Examining Water Quality in Cozine Creek, McMinnville, OR

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INTRODUCTION

Water is a natural resource that is essential to the survival of all living things. Water quality affects public health, economic development, and all ecosystems on Earth. A polluted water supply may mean life or death for specific living organisms. Disrupting one species often means disrupting an entire ecosystem; therefore, the smallest disturbance may potentially influence the health of the ecosystem. Further, freshwater has greater biodiversity than seawater. Freshwater comprises just three percent of global water supplies, yet 30% of fish species are found in freshwater systems. Such freshwater biodiversity may be due to the greater number of niches found in freshwater, including but not limited to lakes, creeks, brooks, and wetlands. These ecologically diverse habitats provide greater opportunities for adaptive radiation of species; thus, protecting freshwater systems proves to be valuable in securing biodiversity (Convention on Biological Diversity 2016).

Less than 3% of global freshwater is potentially useful for human consumption, which makes conservation efforts essential (Conservation in Biological Diversity 2016). The vast majority of freshwater found on planet is largely inaccessible for human consumption, bound in glaciers and ice caps, or found deep within aquifers. When considering the world's total freshwater resources, less than 1% is present in surface water. The anthropocentric perspective highlights the necessity of adequate water quality and conservation methods (Reuther 2000). We first look into the effects of poor water quality on human populations in order to emphasize its importance.

Stakeholders:

From a social justice perspective, it is essential to examine how water quality affects humans, especially those who are marginally displaced. Poor water quality tends to mostly affect disadvantaged communities who disproportionately depend on local streams, rivers, and lakes. In the Pacific Northwest, fish consumption is especially high among Native Americans, minorities, immigrant groups, and low-income populations who often disregard fish advisory warnings in order keep their families fed. Native Americans have lived with and fished in the Pacific Northwest's waters for thousands of years. They have relied on healthy ecosystems to supply fish and wildlife for their survival. They typically consume more fish and shellfish than other people in the Pacific Northwest and are consequently exposed to higher levels of toxins. Toxins that bioaccumulate in aquatic life also bioaccumulate in humans who consume them. As a result, members of these communities face higher health risks like cancer and other diseases attributable to toxins released into our waterways from urban and rural runoff (Nicole 2013). This magnifies the importance of studying and managing the quality of water bodies because of all the affected species, human and other animals. These living systems are interconnected and have a significant effect on human social structures, including the economy.

Economics of Water:

From an economic perspective, the question of whether it is necessary to have good water quality (i.e., in compliance with government microbial and chemical standards) can be interpreted in a variety of ways. The environmental aspect deals with wildlife habitat health, ensuring ecosystem sustainability and making sure water is clean enough for drinking and bathing. This is important to wildlife conservationists and government officials alike, but can often be overlooked when it comes time to write legislation. Policy makers often look at the natural environment with an eye toward monetary value. This is understandable because funds must be available to conserve natural ecosystems; without a sufficient budget, policy makers have little opportunity to make change (Loomis et al. 2000).

Water quality has been one of the leading environmental issues for the last hundred years and remains a problem to this day. Most water pollution comes from nonpoint sources such as agricultural farmland or urban streets. Nonpoint source pollution, as opposed to point source, is extremely difficult to monitor due to the lack of information regarding the location of where the pollutants originate (EPA 2016a). Because of this problem, agricultural and industrial practices have been subject to restrictions and regulations to limit the impact of pesticides, nutrients, sediments, and salts used in many large scale agricultural and industrial institutions. The problem is these regulations lack enough information to enact a solution that benefits both environmental and economic interests. This becomes an issue for large scale agriculture because in order to meet demand needs, they must produce a high quantity of goods with the lowest costs possible. The issue that arises with this simple demand equation is that costs of production are too high, which encourages businesses to cut corners in order to not go bankrupt. This situation happens far too often in today’s age of mass production, fueled by the need to meet economic demands. These economic demands can be correlated to the increasing levels of water pollution and sedimentation occurring in freshwater streams and rivers (Ribaudo et al.1999).

Loomis et al. did a study using surveys to determine how much people were willing to contribute to the restoration of an impaired river. They found the mean contribution would be $21 per month or $252 annually for additional ecosystem services. Accounting for the people who did not respond, they determined that 19 to 70 million dollars could be raised each year. This was more than enough to cover the start up costs of $1.13 million plus the farmland easement costs of $12.3 million. Studies like this examine the value of the environment from a different perspective by comparing the aesthetic values to the economic values (Loomis et al. 2000). Just as water quality plays a large role in the economy, it also is a major component in our forms of governance.

Water Rights:

Rules and policies have been created to ensure human rights, safety and distribution of our freshwater supply in the United States. These rules, referred to as water rights, are an important factor related to water quality. In the United States, prior appropriation and riparian rights are the two major forms of water rights. The East Coast mostly uses riparian rights because of high levels of rainfall and fairly even water distribution across watersheds. On the West Coast, which is drier and receives significantly less rainfall and runoff, the main form of water rights is prior appropriation (Field 2008).

Prior appropriation, used in the state of Oregon, ultimately means the first person to appropriate and make beneficial use of a water supply inherits the rights. That person then receives all the water they need to fulfill a ‘beneficial use’ before any user coming after them (Field 2008). According to the Oregon Department of Environmental Quality, beneficial uses include domestic water, fishing, industrial water, boating, irrigation, water contact recreation, water for livestock, aesthetic quality, fish and aquatic life, hydropower, wildlife and hunting, and commercial navigation, and transportation (ODEQ 2003a).

Most of the water rights in the Yamhill Watershed belong to private landowners, making regulatory action difficult. Agencies and organizations concerned with improving our watershed have to work closely with landowners and community members in order to improve overall water quality (YSWCD 2015). Other methods of relating water quality that many local communities turn to for support exist at a federal level.

Water Policies and Laws:

One of the United States' most influential environmental laws was the Clean Water Act signed in 1972. The Act's goal is to "restore and sustain the chemical, physical, and biological integrity of the nation's waters by preventing point and nonpoint source pollution, providing assistance to publicly owned wastewater treatment facilities, and maintaining the integrity of wetlands" (EPA 2016a). The Clean Water Act requires the adoption of state-specific water quality standards, defining beneficial uses of the state's waters, and establishing conditions designed to protect those uses (EPA 2016b; EPA 2015a).

By developing and implementing water quality standards and clean water plans, the Department of Environmental Quality (DEQ) regulates sewage treatment systems and industrial dischargers, collects and evaluates water quality data, provides grants and technical assistance to reduce nonpoint pollution sources, and provides loans to communities to build treatment facilities (Field 2008). While the DEQ regulates and manages water at the state level, the Environmental Protection Agency manages at the federal level. These agencies and policies were put in place to protect water and maintain healthy standards in our water bodies. Today, regulatory agencies are protecting our water using a watershed approach.

Watersheds:

A watershed is the area of land where water is collected and drained through natural systems into a river, lake, or stream. Small streams feed into larger rivers that ultimately go to larger bodies of water such as lakes or oceans. A variety of social, environmental, and economic benefits are derived from having a healthy watershed (DeBano et al. 2016). Pollution of even the smallest stream may translate into consequences for the entire watershed (GYWC 2015b). Human activities have added to pollution through urban development and agriculture (DeBano et al. 2016). Urban watersheds in particular suffer from large amounts of pollution because of the increased number of impervious sources. Urbanization also increases the amount of nutrients and carbon, potentially harming the watershed (Pennino et al. 2015).

In order to ensure good quality (water that can be used for its intended purpose) of our watersheds, water quality standards are proposed by state, territorial, authorized tribal or federal laws, and then approved by the Environmental Protection Agency (EPA 2016b). These standards define the desired state of a waterbody and the level of protection, or they mandate how the desired state shall be established for the specific waters in the future (ODEQ 2003b). Long-term planning of watersheds is essential, especially with the impending threat due to the effects of climate change.

Climate Change Impacts:

Climate change will play a large role in how governments and institutions manage water resources. In the Pacific Northwest, it has been predicted that droughts will become more frequent due to earlier melting of snowpack resulting in decreased summer flow. Climate change affects the hydrologic cycle and water temperature and evidence shows it is already affecting water in the Pacific Northwest (DeBano et al. 2016). Water quality is impacted when water temperatures rise, a result of increased air temperatures that can stimulate algal blooms. In addition, higher temperatures can decrease the amount of dissolved oxygen in the water to the point where it is hard for aquatic organisms to survive. Less water flowing downstream in the summer could increase concentration of toxins and pollutants because there is less water to dilute them (Praskievicz and Chang 2011).

OUR STUDY

Location:

The Willamette Valley is one of the most productive agricultural lands in the United States and is the world's capital in grass seed production. It also is a major producer of hazelnuts and wine grapes (Noss et al. 1995). The climate of the Willamette Valley is characterized by cool wet winters and warm, dry summers with an average of 40.4 inches of rain per year (Taylor 1993). Before European colonization, much of the valley was covered in oak savanna, conifer stands, prairie, and riparian woodlands. Today, approximately 0.1% of the native grasslands and oak savannas remain, largely replaced by agricultural land and urbanization (Noss et al. 1995). Given the effects of agriculture and urbanization on water quality, such a drastic transition of the plant communities in the Willamette Valley has left aquatic systems vulnerable to pollution (Maret 1996). Further, the common practices of tillage, fertilization, and valley and residue management impact soil erosion, surface runoff, and nutrient cycling. These factors impact aquatic habitat for fish, birds, and invertebrates (Mueller-Warrant et al. 2012).

Cozine Creek is located within the Yamhill Watershed, an area that has been heavily influenced by development over the past few decades (GYWC 2015a). Cozine originates in the agricultural fields southwest of McMinnville, then runs through the city, eastward before flowing into the South Yamhill River. As Cozine Creek runs through McMinnville, the cover by impervious surfaces reduces the area where water can infiltrate and enter into the groundwater supply. Runoff increases after large storm events and excess nutrients carried in runoff can enter water bodies. As storm water flows over urban lands, it can carry pollutants including sediment, nutrients, bacteria, pesticides, metals, and petroleum by-products. These toxins and chemicals can harm fish and wildlife reliant on water. Such nonpoint source pollution is difficult to manage and regulate because it can have multiple origins (USGS 2016a). Therefore, due to these variables, we hypothesized that overall water quality would degrade as Cozine flows downstream.

Goal and Hypotheses:

The Environmental Research Methods class of Fall 2016 examined the effects of urbanization on a local body of water, Cozine Creek. Cozine runs through urban and rural areas so it is affected primarily by nonpoint source pollution. Nonpoint source pollution is due to runoff from various places rather than through a pipe, making it more difficult to control (EPA 2016a). Cozine begins in agricultural fields, thus agricultural nutrients (e.g., nitrogen and phosphorus) will be tested (Newcomer et al. 2016; EPA 2015b). However these nutrients could also be added by urban runoff from lawn and gardens.

Previous Environmental Science Research Methods classes (ENVS 385) from 2011 through 2015 have analyzed the water quality of Cozine Creek. In order to assess water quality of the region, two rural streams, Mill and Gooseneck Creeks, were also studied. The student's goals were to gain a better understanding of water quality at each site and compare the differences between urban and rural creeks. Previous Research Methods Classes found Cozine Creek had the worst water quality based on nutrients, DO, BOD, and macroinvertebrate diversity. They hypothesized Cozine Creek's poor water quality could be attributed to the urban environment of McMinnville, highlighting impervious surfaces that increased nonpoint runoff of nutrients (Blanco et al. 2015).

Our goal was to examine how water quality changed as Cozine Creek flows from an agricultural environment through the more urban setting of the City of McMinnville. Because we are limited our study this year to Cozine Creek, we added two additional sites on the creek. We developed two hypotheses. The first concerns only the data collected by our class of Fall 2016.

1) We hypothesized that the impervious surfaces of an urban setting would facilitate nonpoint source pollution and lead to progressively poorer water quality as Cozine Creek flows from upstream to downstream.

The previous Research Methods classes collected water quality data from the Linfield College site of Cozine Creek beginning in 2011, so we also examined trends in water quality over time.

2) We hypothesized that due to increasing levels of nonpoint pollution caused by a rising population in McMinnville, we would observe a trend of degrading water quality from 2011 to 2016.

Environmental Parameters:

The Environmental Protection Agency (EPA) has national recommended water quality criteria for pH, dissolved oxygen, turbidity, temperature, and streamflow (EPA 2016b). These parameters will be measured during our study because they tend to be good indicators of overall water quality (Fondriest 2016b).

pH is a measure of how acidic or basic a liquid is based on a logarithmic scale. It is measured on a scale from 1 to 14, with numbers less than 7 indicating a more acidic solution (EPA 2012). The majority of aquatic organisms need water between 6.5 and 8.5. Some organisms, especially predatory fish, have specific pH range requirements. Anything outside of this range can have negative physiological impacts on organisms including decreased reproduction, slower growth, and increased chance of disease. For example, salmon are reported to tolerate a pH range of 5.5 to 9.0, with a reported optimal range of 6.8 to 8.0 (Anonymous 2003, Raleigh et al. 1986). As pH decreases, the mobility of toxic chemical increases, increasing the possibility they will affect aquatic life (EPA 2012; Fondriest 2013b).

Dissolved oxygen (DO) is the amount of free oxygen in water and is essential to all life in a stream. Shallow water fish require 4 to 15 mg/L (ppm), whereas bottom feeders, crabs, oysters, and worms need smaller amounts of DO: 1 to 6 mg/L (ppm) (Fondriest 2013a). To maintain healthy habitat for salmon, DO ppm should not fall below 11 ppm any time during the year (Kidd 2011). DO can enter the water through waterfalls, riffles, and wind.

Temperature is also important to water quality. Colder temperatures can hold more dissolved oxygen, making it better habitat for many fish. Temperature also affects fish because they are poikilotherms, which means their internal temperatures and metabolic rates are affected by the ambient temperature of the water (Carter 2005). Fish species have preferred temperature ranges, thus temperature is influential in what species can live in a stream (USGS 2016b). Higher or lower temperatures can affect fish feeding rate, growth, and metabolism. The longer salmon are exposed to temperatures outside of their optimum, the lower the change in temperature needed to negatively affect their health. Temperature can also affect when salmon migrate and spawn. Salmon have different preferred temperatures at different parts of their life cycle, but the average range is 7.2 to 14.5°C (Carter 2005). Anything greater than 25°C is considered lethal to all life stages (Kidd 2011). Typically, colder streams are healthier streams (USGS 2016b).

Water flow also affects the flora and fauna of a stream. Flow is a measure of how quickly water is moving, and is measured by the volume of water that moves across a single point in the stream. Flow can add to the DO content in the water and affects turbidity and sediment transport based on how rapidly the water is moving. Flow can affect salmonid species differently at different life stages. In younger stages, fish eggs can be washed out by too high of a flow – this is called washout. However, a limited amount of flow is needed to provide water to wash away the buildup of sediment. Adult salmonids are much less susceptible to high water flows and flooding (Warren et al. 2015).

Another issue in U.S. waterways today is eutrophication. Eutrophication is caused by excess nutrients (nitrates and phosphates) in the water. Excess nutrients can promote algal blooms, and typically come from fertilizer runoff from agricultural fields, lawns or gardens. Some algae produce toxins that are harmful to aquatic organisms. Even without the toxins, as the algae dies, bacterial populations increase. As the bacteria decompose the algae, they use up DO. This increases the BOD causing lower DO levels. Sometimes algal blooms can reduce DO levels to the extent they cause "dead zones" – spaces where no organisms can live because of the lack of DO (Nadakuvukaren 2011).

Turbidity is a measurement of how much light can penetrate a water sample and is essentially a measure of how clear the water is. High levels of turbidity can be caused by many conditions, including rain washing dirt into the river or algal blooms. Turbidity can also be caused by agriculture (e.g., manure or sediment running from grazing grounds or fields into streams (Nadakavukaren 2011). High water flow can stir up sediment on the bottom. High turbidity is harmful to fish and other aquatic organisms. Turbid waters can harbor pathogens and clog the gills of fish (USGS 2016a). High turbidity can also smother macroinvertebrates and fish eggs as the sediment settles on the bottom of the riverbed (Nadakavukaren 2011). To ensure a healthy system for salmon eggs and other parts of the life cycle, turbidity should not exceed 10 FTUs (Kidd 2011).

Another way to measure the health of a stream is to examine the composition of the macroinvertebrate community. Benthic macroinvertebrates are an important part of the ecosystem and trophic levels because they play an essential role in the nutrient cycle as they decompose organic matter (Freeland-Riggert et al. 2016). We examined benthic macroinvertebrates to determine the level of pollution in Cozine Creek. Macroinvertebrates highlight the effects of habitat disruption and/or damage that would normally be overlooked by simple water quality tests. These freshwater organisms are easy to work with due to their abundance, size, and specific water quality requirements. Different species of macroinvertebrates have different pollution tolerances that can be used to show the effects of the water contaminants. Because these aquatic organisms cannot escape their water environment, they provide information on the long term health of the stream. There are three categories of pollution tolerance that macroinvertebrates fit into: pollution intolerant, wide range of tolerance and pollution tolerant. (Oleson and Chang 2013). By identifying the pollution tolerance level of specific species, water quality can be estimated using the PTI (Pollution Tolerance Index). This index indicates the general water quality of a stream (Student Watershed Research Project 2013).

METHODS

Three study sites along Cozine Creek were chosen: one upstream shortly after the stream enters the city limits of McMinnville (Cozine Upstream), one on the campus of Linfield College (Linfield College), and one downstream (Cozine Downstream) just before the creek empties into the south fork of the Yamhill River (Figure 1). The GPS coordinates for each sampling location at each site are listed in Table 1.

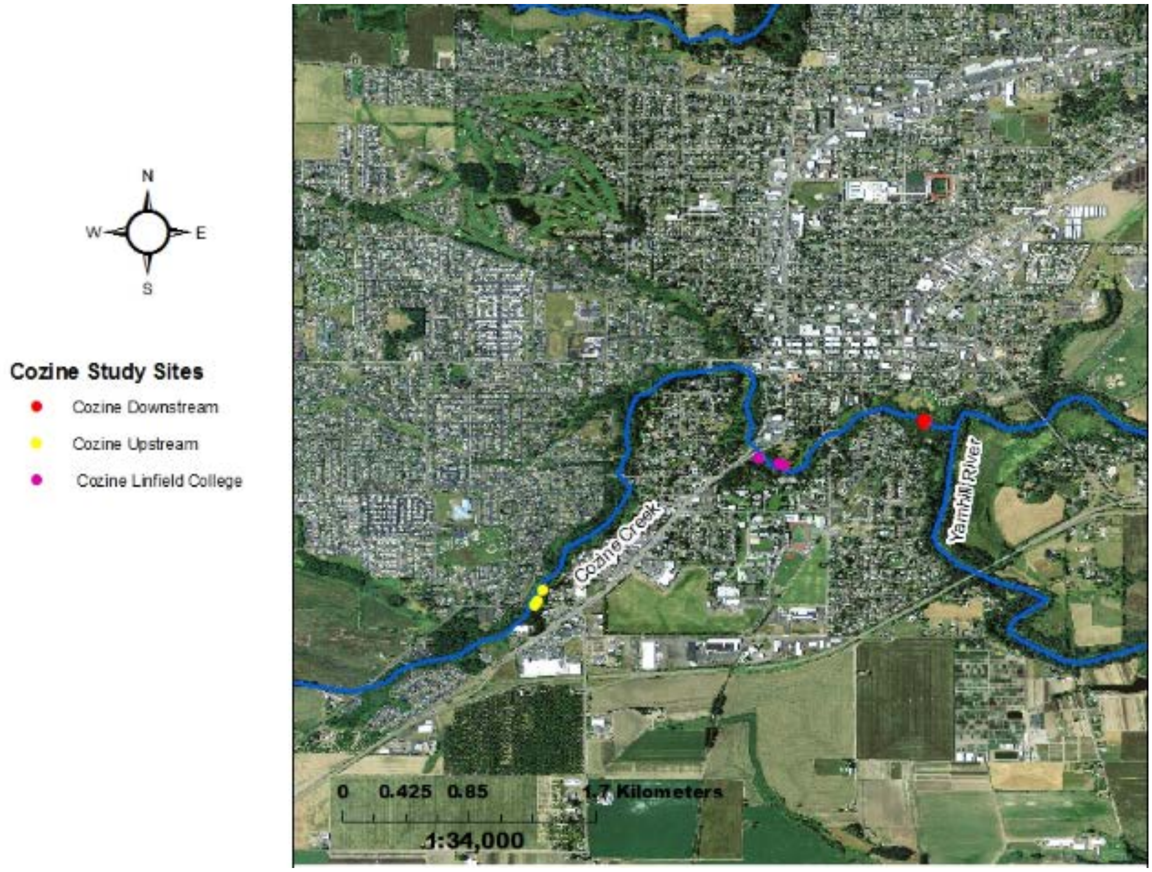

Figure 1. Aerial map showing the three sampling locations along Cozine Creek. Cozine Creek feeds into South Fork of the Yamhill River shortly after the Cozine Downstream site (red).

Table 1: GPS Coordinates for Creek Sample Sites for Fall 2016

Site Name	Sampling Location #	Longitude	Latitude
Linfield College	Site 1	45.20308	123.19797
Linfield College	Site 2	45.2031	123.19833
Linfield College	Site 3	45.20342	123.19955
Cozine Upstream	Site 1	45.19558	123.21257
Cozine Upstream	Site 2	45.19495	123.21290
Cozine Upstream	Site 3	45.19467	123.21307
Cozine Downstream	Site 1	45.20551	123.18959
Cozine Downstream	Site 2	45.20572	123.18965
Cozine Downstream	Site 3	45.20573	123.18939

Site Descriptions:

Cozine Creek Upstream Site -

This site was chosen because it lies downstream from the agricultural fields right after the creek enters McMinnville. It is located in Heather Hollow Park beginning under the Old Sheridan Road Bridge (Figure 2). This is also a location where long term water quality testing has been conducted by the Greater Yamhill Watershed Council (GYWC 2015b). This site should provide information about the water quality of Cozine Creek as it enters McMinnville after flowing through agricultural land. The upstream site features muddy banks alongside a grassy 2.14 acre field west of Cozine Creek (City of McMinnville, 2015). The plant community is dominated by Oregon ash, snowberry, and Himalayan blackberry, an invasive species (Table 2).

Figure 2. Cozine Creek Upstream Site showing Old Sheridan Road Bridge; photo 12/07/16.

Table 2. Common and scientific names (Oregon Flora Project 2016) of plant species found at the upstream sampling site on Cozine Creek

Upstream #1	Upstream #2	Upstream #3
Oregon ash (*Fraxinus latifolia*)	Snowberry (*Symphoricarpos albus*)	Oregon ash (*Fraxinus latifolia*)
Oregon oak (*Quercus garryana*)	Oregon ash (*Fraxinus latifolia*)	English ivy (*Hedera helix*)
Willow *(Salix sp.)*	Himalayan blackberry (*Rubus bifrons*)	Himalayan blackberry (*Rubus bifrons*)
Himalayan blackberry (Rubus bifrons)	Oregon oak (*Quercus garryana*)	Bigleaf maple (*Acer macrophyllum*)
Creeping Jenny (*Lysimachia nummularia*)	Bittersweet nightshade (*Solanum dulcamara*)	Willow (*Salix sp.)*
Reed canary grass (*Phalaris arundinacea*)	Hawthorne (*Crataegus monogyna*)	Reed canary grass (Phalaris arundinacea)
Bittersweet nightshade (*Solanum dulcamara*)	Reed canary grass (*Phalaris arundinacea*)	Creeping Jenny (*Lysimachia nummularia*)
Duckweed (*Lemna minor*)	Lemon balm (*Melissa officinalis*)	Bittersweet nightshade (*Solanum dulcamara*)

Cozine Creek Linfield College Site –

This site was chosen by the spring 2011 (ENVS 385) Environmental Science Research Methods class due to its location on the Linfield College campus. They randomly chose the exact sampling sites along the creek using a random numbers table. The Linfield College sampling site is characterized by a riparian woodland directly surrounding the creek and an upland oak habitat farther away from the Creek. This site featured large live and standing dead cottonwood and Oregon white oak adjacent to the creek (Figure 3). Dominant plant species include creek dogwood*,* Douglas spiraea, snowberry, and Himalayan blackberry (Table 3).

Figure 3. Cozine Creek at the Linfield College Site; photo taken 10/19/16.

Table 3. Common and scientific names (Oregon Flora Project 2016) of plant species found at the Linfield College sampling site on Cozine Creek.

Sampling Location #1	Sampling Location #2	Sampling Location #3
Creek dogwood (*Cornus sericea*)	Creek dogwood (*Cornus sericea*)	Himalayan blackberry (*Rubus* bifrons)
Oregon ash (*Fraxinus latifolia)*	Douglas spiraea (*Spiraea douglasii*)	Morning glory (Ipomoea alba)
Douglas spiraea (*Spiraea douglasii*)	Bittersweet nightshade (*Solanum dulcamara*)	Creeping buttercup (Ranunculus repens)
Trailing blackberry (Rubus ursinus)	Oregon ash (*Fraxinus latifolia*)	Ninebark (*Physocarpus capitatus*)
Himalayan blackberry (*Rubus bifrons*)	Oregon oak (*Quercus garryana*)	Willow (*salix sp*.)
Snowberry (*Symphoricarpos albus*)	Snowberry (*Symphoricarpos albus*)	Red alder (*Alnus rubra*)
Creeping jenny (*Lysimachia nummularia*)	Common selfheal (Prunella vulgaris)	Snowberry (*Symphoricarpos albus*)
Common selfheal (*Prunella vulgaris*)	Poison oak (*Toxicodendron diversilobum*)	Black cottonwood (*Populus trichocarpa*)
Reed canary grass (Phalaris arundinacea)	Himalayan blackberry (*Rubus bifrons)*	Oregon ash *(fraxinus latifolia*)

Downstream Cozine Creek Sampling Site **-**

This site was chosen because it is near the end of the Creek (just before it empties into the South Fork of the Yamhill River) and because it also has had regular water quality monitoring by the Greater Yamhill Watershed Council. They have a device placed at the location that monitors different water levels (GYWC 2016a). This site featured a steep, clay embankment and a muddy bottom (Figure 4). The dominant plants at the Cozine Downstream site were Oregon ash, snowberry, and *Rosa multiflora* (Table 4).

Figure **4.** Cozine Creek Downstream Site, 9/28/16

Table 4. Common and scientific names of plant species (Oregon Flora Project 2016) found at the downstream sampling site on Cozine Creek

Downstream #1	Downstream #2	Downstream #3
Oregon ash (*Fraxinus* latifolia)	Creek dogwood (*Cornus sericea*)	Oregon ash (*Fraxinus latifolia*
Rosa multiflora (*Rosa* multiflora)	Oregon ash (*Fraxinus Latifolia*)	Trailing blackberry (*Rubus ursinus*)
Trailing blackberry (Rubus ursinus)	Rosa multiflora (*Rosa multiflora*)	Yellow iris (*Iris pseudacorus*)
Creeping jenny (Lysimachia nummularia)	Black hawthorne (*Crataegus douglasii*)	Creek dogwood (*Cornus sericea*)
Morning glory (Calystegia occidentalis)	Creeping buttercup (*Ranunculus repens*)	Sow thistle (*Sonchus oleraceus*)
	Thistle (*Carduus sp.)*	Knotweed (*Fallopia japonica*)
	Leafy beggar tick (*Bidens frondosa*)	Field mint (*Mentha arvensis*)
	Plantain (*Plantago major*)	Creeping jenny (*Lysimachia nummularia*)

FIELD MEASUREMENTS

Water Samples:

We collected water samples to be analyzed later for turbidity, nutrients, coliform bacteria, and BOD before we disturbed the creek sediment. We collected water in a sterile bottle from each of our three sampling areas at each site location along Cozine Creek. We also measured the depth of the creek at this location. The bottle of water was placed in a cooler until it was taken back to the Environmental Science Laboratory on the Linfield College Campus where it was placed in the freezer. At a later date, this water sample was used to test for turbidity, coliform bacteria, and nutrients.

We took an additional sample of water to measure Biochemical Oxygen Demand (BOD) at the same locations where we collected the sterile sample. The sample was collected in a BOD bottle in such a manner so as to ensure no air bubbles were in the sample. To prevent photosynthesis the bottle was wrapped in foil and stored in a cooler until it was returned to the Environmental Science Laboratory on the Linfield College Campus. In the lab, the BOD bottles were placed in a dark location at room temperature for five days. After five days, the sample was removed, five aliquots were poured, and the DO was measured using a Hanna DO meter. The calculated difference between the five day DO value and the average initial DO was the biological oxygen demand (BOD) of the sample (Delzer and McKenzie 2003).

Weather Conditions:

We also measured the air temperature at each site with a thermometer to record the weather the day we collected data. Air temperature could affect the stream temperature, an important factor in stream health (Fondriest Environmental Inc. 2016a).

Dissolved Oxygen and Temperature:

A Hanna instrument (model number SNE0052397) was used to record DO from each site. Before going into the field, this instrument was calibrated using a two-point method. The meter was calibrated to 100% at each site prior to collecting data. We then submerged the DO probe into the water and took five readings, removing the probe from the water between each reading. At each site, we measured the DO as percentage and in parts per million (ppm) oxygen (Hanna Instruments 2010).

pH:

pH readings were taken using a Hanna pH meter (model number HI 98128). The meter had a two-point calibration done in the lab prior to entering the field. We measured pH at each site location by submerging the probe until the reading stabilized. We took five readings at each location, removing the probe briefly between readings (Hanna Instruments 2015a).

Flow:

The rate of water flow was measured using a Flow Watch flow meter. We placed the probe into the body of water with the prop facing up-stream so the water flowed across it. We held the probe arm as still as possible until a constant average reading was achieved. We took five readings at each site location, removing the probe from the water briefly before the next measurement (Flow Watch 2016).

Water Temperature:

The DO meter, pH meter, and flow meter all measure water temperature. We used the measurements from the DO meter at most locations. However, the temperature probe on the DO meter was not submerged at shallow creek depths; for those locations, we used the pH meter or flow meter readings.

Macroinvertebrate Collection:

To collect macroinvertebrates we randomly selected five locations at each creek. We measured the depth of the creek at each macroinvertebrate collection site. We then used two, D-frame kick nets; we placed the first D net against the creek bottom, facing upstream so that water and any floating material flowed into the net and was caught. We submerged the second D-net facing downstream with the open part of the net facing the opening of the first D-net. We pushed the nets together with one sweeping motion to trap all of the material inside the nets. The collected material was sorted, and all macroinvertebrates observed were collected and placed into jars containing 70% alcohol (Hayslip 2007).

LABORATORY MEASUREMENTS

Turbidity, nutrient levels, and bacterial counts were done using the water samples that had been collected in the sterile bottles. These samples that had been frozen and stored in the lab freezer were thawed before measurements.

Bacteria:

We first tested each water sample for bacteria to minimize potential contamination. Using sterile technique, we tested the water from each sample for *E. coli*, *Salmonella*, *Aeromonas*, and other coliforms using Easy Gel Test Kits according to the instructions. We prepared five plates for each water sample collected. We used five ml of water from each site along Cozine Creek per plate because we assumed the water was relatively clean. Prepared plates were placed in the incubator in the lab at 35°C. After 48 hours, the plates were removed from the incubator and the colonies counted. We recorded the number of colonies by color: *E. coli* colonies were dark blue, *Salmonella* colonies were teal, *Aeromonas* colonies were pink, and other coliforms were gray blue (Micrology 2008).

Turbidity:

The water samples were measured for turbidity using a Hanna Instruments microprocessor turbidity meter (model HI 93703). The water samples were well mixed and then a sample poured into the turbidity meter cuvette. The cuvette was inserted into the meter and the turbidity was read and recorded in FTU units. Each water sample was measured five times, with a different pour from the mixed collecting bottle each time (Hanna Instruments 2015b).

Nutrients:

We tested each water sample for levels of nitrate, ammonia, and phosphate using LaMotte test kits. We tested for nitrate using the LaMotte Nitrate Nitrogen Tablet Kit (Code 3354-01), for phosphate using the LaMotte Low Range Phosphate Kit (Code 3121-02), and for ammonia using the LaMotte Ammonia-Nitrogen Kit (Code 5864-01). For each kit, we followed the instructions with the kit and did five replicates from each water sample (LaMotte 2016a, LaMotte 2016b, LaMotte 2016c).

Macroinvertebrates:

To identify and count macroinvertebrates, we viewed the contents of each jar under an Olympus Dissecting Scope. We used the *Stream Insects of the Pacific Northwest* booklet (Edwards 2008), the *Identification Guide to Freshwater Macroinvertebrates* handout (Gill 2011) and the *Freshwater Macroinvertebrates from Streams in Western Washington and Western Oregon* website (Clapp 2010) to help us identify specimens to the lowest taxa.

We calculated the Pollution Tolerance Index (PTI). To calculate PTI, we classified the collected organisms into one three groups based on the pollution tolerance of each species. The three groups are pollution intolerant, wide range of tolerance, and pollution tolerant. Each species got three points, two points, or one point, respectively. This sum of the pollution tolerance points is the Pollution Tolerance Index (PTI). That value can be used to indicate the general quality of the stream (10 or less=poor, 11-16=fair, 17-22=good, 23 or more=excellent) (Student Watershed Research Project 2013).

Statistical Analysis of Data:

We used JMP 11 statistical software program to analyze our data using ANOVA. ANOVA tests compare the means of more than two independent variables. The test assumes all data is numerical, the independent variable is at least three nominal categories, independence of observation, no significant outliers, a normal distribution, and nearly equal variance among the groups. We analyzed each water quality variable gathered this year (dependent variable) using the site locations as the independent variable. We also compared the water quality data we collected this year to that from previous years at the Linfield College site. Tests that were significant ($p < 0.05$) were further analyzed using a Tukey HSD Post-Hoc test that determined which sites were significantly different from each other (JMP 2016a and JMP 2016b).

RESULTS

We found percent DO and temperature were significantly lower at the Cozine Upstream (US) site than at the Cozine Downstream (DS) or the Linfield College (LC) sites (Table 5) but that were there significantly more *E coli* colonies UP that DS or LC. DO in ppm was significantly lower at US than DS. Flow was significantly higher DS than US or LC. Nitrate was significantly higher at LC than US or DS, whereas turbidity was significantly lower at LC than US or DS. Flow was significantly higher DS than US or LC. We found more *Salmonella* DS than UP and more *Aeromonas* at LC than US.

Table 5. Mean (standard deviation) and probability from ANOVAS for water quality variables at our three Cozine sites in fall 2016. Means with different letters are significantly different from one another as per Tukey HSD.

Parameter	Cozine US	Cozine LC	Cozine DS	P-value
DO %	15.90 (10.61) A	63.09 (3.73) B	57.89 (1.3) B	0.0001
DO ppm	1.48 (1.24) B	6.2 (0.35)A B	9.13 (13.54) A	0.0353
BOD %	14.79 (10.07)	13.06 (5.73)	8.91 (2.79)	0.066
pH	7.36 (0.08)	7.30 (0.12)	7.34 (0.06)	0.1377
Temp °C	13.7 (1.1) C	15.9 (0.6) A	15.2 (0.4) B	0.0001
Flow cm/s	0 (0) A	7 (7.6) A	11.1 (8.2) B	0.0001
Phosphate ppm	0.13 (0.17)	0.07 (0.05)	0.10 (0.15)	0.4802
Nitrate ppm	0.4 (0.9) B	2.5 (2.5) A	0.4 (0.9) B	0.001
Ammonia ppm	0.17 (0.07)	0.20 (0.10)	0.16 (0.07)	0.4243
Turbidity ftu	24.7 (7.0) A	5.9 (0.9) B	18.8 (12.6) A	0.0001
E.Coli	20.3 (37.7) A	2.4 (6.6) B	1.7 (5.6) B	0.0001
Other	3.9 (13.0)	5.6 (17.6)	3.0 (9.6)	0.6073
Salmonella	2.1 (6.1) B	5.2 (12.9) AB	10.7 (20.3) A	0.0166
Aeromonas	1.18.1 (223.7) A	10.4 (27.5) B	23.7 (33.0)	0.0001

The PTI, number of tolerant species, and total number of macroinvertebrate species were all significantly higher at the Linfield College site than the other two sites on Cozine Creek (Table 6).

Table 6. Mean (standard deviation) and probability by ANOVA for macroinvertebrate variables among sites on Cozine Creek for Fall 2016. Means with different letters are significantly different from one another as per Tukey HSC.

Site	Fall US	Fall LC	Fall DS	P-value
PTI	1.8 (1.3) B	8.4 (3.6) A	4.4 (2.2) AB	0.0053
# Tolerant	1.2 (0.5) B	3.8 (0.8) A	1.8 (1.1) B	0.0009
# Intermediate	0.0 (0.0)	1.6 (1.7)	2.0 (1.4)	0.0635
# Intolerant	0.6 (0.9)	3.0 (3.0)	0.6 (1.3)	0.1442
# Species	1.4 (0.6) B	5.6 (1.7) A	3.0 (1.2) B	0.0006

When comparing our 2016 data of Linfield College campus (LC) to previous years we found BOD was significantly lower in 2016 than in 2015 (Table 7). pH was significantly higher this year and last compared to earlier years (2011-2014). Phosphate was significantly lower this year, as was turbidity. And overall bacterial counts were significantly lower than in previous years – *E. coli*, *Aeromonas*, *Salmonella*, and other coliforms were all significantly lower this year than in 2012.

Table 7. Mean (standard deviation) and probability from ANOVA for water quality variables at Cozine Creek each fall from 2011 to 2016. Means with different letters are significantly different from one another as per Tukey HSC. N/A means the value were not measured that fall.

Average	**Cozine LC (2016)**	**Cozine LC (2015)**	**Cozine LC (2014)**	**Cozine LC (2013)**	**Cozine LC (2012)**	**Cozine LC (2011)**	**p-Value**
DO %	45.63 (22.30) B	58.84 (2.86) AB	52.43 (10.07) AB	58.54 (6.45) AB	58.18 (0.10) AB	69.29 (2.95) A	0.001
DO ppm	5.61 (8.31)	N/A	5.09 (1.15)	6.42 (0.64)	N/A	N/A	0.9221
BOD	13.06 (5.73) BC	24.85 (14.16) A	16.23 (16.78)AB C	9.84 (6.01) BC	3.68 (3.76) C	6.28 (0.47) AB	0.0001
PH	7.30 (0.12) A	7.18(0.04) A	6.30 (0.31) C	6.28 (0.47) C	6.49 (0.26) C	6.84 (0.23) B	0.0001
Temp	15.9 (0.6) B	16.6 (0.7) A	13.5 (1.2) C	11.5 (1.4) D	9.6 (0.4) E	12.3 (0.1) CD	0.0001
Flow	7.0 (7.6) B	3.0 (4.4) B	NA	0.7 (1.0) B	10.5 (8.6) B	44.9 (73.6) A	0.0004
Phosphate ppm	0.07 (0.05) BC	0.31 (.18) A	0.11 (0.18) BC	0.04 (0.05) BC	0.00 (0.00) C	0.20 (0.04) AB	0.0001
Nitrate ppm	2.5 (2.5)	2.6 (3.9)	1.9 (3.2)	0.11 (0.22)	0.00 (0.00)	0.00 (0.00)	0.0173
Ammonia ppm	0.20 (0.10)	0.14 (0.13)	0.15 (0.06)	0.23 (0.08)	NA	NA	0.18
Turbidity	5.95 (0.86) B	9.49 (4.05) A	5.04 (0.65) B	5.95 (2.37) B	NA	NA	0.002
E. Coli	2.4 (4.1) B	15.0 (3.7) AB	0 (9.6) B	17.8 (9.6) AB	44.4 (9.6) A	22.2 (9.6) AB	0.0016
Other (Coliforms)	5.6 (17.6) D	25.0 (43.7) BC	22.2 (44.1) BCD	55.6 (37.1) AB	75.6 (44.5) A	0.0 (0.0) CD	0.0001
Aeromonas	10.4 (29.4) C	126.7 (257.7) B	0 (0) BC	NA	1173.3 (465.8) A	8.9 (14.5) BC	0.0001
Salmonella	5.2 (14.5) B	30 (13.2) B	155.6 (34.1) A	NA	0 (34.1) B	17.8 (34.1) B	0.0026

The Pollution tolerance Index (PTI) and the number of intermediate species were significantly higher in 2014 than in 2016 and 2014 (table 8). There were significantly more macroinvertebrate species in 2015 than 2014.

Table 8: Mean (standard deviation) and probability from ANOVA for macroinvertebrate variables at Cozine Creek each fall from 2013 to 2016. Means with different letters are significantly different from one another as per Tukey HSC.

	Fall 16	Fall 15	Fall 14	Fall 13	P-value
PTI	4.8 (3.7) B	9.2 (2.5) A	5.4 (2.6) B	7.1 (2.1) AB	0.008
# Tolerant	2.3 (0.4)	3.2 (1.3)	2.8 (1.6)	2.2 (1.3)	0.3410
# Intermediate	1.2 (1.5) B	4.7 (2.8) A	1.3 (1.4) B	2.9 (2.0) AB	0.0007
# Intolerant	1.4 (0.5)	1.3 (0.7)	1.3 (1.6)	2.0 (2.1)	0.8790
# Species	3.3 (2.1) B	5.8 (1.5) A	3.9 (1.7) AB	4.3 (1.6) AB	0.0262

DISCUSSION

Cozine Creek Across the Sites:

Our results indicate that this fall Linfield College site had the best aquatic health of the three sites examined on Cozine Creek. We reject our hypothesis that Cozine Creek's water quality will become progressively poorer as it flows downstream. In fact, the poorest water quality by many measures was found at the Upstream site as evidenced by significantly lower DO, flow, and PTI compared to the Linfield College and Downstream sites.

The DO at the Upstream site (Figure 5) was below the optimal value conducive for salmon. The Linfield College site had significantly higher DO levels than the Upstream site (Figure 1), although it was barely above minimum salmon DO requirement of 6 to 11 ppm (Kidd 2011). The higher DO at the Linfield College site is one indication our hypothesis was incorrect, as higher DO levels indicate a healthier habitat. If our hypothesis had been correct, we should have found the highest DO at the upstream site. And even though the College site was above the minimum DO, it was barely, and both the other sites were below the level.

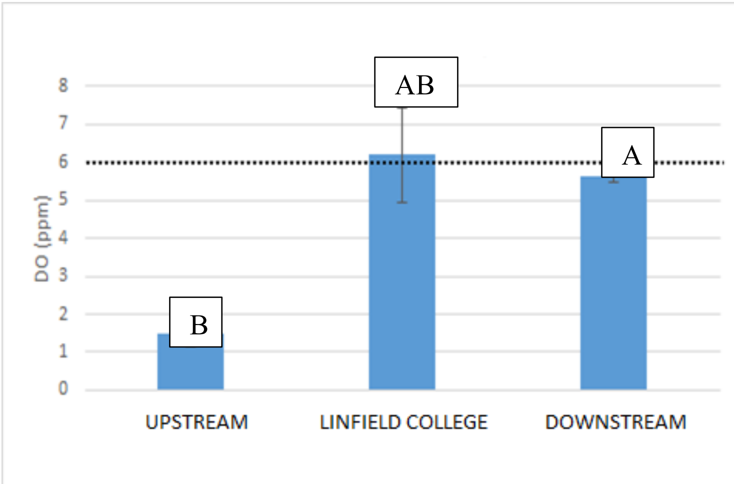

Figure 5. Mean DO (ppm) levels for all three sites along Cozine. The dashed line indicates the optimal minimal level for salmon.

Flow increased as we moved downstream. The Downstream site had significantly higher flow than the other two sites along Cozine Creek (Figure 6). The increased flow could have been caused by large rain events that occurred between the dates we observed flow at the Upstream and Downstream sites (Weather History 2016). This would have increased the flow rate at all three sampling locations because we measured the sites from Upstream to Downstream with a week in between sampling dates. It would be beneficial to conduct future testing on the same day in order to reduce similar disparities across sites. Further, the low flow at the Upstream site (Figure 2) correspond with the low level of DO at that site (Figure 5). There is a positive correlation between DO and flow (EPA 2016a), with higher flow rates yielding higher DO.

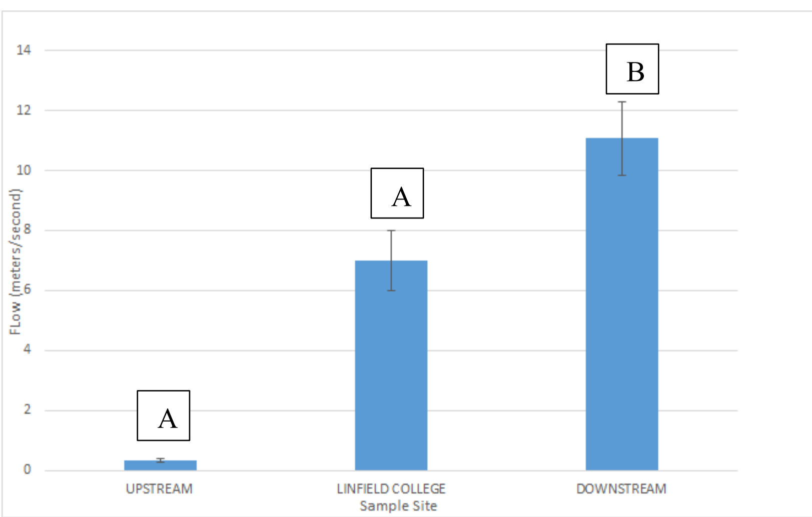

Figure 6. Mean flow rates for all three sites along Cozine measured in cm/second.

Turbidity at the Linfield College site had was significantly lower than the Upstream and Downstream sites (Figure 7), which both had higher turbidity values than what salmon could tolerate. This result also is contradictory to our initial hypothesis that water quality would decrease as we moved downstream. Lower levels of turbidity at the College site may be attributed to the North Fork of Cozine that enters the main branch of the creek slightly upstream from our College site. This tributary may have diluted the more turbid water flowing from Upstream to Linfield College. Adding a site on the North Fork next year could help determine its effects on the Linfield College site of Cozine.

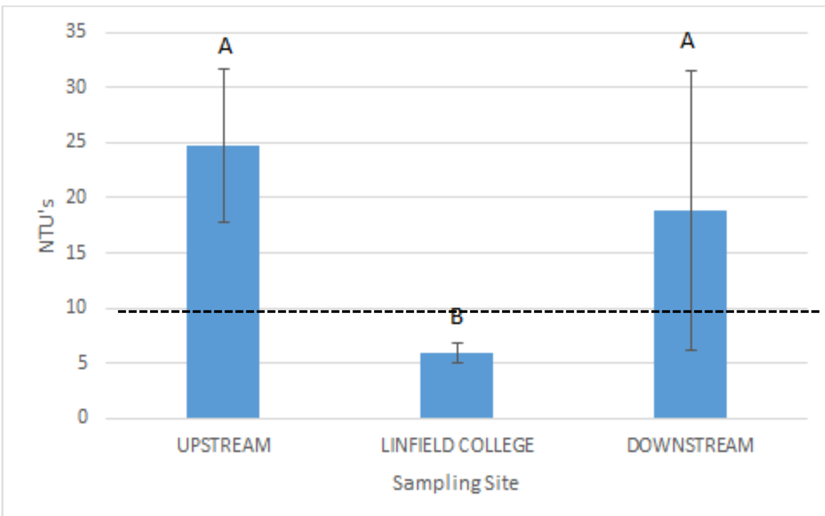

Figure 7. Mean turbidity levels for all three sites along Cozine Creek measured in NTUs. The dashed line shows the maximum turbidity for salmon.

The Linfield College site had significantly lower levels of *E. coli* than either of the other two sites (Figure 8). Although, the Upstream and Downstream site appear to have relatively high *E. coli* levels , the EPA limit for recreational use is 126 colonies/100 ml. Therefore, the water in Cozine at the college could theoretically be used for swimming. The variation among the sites could be attributed animals such as birds, deer, or nutria contaminating the sites with fecal matter. *E.coli* is in all warm-blooded animals digestive tracts and occurs as a natural part of the animal's excrement (CDC 2015). In future studies, we recommend that *E.coli* levels be monitored throughout the year.

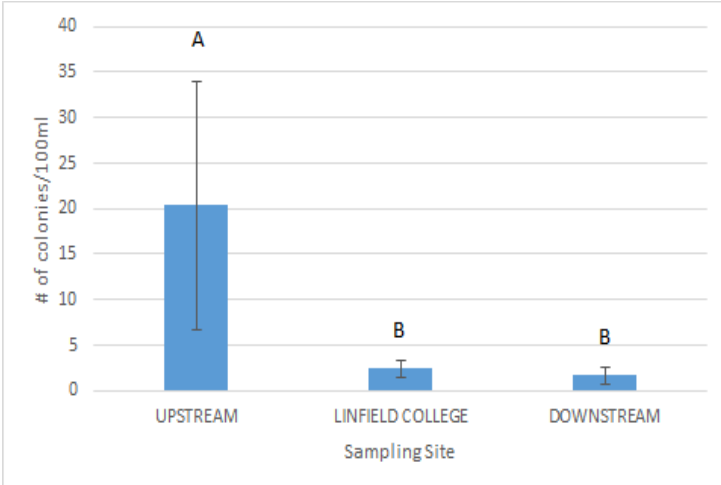

Figure 8. Mean E. coli levels from all three sites along Cozine measured in #colonies/100ml.

The Linfield College site had a significantly higher Pollution Tolerance Index (PTI) than the other two sites. This indicates the Linfield College site provides a better habitat for aquatic organisms, reflected by the larger prevalence of pollution tolerant and intolerant species. However, all three sites have PTI values that are rated as poor, indicating that Cozine does not have good water quality.

Although the Linfield College site appeared to have the best water quality in several measures, it also had worse quality according to some other measures. For example, the level of nitrate was significantly higher that Linfield than the other two sites. This could be due to fertilizer use along Cozine Creek in recent years. Nitrate is a common nonpoint pollutant (Nadakuvukaren 2011). And the level of nitrate was not excessively high at any site.

The Upstream site appeared to be less suitable for aquatic organisms because it had the lowest DO and flow, and the highest turbidity, as well as the lowest PTI. These parameters indicate poor water quality We conjecture that the Upstream site was degraded from agricultural use before Cozine enters the city. In the future, sampling the water for chlorine will help determine if the source of the water is urban (city was has been chlorinated) or rural.

As stated earlier, we rejected our hypothesis that Cozine Creek's water quality would decrease as it flowed downstream. This could be attributed to the unforeseen, restorative impact of vegetative buffers found as moved downstream. The Upstream site has a progressively greater riparian buffer around Cozine Creek. Further, we hypothesize that the progressively larger riparian buffers found within the urban boundary of McMinnville, effectively hinder erosion (seen in lower turbidity values downstream) and prevent the nonpoint pollutants of nutrients and bacterial contaminants from flowing into Cozine. In fact, this hypothesis is rooted in the scientific consensus that riparian buffers help prevent sediment, pesticides, nutrients and other pollutants from reaching waterways (US Fish & Wildlife Services 2015). In the future, we suggest Research Methods classes to evaluate the benefits of the riparian boundary along Cozine so our hypothesis of riparian health can be made. We suggest future classes evaluate the small tributary north of Cozine, as to determine how the water from this tributary may be impacting the health of Cozine at the Linfield College and Downstream sites.

Cozine Creek Across the Years:

The only site that we have measured every fall since 2011 was the Linfield College site and so we are making our analysis based on this one site. Our hypothesis that water quality would degrade over time was somewhat confirmed by our results. We found that 2016 reflected the worst water quality from 2011 to 2016 based on temperature, nitrate, *E. Coli*, and macroinvertebrate diversity. Because these environmental variables reflect poor water quality and because they have tended to decline over the years, we accpet our hypothesis.

Water temperature at the Linfield College sampling site have shown a gradual increase in temperature since 2012 (Figure 9). Water temperature was significantly lower in 2012 than in 2015 ($p<0.0001$). The average temperature at the Linfield College site for the last two years has been approximately 16°C. The ideal temperature for adult salmon is below 11°C and their livable range is 3-16°C (Kidd 2011). In fact, since the ENVS 385 class has been monitoring the site, it has only been below this critical temperature in 2012. It will be important to monitor this concerning trend of elevated temperature.

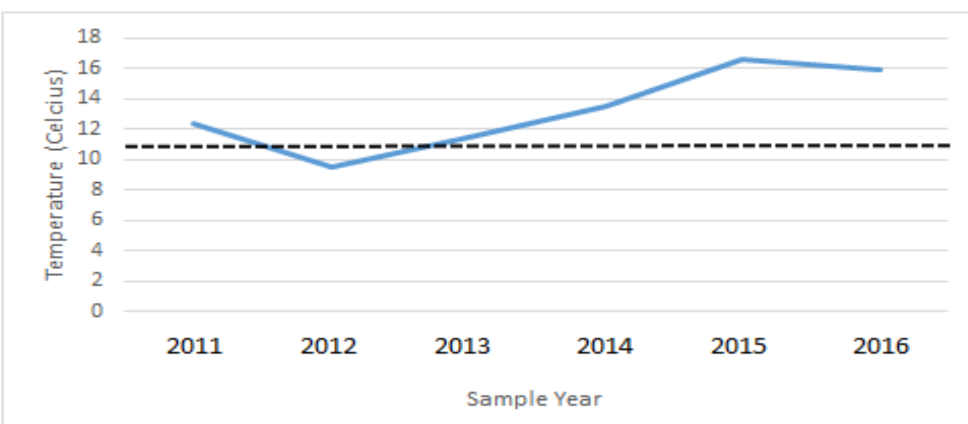

Figure 9. Temperature in °C for the Linfield College site from 2011 to 2016

Levels of phosphate and ammonia have remained relatively low in the years ENVS 385 has been measuring it, however nitrate increased from 2013 to 2016 (Figure 10). From 2015 to 2016 Nitrate was significantly higher in 2015 and 2015 than in 2013 ($p<0.0001$). We speculate that an increase in fertilizer use may causing these elevated nitrate levels, but more investigation would be necessary to confirm this.

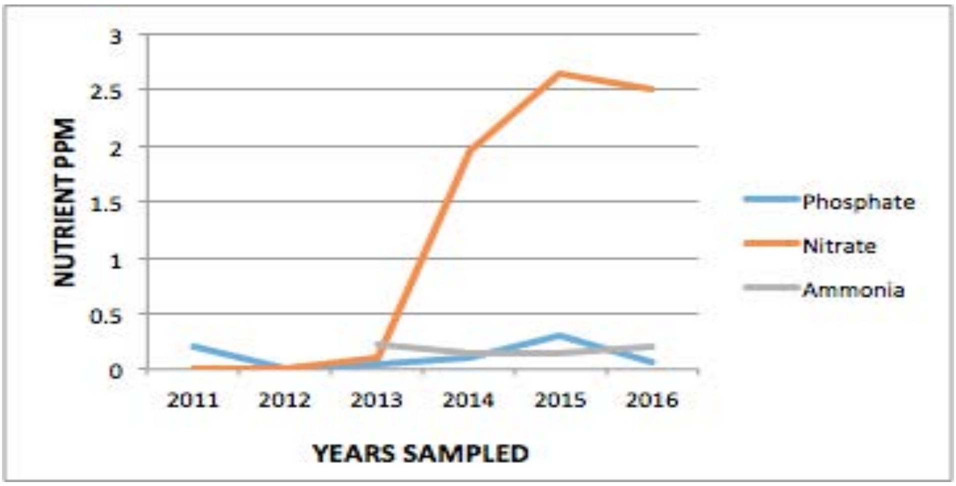

Figure 10. Nutrient levels for the Linfield College site (LC) from 2011 to 2016 measured in ppm

E. coli and other coliform bacterial levels decreased from 2012 to 2016 (Figure 11). *E. coli* was significantly lower in 2014 and 2016 than in 2012 ($p<0.016$).,Other coliform levels were significantly lower in 2014 and 2015 than in 2012 ($p<0.0001$). This is a positive trend that we hope continues. However, levels of coliform bacteria should be closely monitored by future classes as this is a critical measure of water quality.

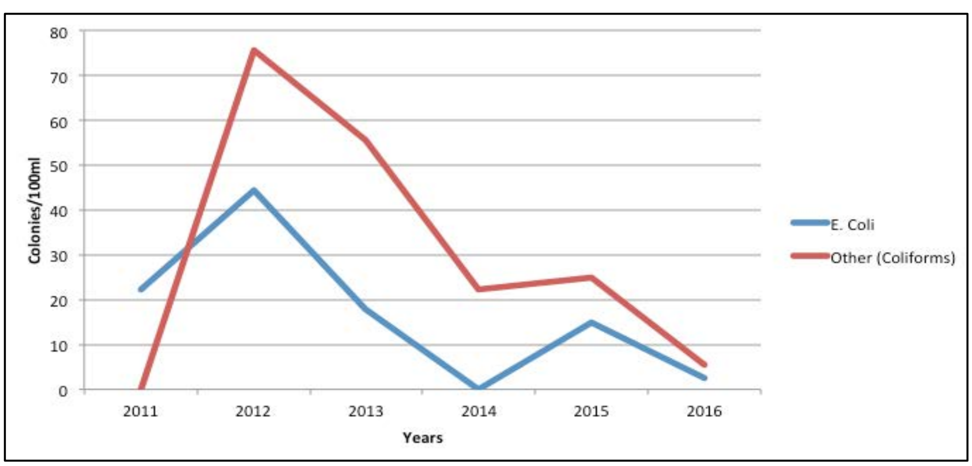

Figure 11. E. coli and Other Coliform levels for the Linfield College site from 2011-2016.

The PTI values at the Linfield College site have never been above 10; meaning the site has continually had poor water quality according to the macroinvertebrates data (Figure 12). There appears to have been a spike of PTI in 2015, however we attributed this to the "Macro-Queen Effect". We created this informal term to highlight the fact that the 2015 Research Methods class had a meticulous and thorough macroinvertebrate sorter. The total abundance of specimen counted in fall 2015 was far greater than in any other year

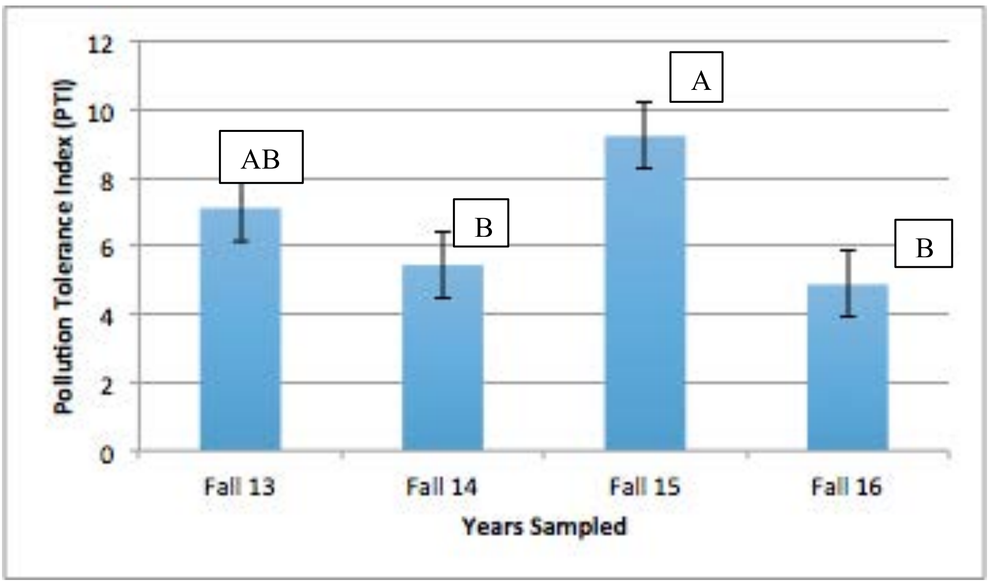

Figure 12. PTI values for the Linfield College site from 2013 to 2016.

In conclusion, we feel that Cozine Creek's water quality appears to be declining from 2011 to 2016 in terms of temperature, nitrate level, while macroinvertebrate diversity has remained low. We predicted that as population increased, so would levels of urban runoff resulting in declining water quality. These results appear to confirm our hypothesis and point out the need for continued annual monitoring.

REFERENCES

Anonymous. 2003. The Effects of Temperature on Steelhead Trout, Coho Salmon, and Chinook Salmon Biology and Function by Life Stage. http://www.swrcb.ca.gov/northcoast/water_issues/programs/tmdls/shasta_river/060707/28appendixaetheeffectsoftemperatureonsteelheadtroutcohosalmonandchinooksalmonbiologyandfunction.pdf

Blanco, R., R. Gernhart, M. O'Rourke, A. McCarrel, M. Specht, S. Thomas, K van Dyk, and R. Yonemura. 2015. Environmental Research Methods Water Quality Report for Cozine, Gooseneck, and Mill Creeks. Research Paper for Fall 2015 ENVS 385 Course at Linfield College.

Carter, Katharine. 2005. The Effects of Temperature on Steelhead Trout, Coho Salmon, and Chinook Salmon Biology and Function By Life Cycle. http://www.swrcb.ca.gov/northcoast/water_issues/programs/tmdls/shasta_river/060707/28appendixaetheeffectsoftemperatureonsteelheadtroutcohosalmonandchinooksalmonbiologyandfunction.pdf

CDC (Centers for Disease Control and Prevention). 2015. *E.Coli* General Information. https://www.cdc.gov/ecoli/general/

Clapp, Michael. 2010. Freshwater Macroinvertebrates from Streams in Western Washington and Western Oregon. NWNatures Macros Field Guide. http://www.nwnature.net/macros_guide/guide.html

Convention on Biological Diversity. 2016. Inland Waters Biodiversity-Why is it so Important? https://www.cbd.int/waters/importance/

DeBano, S, D. Wooster, J. Walker, L. McMullen, and D. Horneck. 2016. Interactive influences of climate change and agriculture on aquatic habitat in a Pacific Northwestern watershed. Ecosphere 7(6): 2.

Delzer, G.C. and McKenzie, S.W. 2003. Five-Day Biochemical Oxygen Demand. https://water.usgs.gov/owq/FieldManual/Chapter7/NFMChap7_2_BOD.pdf

Edwards, P. 2008. Stream Insects of the Pacific Northwest. 35 pages.

EPA (Environmental Protection Agency). 2012. What is pH and why is it important? http://water.epa.gov/type/rsl/monitoring/vms54.cfm

EPA (Environmental Protection Agency). 2015a. History of the Clean Water Act. http://www2.epa.gov/lawsregulations/history□clean□water□act

EPA (Environmental Protection Agency). 2015b. Nutrient Policy and Data: Nutrient Indicators Dataset. http://www2.epa.gov/nutrient-policy-data/nutrient-indicators- dataset

EPA (Environmental Protection Agency) 2016a. Polluted Runoff: Nonpoint Source Pollution. https://www.epa.gov/nps

EPA (Environmental Protection Agency). 2016b. Water Quality Standards. https://www.epa.gov/standards-water-body-health/what-are-water-quality-standards

Field, B. 2008. *Natural Resource Economics*. Waveland Press, Inc., Long Grove, IL.

FlowWatch. 2016. Scientific FlowWatch general data. http://www.jdc.ch/en/scientific-line/flowatch/

Fondriest Environmental, Inc. 2013a. Dissolved Oxygen. Fundamentals of Environmental Measurements.http://www.fondriest.com/environmental-measurements/parameters/water-quality/ph/.

Fondriest Environmental, Inc. 2013b. pH of Water. Fundamentals of Environmental Measurements. http://www.fondriest.com/environmental-measurements/parameters/water-quality/ph/.

Fondriest Environmental, Inc. 2016a. Fundamentals of of Environmental Measurements: Water temperature. http://www.fondriest.com/environmental-measurements/parameters/water-quality/water-temperature/

Fondriest Environmental, Inc. 2016b. Fundamentals of Environmental Measurements: Water Quality. http://www.fondriest.com/environmental-measurements/parameters/water-quality/.

Freeland-Riggert, B, S. Cairns, B. Poulton, and C. Riggert. 2016. Differences found in the Macroinvertebrate Community Composition in the Presence or Absence of the Invasive Alien Crayfish, *Orconectes hylas*. Plos ONE 11(3): 1-27.

Gill, K. 2011. Identification Guide to Freshwater Macroinvertebrates. Stroud Water Research Center. http://www.stroudcenter.org/education/MacroKey_Complete.pdf

GYWC (Greater Yamhill Watershed Council). 2015a. Our Watershed Facts: Facts about the Greater Yamhill Watershed. http://gywc.org/ourwatershedfacts

GYWC (Greater Yamhill Watershed Council). 2015b. What is a Watershed? http://gywc.org/whatisawatershed#

Hanna Instruments. 2010. Dissolved Oxygen and Temperature Meter. Code:9146.

Hanna Instruments. 2015a. pH/Temperature Tester. http://shop.hannainst.com/products/testers/hi98128-phep-ph-testers.html

Hanna Instruments. 2015b. Portable Logging Turbidity Meter http://hannainst.com/usa/prods2.cfm?id=010002&ProCode=HI%2093703

Hayslip, G. 2007. Methods for the collection and analysis of benthic macroinvertebrate assemblages in wadeable streams of the Pacific Northwest. Pacific Northwest Aquatic Monitoring Partnership, Cook, Washington. Pg 4-5. http://www.colvilletribes.com/media/files/2007_0612PNAMP_macroinvert_protocol_final.pdf

JMP: Statistical Discovery. 2016a. Compare Means. http://www.jmp.com/support/help/Compare_Means.shtml

JMP: Statistical Discovery. 2016b. Means/Anova and Means/Anova/Pooled t. http://www.jmp.com/support/help/Means_Anova_and_Means_Anova_Pooled_t_Options.shtml

Kidd, S. 2011.Table 2: Summary of standard parameter ranges for salmonid habitat and general stream water quality. http://www.pdx.edu/soe-gk12/sites/www.pdx.edu.soe-gk12/files/Chem_Data_information.pdf

LaMotte. 2016a. Nitrate Nitrogen Tablet Kit Instructions. http:/en/water-wastewater/individual-test-kits/3319.html

LaMotte. 2016b. Low Range Phosphate Kit Instructions. http:/en/water-wastewater/individual-test-kits/3121-02.html

LaMotte. 2016c. Ammonia-Nitrogen Kit Instructions. http:/en/water-wastewater/individual-test-kits/5864-01.html

Loomis, J., P. Kent, L. Strange, K. Fausch, and A. Covich. 2000. Measuring the total economic value of restoring ecosystem services in an impaired river basin: results from a contingent valuation survey. Ecological Economics 33: 103-117.

Maret, M. 1996. Effect of Fire on Seedling Establishment in Upland Prairies of the Willamette Valley, Oregon. Oregon State University, Thesis.

Micrology. 2008. Detection of Waterborne *E. coli*, Total Coliforms, *Aeromonas*, and *Salmonella* with ECA Check (Plus) Easygel.

Mueller-Warrant, G. W., SM Griffith, GW. Whittaker, GM Banowetz, WF Pfender, TS Garcia, and GR Giannico. 2012. Impact of land use patterns and agricultural practices on water quality in the Calapooia River Basin of western Oregon. Journal Of Soil & Water Conservation, 67(3): 183-201.

Nadakavukaren, Anne. 2011. *Our Global Environment*. Waveland Press, Inc. Long Grove, Illinois.

Newcomer Johnson, T, S. Kaushal, P. Mayer, R. Smith, and G. Sivirichi. 2016. Nutrient Retention in Restored Streams and Rivers: A Global Review and Synthesis. 8(4): 1-28.

Nicole, W. 2013. Meeting the needs of the people: Fish consumption rates in the Pacific Northwest. Environmental Health Perspectives 121: A334-9.

Noss, R, T. LaRoe, and J.M. Scott. 1995. Endangered Species of the United States: A Preliminary Assessment of Loss and Degradation. http://noss.cos.ucf.edu/papers/Noss%20et%20al%201995.pdf

ODEQ (Oregon Department of Environmental Quality). 2003a. Beneficial Uses of Oregon's Waters. http://www.deq.state.or.us/wq/standards/uses.htm

ODEQ (Oregon Department of Environmental Quality). 2003b. Water Quality. http://www.deq.state.or.us/wq/yamhill/monitoring.htm

Oleson, Diane and H. Chang. 2011. Impacts of climate change and urban development on water resources in the Tualatin River Basin, Oregon. Annals Of The Association Of American Geographers 101(2): 249-271.

Oregon Flora Project. 2016. Oregon Vascular Plant Checklist. Web. http://www.oregonflora.org/checklist.php

Pennino, M, S. Kaushal, P. Mayer, R. Utz, and C. Cooper. 2015. Stream Restoration and Sanitary Infrastructure Alter Sources and Fluxes of Water, Carbon, and Nutrients in Urban Watersheds. Hydrology & Earth System Sciences Discussions. 12(12):13149-13196.

Praskievicz, S, and Chang, H. 2011. Impacts of climate change and urban development on water resources in the Tualatin River Basin, Oregon. Annals Of The Association Of American Geographers 101(2): 249-271.

Raleigh, R. F., W. J. Miller, and P. C. Nelson. 1986. Habitat Suitability Index Models and Instream Flow Suitability Curves: Chinook Salmon.U.S Fish Wildl. Serv. Biol. Report # Rep. 82(10.122).

Reuther, C, G. 2000. Saline Solutions: the quest for freshwater. Environmental Health Perspectives. 108 (2): A78-A80.

Ribaudo, M., RD Horan, ME Smith. 1999. Economics of Water Quality Protection from NonPoint Sources: Theory and Practice. Agricultural Economic Report #782. Pg 83-85.

Student Watershed Research Project. 2013. Macroinvertebrates. Portland State University. pg 1-3.

Taylor, George. 1993. The Climate of Oregon, Climate Zone 2, Willamette Valley. http://ir.library.oregonstate.edu/xmlui/bitstream/handle/1957/5907/sr%20no.%20914_ocr.pdf?sequence=1

US Fish & Wildlife Services. 2015. Riparian Buffers. Stream Notes. Volume 1, number 3. http://www.bae.ncsu.edu/programs/extension/wqg/sri/riparian5.pdf

USGS (United States Geological Survey). 2016a. Turbidity. http://water.usgs.gov/edu/turbidity.html

USGS (United States Geological Survey). 2016b. Water Properties: Temperature. http://water.usgs.gov/edu/temperature.html

Weather History. 2016. Weather History for McMinnville. 2016. https://www.wunderground.com/history/airport/KMMV/2016/9/17/DailyHistory.html?req_city=&req_state=&req_statename=&reqdb.zip=&reqdb.magic=&reqdb.wmo=

Warren, M, M. Dunbar, and C. Smith. 2015. River flow as a determinant of salmonid distribution and abundance: a review. Environmental Biology Of Fishes 98(6): 1695-1717.

YSWCD (Yamhill Soil and Water Conservation District). 2015. Wildlife Habitat. .http://www.yamhillswcd.org/wildlifehabitatfarms