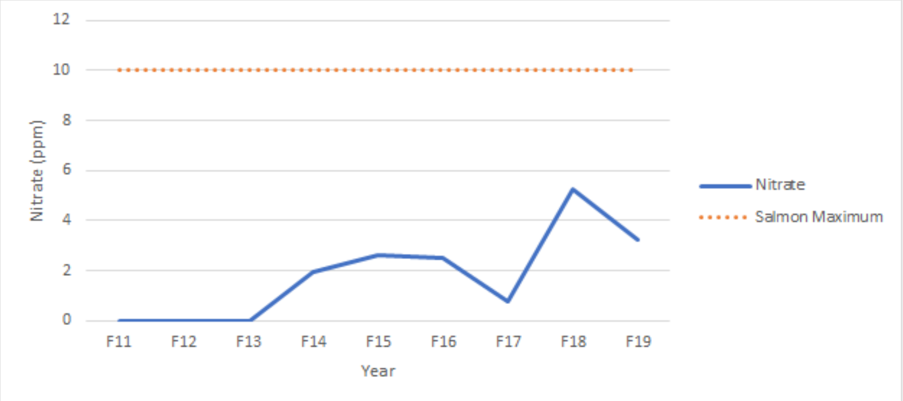

Figure 20. Mean nitrate (ppm) at the Linfield College site in fall 2011 to 2019. The dotted line represents the acceptable maximum nitrate (ppm) level for salmon, 10 ppm (Kidd, 2011).

Levels of ammonia were significantly higher in 2018 than all other years (Figure 21). There is no DEQ recommended maximum ammonia ppm for salmon health due to varying ecosystem conditions, however high levels of ammonia are toxic to fish, causing symptoms such as hyperplasia in gill linings, reduced growth rates, and damage to the liver and kidneys (Oram, 2019). Similar to nitrate, increased ammonia levels result in eutrophication, which leads to algal blooms that increase BOD and decrease DO (McGlynn, 2019). Since 2013, the potential for eutrophication due to ammonia has increased at the Linfield College site, but remains very low (reaching its highest potential at less than half of a part per million in 2018). Ammonia also often makes its way into waterways as a result fertilizer runoff. We believe this to be the primary source of ammonia within Cozine Creek as the ammonia based fertilizer used by Linfield (Personal communication, Javier Mendoza, November 25th, 2019) .

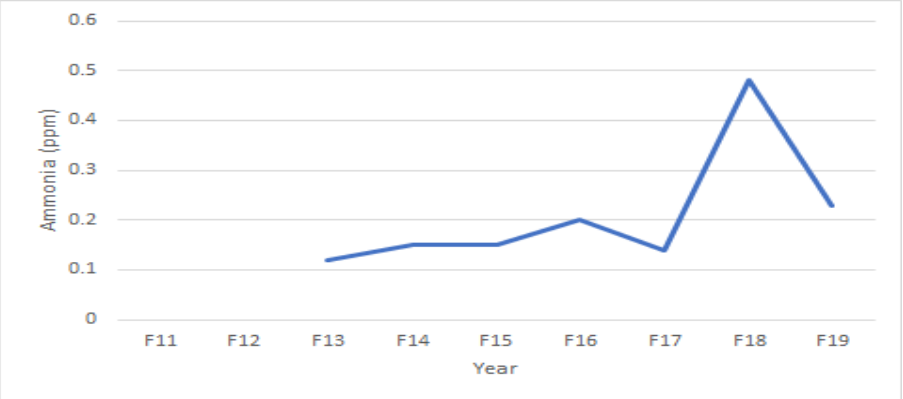

Figure 21. Mean ammonia (ppm) data at the Linfield College site in the fall from 2013 to 2019.

Coliform bacterial levels in Cozine Creek have decreased since 2011. *E. coli* level have been significantly lower since 2011 (Figure 22). *Salmonella* were significantly higher in 2011 than 2013, which was higher than all other years (Figure 23). *Aeromonas* levels were significantly in 2011 than 2012, which was higher than levels in 2015 to 2019 (Figure 24). The high levels in 2011 were due to a broken sewer pipe upstream. The repair of that has led to much lower levels since. Lower levels mean that there are less potentially harmful bacteria in the waterway. It also means that the fecal waste from warm-blooded vertebrates has been reduced. (CDC, 2015). The decrease in coliform levels should be beneficial for DO as bacteria consume DO (Connolly et al., 2004), however DO levels in the creek have continued to remain low suggesting bacteria are not the cause of the low oxygen in Cozine Creek.

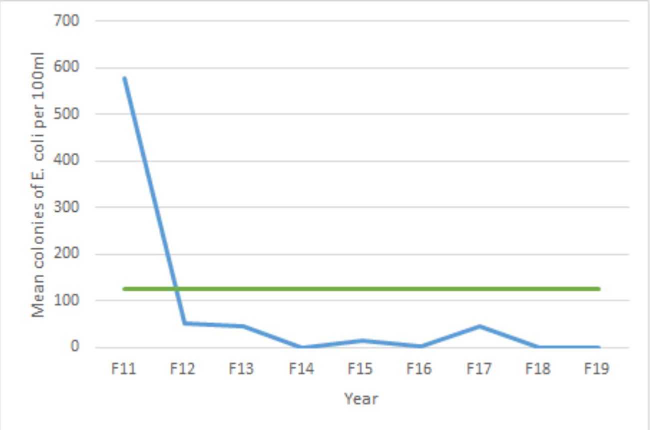

Figure 22. Mean levels of *E. coli* (colonies per 100ml) at the Linfield College site in the fall from 2013 to 2019.

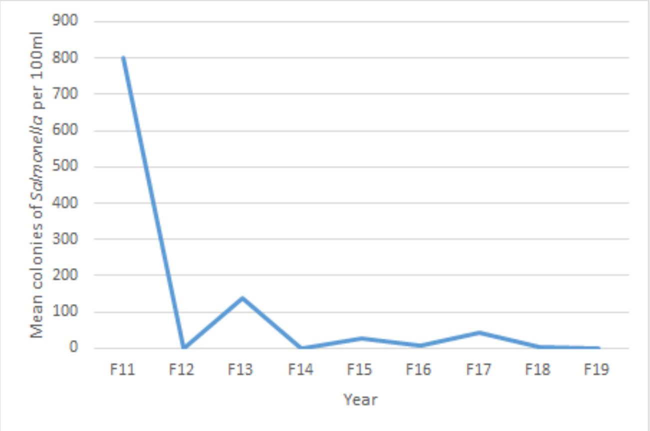

Figure 23. Mean levels of *Salmonella* (colonies per 100ml) at the Linfield College site in the fall from 2013 to 2019.

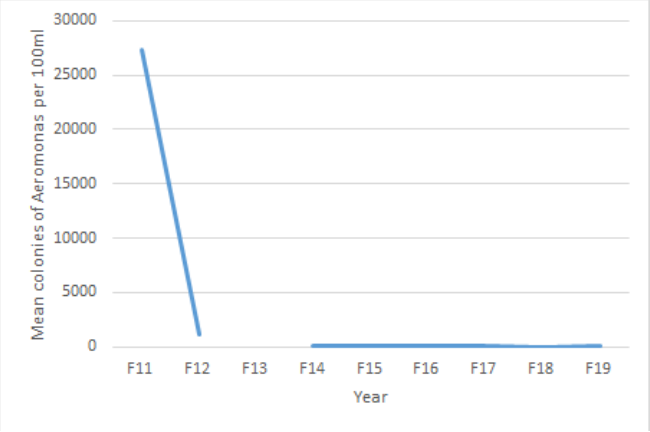

Figure 24. Mean levels of *Aeromonas* (colonies per 100ml) at the Linfield College site in the fall from 2013 to 2019.

The abundance and diversity of macroinvertebrates indicate the overall health of a waterway. Macroinvertebrates are often studied due to the frequency and availability of organisms in the waterway (EPA, 2016a). The PTI (pollution tolerance index) has always shown Cozine Creek to be in the poor category of water quality, which is less than 11 (Figure 25) (IDEM, 2017). Because macroinvertebrates spend much of the year in the creek, they are excellent indicators of longer terms water quality (EPA, 2016a). This indicates that Cozine has had and continues to have poor water quality. Because macroinvertebrate diversity is related to DO, BOD, temperature, and flow (SOURCE?), the PTI reflects our findings. The low PTI also reflects the muddy bottom of our stream as substrate has a large impact on what macroinvertebrates will be present (SOURCE?).

Figure 25. Mean PTI for the Linfield College site in the fall from 2013 to 2019. The orange line is the division between poor and fair water quality (IDEM, 2017).

Changes in Vegetation

We found the percent cover by invasive species on Newby Hill was significantly lower in 2018 than in 2017 or 2019 (Figure 26). Although the increase this fall may seem to be indicative of a negative change in riparian habitat, it is likely better than it shows. We do not have any baseline data for the original plant cover on Newby Hill before invasive species removal began in fall 2017. Volunteers at Newby Hill have been manually removing invasive species since August 2016. We first set up transects and began collecting data in fall 2017. Somewhat monthly work parties have been happening since August of 2016. This means there was over a year of invasive species removal prior to our initial data that was collected after three work parties had been completed (Personal Communication, Bill Fleeger, December 9th). Our initially reported cover by invasive species should be much lower based on what was originally present at the site. The increase since last fall may be due to the infrequent work parties that remove a small portion at each session. It also could be due to an increase in disturbed soil from restoration project activities; disturbed soil is preferred by many invasive species (Dix et al., 2010).

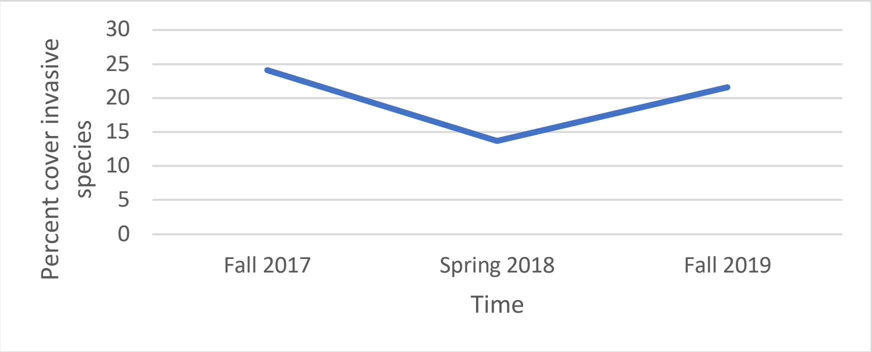

Figure 26. Percent cover by invasive species on Newby Hill during fall 2017, spring 2018, and fall 2019.

The composition of invasive species on the site was 16 species that included Himalayan blackberry, English ivy, yellow-flag iris, Italian arum, and reed canary grass. The only species that had significant changes was English ivy, which had significantly greater cover in 2017 and 2019 than 2018, potentially for the same reasons we listed above (Figure 27).

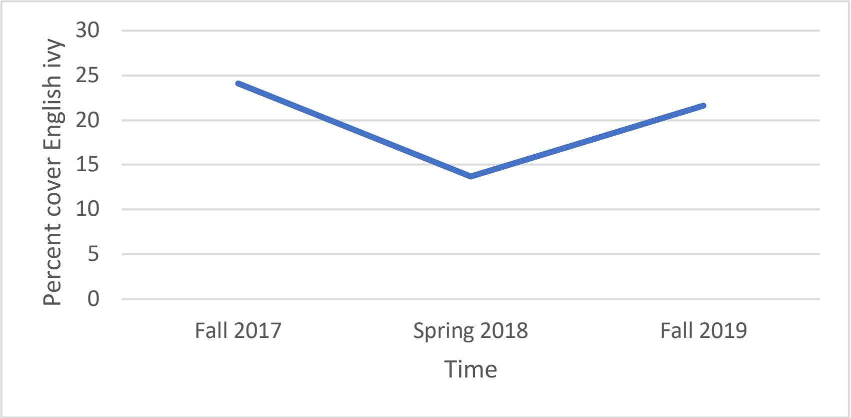

Figure 27. Percent cover by invasive English ivy on Newby Hill during fall 2017, spring 2018, and fall 2019.

We found low survivorship of the three native species that had been planted on Newby Hill. Last year's ENVS 460 class found low survivorship for Oregon grape and Indian plum between spring 2018 and fall 2018 and speculated that it may have been due to excessively warm weather and low rainfall during that summer (Schmidt et al. 2018). The continued decline in survival for all three species could be due to a second summer of hot, dry weather, as well as competition from the increasing cover by invasive plants that shade out native plants and utilize the nutrients and water the native plants need for survival (Muth, 2014). As temperatures continue to increase with the treads expected with change in climate and soils dry with the increased heat and potential for decreased rainfall, native plants that require adequate rainfall and temperate weather will struggle to survive and thrive in the changing climate, potentially decreasing survivorship further (Cowles et al., 2018).

CONCLUSIONS

Our findings suggest that Cozine Creek has had poor water quality since 2011, a trend that will probably continue. Temperature and dissolved oxygen continue to be outside of the allowable salmon thresholds, which signifies a low capability of sustaining aquatic life and no chance of supporting salmon (Connolly et. al., 2004). Temperature in particular has been rising over the past few years and in 2019 was above the maximum survivable level (Kidd, 2011). One possibility as to why Cozine Creek is experiencing rising temperatures could be warming due to climate change. The Willamette Valley, like many other areas of the world, has been experiencing the negative effects associated with climate change, one symptom of which is the hot and dry summers the valley has been experiencing (Floyd, 2019). In 2018, Portland Oregon broke 2015's record of 29 days over 90 degrees Fahrenheit with 31 days over 90-degrees (Herron, 2018; KOIN, 2018). In 2019, Portland broke heat records with a 98-degree Fahrenheit day, which broke the 1972 record by one degree (Ramakrishnan, 2019). Warmer atmospheric temperatures will warm aquatic temperatures, leading to lower DO as water with higher temperature can hold less dissolved oxygen (USGS, 2016c). This could be part of the reason for the continual low DO, which are below the allowable levels for salmon to survive (Kidd, 2011). Another reason that could be contributing to such low DO levels in Cozine Creek is its relatively low flow; higher levels of flow incorporate more oxygen into the water. Because of this, it is important to address barriers to flow along the water way and assess whether their removal would be important for increasing flow, thus increasing DO (USGS, 2014). Removal of such barriers could also allow for a more diverse set of aquatic animals (SOURCE).

Our research over the course of the term has shown that Cozine Creek continues to have poor water quality that is not suitable for salmon habitat. One of the biggest roadblocks in the water quality variables for making the stream adequate for salmon is dissolved oxygen levels; DO levels in Cozine Creek this year were barely above half of the minimum amount required for salmon. Another area of concern is temperature. Last year, temperature in Cozine Creek crossed the threshold for the salmon 7-day moving average maximum, and this year it continued to rise (Kidd, 2011). Although temperature and DO levels worsened since last year's report, there were some positive changes. Flow increased; turbidity, phosphate, nitrate, and ammonia all declined; coliform bacterial levels remained low.

It is impossible to say how much of an effect, if any, the restoration project has had. But restoration work is recent, and there is still much work that can be done. Our project is a beginning but we will need many more along the stream before Cozine Creek can become a suitable habitat for salmon. In addition, the culvert under Davis Street prevents salmon and lamprey from traveling upstream to our site. It is important that the city of McMinnville consider its replacement with salmon friendly options in the future.

WATER QUALITY IN COZINE CREEK IN THE FUTURE

Since the recognition and repair of the sewage leak in 2011, we have seen coliform bacteria decline to healthy levels (Table 9). Although there has been little improvement in levels of *E. coli* in Cozine Creek since 2011, they continue to remain below the critical threshold at relatively safe levels (Figure 22). We expect the vegetation restoration efforts to increase native species with concomitant decreases invasive plants, which will cover the stream bank with healthier riparian vegetation. More trees and shrubs will provide more shade that will help decrease water temperature, which will increase dissolved oxygen. These changes will increase water quality and result in a better habitat for macroinvertebrates (EPA., 2016a; EPA, 2019d; USGS, 2016b; USGS 2016c). Hopefully future changes will allow for the return of salmon to Cozine Creek.

Continued monitoring of water quality variables in Cozine Creek provides the Greater Yamhill Watershed Council with useful information on the creek's health, providing details on water pollution and conditions still below the minimum requirements for salmonids. Dissolved oxygen and water temperature must improve in order for salmonids to survive in the creek; providing information annually on the quality of water will help with problem solving and promote further improvements. We predict the quality of water will improve due to the restoration project. We also predict water quality will increase as the local community becomes more aware of the effects their actions have on the quality of the water.

We believe a healthier riparian habitat is integral to the improved water quality of Cozine Creek. The removal of excess nutrients from farmland runoff, neighborhood lawns, and the Linfield College campus in concert with increased shade due to planting more trees and shrubs is crucial to the rejuvenation of the creek. We have much optimism for the effects of the restoration project in future years as the riparian habitat becomes healthier and better provides for the increased health of the creek.

SUGGESTIONS FOR THE FUTURE

There many things that could be done to help improve the quality of the water in Cozine Creek in the future. Efforts should be made to encourage members of the community to maintain healthy lawns and gardens using no or lower levels of fertilizer and pesticides. This will help reduce runoff of nutrients and toxins in local waterways. Increasing the number of community members that volunteer to remove invasive species and replant native species of shrubs and trees would help improve riparian habit and reduce water temperature by providing shade (National Wildlife Federation, 2019). Another idea would be to design a monitoring program for the early detection of invasive species in the Cozine Creek area. The program should include training on how to properly identify and remove invasive species, as well as proper disposal methods. Volunteers in the program could help keep records of location and notes of new invasive species. The planting of native species on Linfield Campus's portion of Cozine Creek will be taking place this winter and spring; we hope more people will volunteer to help with this important part of the restoration project. We also hope our restoration project encourages other community members who live along Cozine Creek to get rid of invasive species and plant more native ones. Planting of native species can be especially beneficial for a couple of reasons according the East Multnomah Soil and Water Conservation District (EMSWCD). The first is that many native plants have deeper root systems and can hold more water. Native plants also provide habitat for birds, insects, and other pollinators as well as help reduce the abundance of invasive species that cost the state of Oregon approximately $125 million a year in pest control (EMSWCD, 2019).

Limitations

This project had a few limitations. Due to the nature of the course, measurements could only be taken once at each site, which probably resulted in changes in variables due to weather rather than the creek. We also potentially had problems with bacterial counts due to the subjective nature of identify the different types of bacteria. We also had some issued locating the exact location to start some vegetation transects due to the inaccuracy of GPS measurements. Vegetation may have also been misidentified or missed due to inexperienced students doing the sampling.

Acknowledgements

We would like to thank Nancy Broshot for her leadership and consultation with both the collection of data and the writing of this research paper, Barbara Van Ness for her continued support in both the lab and the field, and Bill Fleeger for supporting our efforts. We would also like to thank Luke Westphal of the Greater Yamhill Watershed Council for facilitating restoration events for the health of Cozine Creek and for providing information about the local watershed, as well as Amie Loop-Frison of the Homeowners Association of Michelbook Meadows subdivision for providing us access to that research site on several occasions.

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