The Affiliation of Climate Change, Trout, Aquatic Ecosystems, and Socio-economic Processes: Western Montana as a Case Study

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Abstract

In this review article, I create a framework that assesses climate change vulnerability for native and non-native non-anadromous salmonids (those that **do not** migrate to saltwater) in Western Montana, separating threats and benefits that may occur for individual species. Much of my focus is on non-native rainbow trout and native bull trout. It is important to note that this framework relies on an assemblage of secondary resources for information and data (all climate and precipitation data was gathered from the NOAA). I then assess the impact that these changing populations will have on 1) the ecological health of the region, and 2) the sport-fishing culture and industry in the region. Next, I discuss both the applicability of these findings, as well as the larger implications. Ultimately, projected climate change will lead to two scenarios: *Scenario 1,* in which western Montana experiences a decrease in future trout populations, and *Scenario 2,* which experiences a decrease in bull trout populations along with a comparative increase in rainbow trout populations. These projected scenarios will result in adverse ecological and socio-economic impacts in the region of western Montana, as in *scenario 1* the fly-fishing industry and culture will largely be compromised, and in *scenario 2* ecological diversity will be threatened. The applicability of these findings, however, will vary from region to region depending on both climate and socio-economic processes that are present across different regions, highlighting the complexity of the interplay between climate change, aquatic ecosystems, socio-economic processes, and environmental problems as a whole.

Introduction

It is undeniable that freshwater ecosystems are extremely important to many regions worldwide. Some regions find great recreational value in freshwater ecosystems (i.e. fishing, swimming, etc.) while others depend on them as a means of survival (i.e. water and food consumption). For example, every 10th EU citizen partakes in fishing as a leisurely activity, one that can ultimately benefit wild fish stocks in freshwater lakes and streams (Arlinghaus et al. 2010). On the contrary, fish populations act as an extremely necessary protein source in many developing regions (World Ocean Review 2015). This exhibits the differing importance of freshwater ecosystems across multiple social, economic, and cultural realms, and it is important to understand that their relevance to each of these realms will vary on a global scale. It is also important to realize that anthropogenic climate change will have a large impact on these freshwater ecosystems, as increased pollution and warming air temperatures can directly affect water conditions (Jones 2012). The interplay between climate change and aquatic ecosystems will be evident in the future, but the severity of this relationship will vary from region to region depending on 1) future projected climate changes, and 2) ecological processes that occur in each region.

In this review article, I will use trout populations in western Montana as an exemplar to illustrate the relationship between climate change and aquatic ecosystems. In doing so, it will be possible to understand the social, economic, and cultural significance that trout and aquatic ecosystems in general have in this region. Ultimately, though, it is important to determine to what extent these findings will be applicable in other regions worldwide, with an understanding that different regions will have different niches for aquatic ecosystems that are largely dependent on their cultural and socio-economic status.

In order to best understand the impacts that climate change may have on trout species in Western Montana, it is first important to understand past climate trends and future climate projections. Climate change will not be comparable in every region throughout the world, so finding trends and projections for this specific region is critical to understanding the impact that it will have on these fish. It is also important to recognize that climate change may alter weather patterns in two ways. The most common perception is that the climate will get warmer, which could spell difficulty for cold-water species such as trout. However, climate change can also alter seasons by shifting temperature and precipitation patterns slightly forward or backward, which would also be detrimental for some trout depending on the time of year they spawn. In the following section, I will discuss past climate trends and future climate projections that we might expect to see in Western Montana.

As a result of anthropogenic greenhouse gases, it is undeniable that we will experience an increase in temperature, but to what degree? On a global scale, the rate of increase in mean temperature is predicted to be about .3°C per decade. This will result in an increase in global mean temperature of about 3°C before the end of the next century (Tobey et al. 1992). This is especially significant because this prediction was made in 1992, which means that we can expect that significant changes in temperature have already been experienced since then. These are only global predictions though, so it is important to focus on our region of interest, western Montana, in order to define the changes we might expect to see. Models conducted by the IPCC predict that surface air will warm faster over land than over oceans, and that temperature increases in Southern Europe and central North America also are predicted to be higher than the global mean (Tobey et al. 2012). This is extremely relevant for native species of trout in western Montana, as this is a region that is both 1) a region whose surface air will warm faster, as it is over land, and 2) a region located roughly in central North America. Along with this above average warming, projections tell us that we can expect to see dryer summers in northern mid-latitudes, which is exactly where Montana resides (Tobey et al. 2012).

In order to support Tobey's future claims, and as part of focusing even more on the region of western Montana, I gathered historical precipitation and temperature data from a weather station at Creston, MT, located just east of Kalispell. It is important to note that Creston lies in a valley that is just north of Flathead National forest, South of Glacier National Park, and southeast of Kootenai National Forest. Surrounding Creston are streams and rivers that are fed by Flathead Lake, Whitefish Lake, Lake McDonald, Tally Lake, and many smaller tributaries. These are all part of the northern section of the famous Rocky Mountain Range that starts in Canada, drives through western Montana and eventually runs south through the country, into Mexico (Madej et al. 2007).

Precipitation Data

The data gathered was representative of the total precipitation in the months of July, August, and September, for every year from 1970 to 2014. Identifying trends in the data that has been gathered is important to understanding the changes we will see in the future, and how these changes might impact trout populations. Some of the trends that presented themselves included a total decrease in precipitation as the years elapsed, and also a shift in time period when the most precipitation occurred.

One of the most important trends that I noticed immediately was the fact that total precipitation for all three months seems to have declined much in recent years. For example, from 1970 to 1992 (time period one), there were 15 total years in which the total amount of precipitation for the months of July, August, and September was above 4 inches. I then decided to look at the same statistic for the next 22 years, from 1993 to 2014 (time period two), as an attempt to most evenly and accurately split the years into two equal (or in this case, almost equal) time periods. After examining the precipitation data for time period two, I noticed that there were only 8 years in which total precipitation rose above four inches for all three months, as compared to the 15 years that were experienced for time period one. This data tells us that instances in which summer precipitation in Creston, MT is plentiful (or in this scenario, above four inches) are declining, and if the trend of this data holds true, these instances will continue to decline in the future.

Another trend that has presented itself has been the average amount of precipitation for all three months over the last 45 years. For time period one (1970 to 1992) the average amount of precipitation for the sum of all three months was 5 inches, whereas the average amount for time period two (1993 to 2014) was 3.78 inches, which marks a decrease of 1.22 inches in average precipitation between time period one and time period two. This leads us to believe that the amount of precipitation for these three summer months is decreasing at an unprecedented rate in Creston, MT. T-tests were conducted on these two data sets in order to determine whether or not these findings are statistically significant, and the p-value was recorded at .0298 with 5% confidence intervals (every p-value conducted in this paper will use 5% intervals), which suggests we may reject the null hypothesis and accept the alternative hypothesis that point to declining precipitation patterns, making the data statistically significant. It is also important to note that this data even accounts for the abnormally high 9.74 inches of total precipitation that was experienced in July, August, and September of 1993, which can be considered an anomaly. 1993 is also the earliest year in period two, so the data is still very representative of the chronic decreasing precipitation patterns that are being experienced in Creston, MT. This trend, much like the one discussed in the previous paragraph, shows that precipitation in these critical summer months is decreasing in the region of western Montana, and we can expect these trends to continue to occur in the future.

Ultimately, these two trends prove to us the point Tobey et al. was trying to make when stating that mid-northern latitudes will experience dryer summers. The data reveals to us that 1) summers of adequate precipitation (i.e. at least 4 inches) are significantly declining in number, and 2) that the average amount of precipitation in this region is declining, seemingly at an annual rate. If these trends continue as these tables below suggest, then the region of western Montana will continue to experience dryer summers.

One more important trend to take note of when examining this precipitation data is the seasonal shift in occurrence of precipitation. Using the same precipitation data that was gathered for the above analysis, I examined the changes/shift in precipitation that we have seen (and might expect to continue to see in the future) for the months of July and September in order to dissect any potential changes in seasonal precipitation occurrence.

July provides a very compelling case, as it experienced an average precipitation of 1.84 inches for time period one, as compared to an average precipitation of 1.36 inches for time period two. This gives us a decrease of .48 inches from time period one to time period two, which indicates that if this pattern continues, the month of July will continue to experience a depression of precipitation in the future. However, the p-value recorded for these two datasets was .13, which suggests that we may not accept the alternative hypothesis that precipitation patterns in July are changing, but it is still important to notice these trends in precipitation that are occurring. Furthermore, this data is made even more compelling by the year 1993, which is the very first year of time period two. July sustained seven inches of precipitation in 1993, which is by far the most precipitation that had been experienced in any month of any year between 1970 and 2014 in Creston. This is significant because when situating the year 1993 into time period one as opposed to time period two, we experience an even more dramatic change in precipitation in July in the two time periods. As opposed to the .48 inch difference in precipitation that was experienced in the first examination that classified 1993 as part of time period two, a whopping 0.97 inch difference was experienced in the second examination that placed 1993 in time period one. This is significant because it demonstrates to us that if it were not for the abnormally high amount of precipitation in July of 1993, the discrepancy in precipitation for the month of July would be even greater between time periods one and two, even though it is still at a respectful .48 inches.

Comparing the above data with similar data in the month of September is the next important step in determining what kind of seasonal changes in precipitation we can expect to see. In time period one, September experienced an average precipitation of 1.65 inches, as compared to 1.43 inches of precipitation that it experienced in time period two. This denotes a decrease of .22 inches from time period one to time period two, which is much smaller (not quite half) than the .48 decrease that was noticed in July. It is also important to note that average precipitation for time period one in July (1.84 inches) was higher than that of time period one for September (1.65 inches). However, in time period two, July experienced an average of 1.36 inches, which is actually lower than the average of 1.43 inches that was endured in September. On top of this, the T-tests conducted for the datasets for the month of September provided a p-value of .23, which suggests that we must accept the null hypothesis that states precipitation patterns in the month of September are not changing at a statistically significant rate. All of this shows us that even though average precipitation has decreased from period one to period two in the month of September, it is still significantly higher relative to the average precipitation in July during period two.

It is also important to look at instances in which precipitation fell below one inch in July and September, as these instances are also telling of seasonal shifts in precipitation. In time period one, July saw five years/instances in which total precipitation fell below one inch, compared with an astounding 12 instances in time period two. This means that years that saw a meager amount of precipitation in Creston, MT more than doubled in time period two, suggesting more extended periods of drought in the future. September, however, experienced eight such instances in time period one, and it actually dropped down to seven such instances in time period two. This would suggest that periods of drought and inconsistent precipitation are becoming much more frequent in the month of July, and relatively stable (maybe even less frequent) in the month of September.

By looking at both average monthly precipitation and total instances in which precipitation falls below one inch each month, we can begin to notice changing patterns of precipitation. All of this data would suggest that although we do not see an increase in precipitation in September, the amount of precipitation in September relative to July has increased dramatically in time period two.. This points to a shift in periods of precipitation that are now occurring later in the year, (i.e. September as opposed to July) which may have adverse impacts on fall spawning trout populations (i.e. native bull trout).

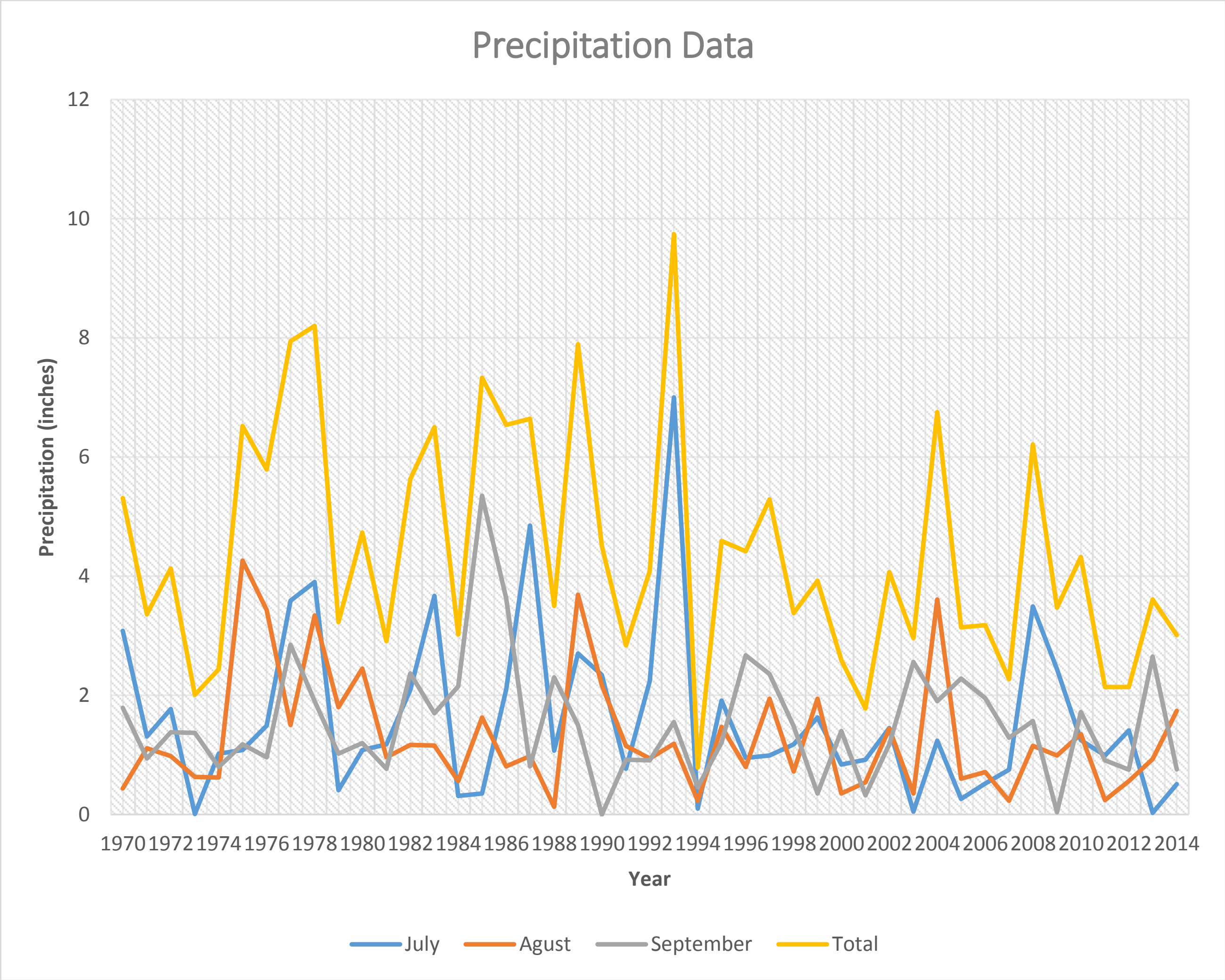
Ultimately, climate change has the ability to impact the amount of precipitation worldwide. Two of these critical impacts mentioned above include 1) a chronic decrease in precipitation, and 2) a shift in seasonal precipitation patterns worldwide. This is especially true for the region of Western Montana, as evidenced by the precipitation data collected from the NOAA. Now that these impacts and trends are evident, it is important to reveal what they mean for trout? Later in this review, I will discuss why these wavering trends of precipitation in western Montana will have adverse impacts on trout populations in the region. Below, *Table 1* reveals the raw data with which the above analysis was based on, and *Table 2* consists of a summary of important data points that were mentioned above.

Table 1

	1970-1992	1993-2014	T-test P-values @ 5% Confidence Intervals
Instances where total precipitation in months of July, August, and September was above 4 inches	15 instances	8 instances	N/A
Average precipitation of July, August, and September combined	5.00 inches Std. Dev= 1.96	3.78 inches Std. Dev= 1.93	P=0.0298
Average precipitation in July	1.84 inches Std. Dev= 1.32	1.36 inches Std. Dev= 1.50	P= 0.1301
Instances in which precipitation fell below one inch in July	5 instances	12 instances	N/A
Average precipitation in September	1.65 inches Std. Dev= 1.15	1.43 inches Std. Dev= 0.79	P= 0.2258

Instances in which precipitation fell below one inch in September	8 instances	7 instances	N/A

Table 2



Climate Data

Along with these projected changes in precipitation, changes in temperature are another important factor that have the ability to influence trout populations in alarming ways. The temperature data gathered from Creston, MT is no exception, as it seems to fully support the claims made by Tobey et al. The data that was gathered was once again representative of the months of July, August, and September, but this time over the span of 35 years (1980 to 2014). It records the air temperature at the weather station in Creston, MT for each individual month. It is important to note that for this data set, *Time Period One* (a span of 18 years) will refer to years 1980 to 1997, and *Time Period Two* (a span of 17 years) will refer to years 1998 to 2014.

After examining the data, one immediate trend that I noticed was the age old allegation of an increase in temperature as a result of climate change. I was able to identify this trend by analyzing the gathered data using two different methods. First, I was able to identify the average temperature for all three months in every year, using these averages to compute a total average temperature over the span of time period one. I then repeated this process in order to discover the total average temperature over the span of time period two. The results were quite distressing, as time period one experienced an average temperature of 75.03 degrees Fahrenheit for the three object months (July, August, and September). Time period two, however, felt a jump in two degrees, with its average temperature for all three months settling at 77.05 degrees Fahrenheit. Furthermore, T-tests were conducted on these data sets and pointed to a p-value of .019 at the same confidence interval of 5% (remember, all confidence intervals in this paper are recorded at 5%), which indicates we can accept the alternative hypothesis that states temperature is indeed increasing for these months. This seems to be the most reliable, surefire way to prove that the climate is indeed warming in western Montana (particularly in the summer months), as two different spans of time under two decades experienced a jump in over two degrees Fahrenheit. The month of July alone saw an even bigger spike in average temperature, as its average temperature for time period one was recorded at 77.1 degrees Fahrenheit, and its average temperature for time period two jumped up to 81.2 degrees Fahrenheit. This more than doubles the increase felt by the average temperature for all three months combined, as it represents an increase of 4.1 degrees Fahrenheit (compared to the 2.02 degrees Fahrenheit experienced by the average temperature for all three months). Using the same T-test method, the p-value for these datasets was recorded at .00, deeming it extremely statistically significant. According to this historical data, we can only expect trends like this to continue to occur, which makes Tobey's claims of an increase by 3 degrees Celsius (37.4 degrees Fahrenheit) quite applicable to the region of western Montana. If we experience an increase in temperature of 4 degrees Fahrenheit every 15 year period, then we can expect to reach this increase of 3 degrees Celsius in approximately 140 years. However, the above analysis assumes a linear trend, and given the slightly exponential rate of increase in temperature that is most commonly expected, this claim may prove to be almost exact for the month of July in western Montana.

The second method that was used to analyze this data involved identifying instances/years in which the average temperature for all three months was recorded at above 75 degrees Fahrenheit, which we will identify as periods of "significant warmth". For time period one, there were 7 individual years in which the average temperature for all three months was recorded as being above 75 degrees Fahrenheit. These instances doubled in time period two, as it experienced 14 individual years in which the average temperature for all three months was recorded above 75 degrees Fahrenheit. These already astonishing results are made even more significant when we take into consideration that time period one accounts for an extra year (18 years, compared to 17 years for time period two). This data shows that instances of significant warmth are occurring much more frequently than they used to be, which further solidifies the claim that this region is experiencing an increase in temperature as a result of climate change.

Ultimately, recent historical data has proved that the air temperature in western Montana is chronically increasing (at least, for our three object months). If these current trends are indicative of future projections, we can only expect the rate of increase to escalate in the future, which may have adverse impacts on trout populations.

One other significant trend that I came across while examining this temperature data was the comparative difference in temperature changes between months. For example, along with average temperature every year for all three months, I computed the average temperature of each individual month for every year. One immediate tendency that presented itself was an in increase in average temperature for each month from time period one to time period two, but the rate of increases differed in a significant manner. For example, average temperature in the month of July was recorded at 77.1 degrees Fahrenheit for time period one, and 81.2 degrees Fahrenheit for time period two. This represents a total increase of **4.1** degrees Fahrenheit for the average temperature in the month of July. The average temperature in the month of August was recorded at 79.5 degrees Fahrenheit for time period one, and 80.2 degrees Fahrenheit for time period two, which represents a total increase of **0.7** degrees Fahrenheit. Lastly, the average temperature in the month of September was recorded at 68.4 degrees Fahrenheit for time period one, and 69.7 degrees Fahrenheit for time period two, which represents a total increase of **1.3** degrees Fahrenheit. It is important to note that the p-values for these two months were recorded at above .05, which suggest that we must accept the null hypothesis that temperature is not significantly increasing. Also, although the average temperature for every month is chronically increasing, the rate of increase seems to decrease (comparatively) from month to month. This tells us that the month of July will likely experience a greater increase in temperature in the future because it has the greatest comparative increase from time period one to time period two. However, this could also mean that we might be experiencing an exaggeration of seasons as a result of climate change, particularly in summer months. This is because, comparatively, the rate of projected increase in temperature is much less in the month of September than it is in July. However, it is important to note that temperature is still increasing in other months. This could indicate that, along with more extreme periods of warmth in the summer months, periods of warmth and warm seasons are actually expanding and being elongated. This could ultimately result in a slight shifting of the seasons, which has the ability to have adverse impacts on trout species.

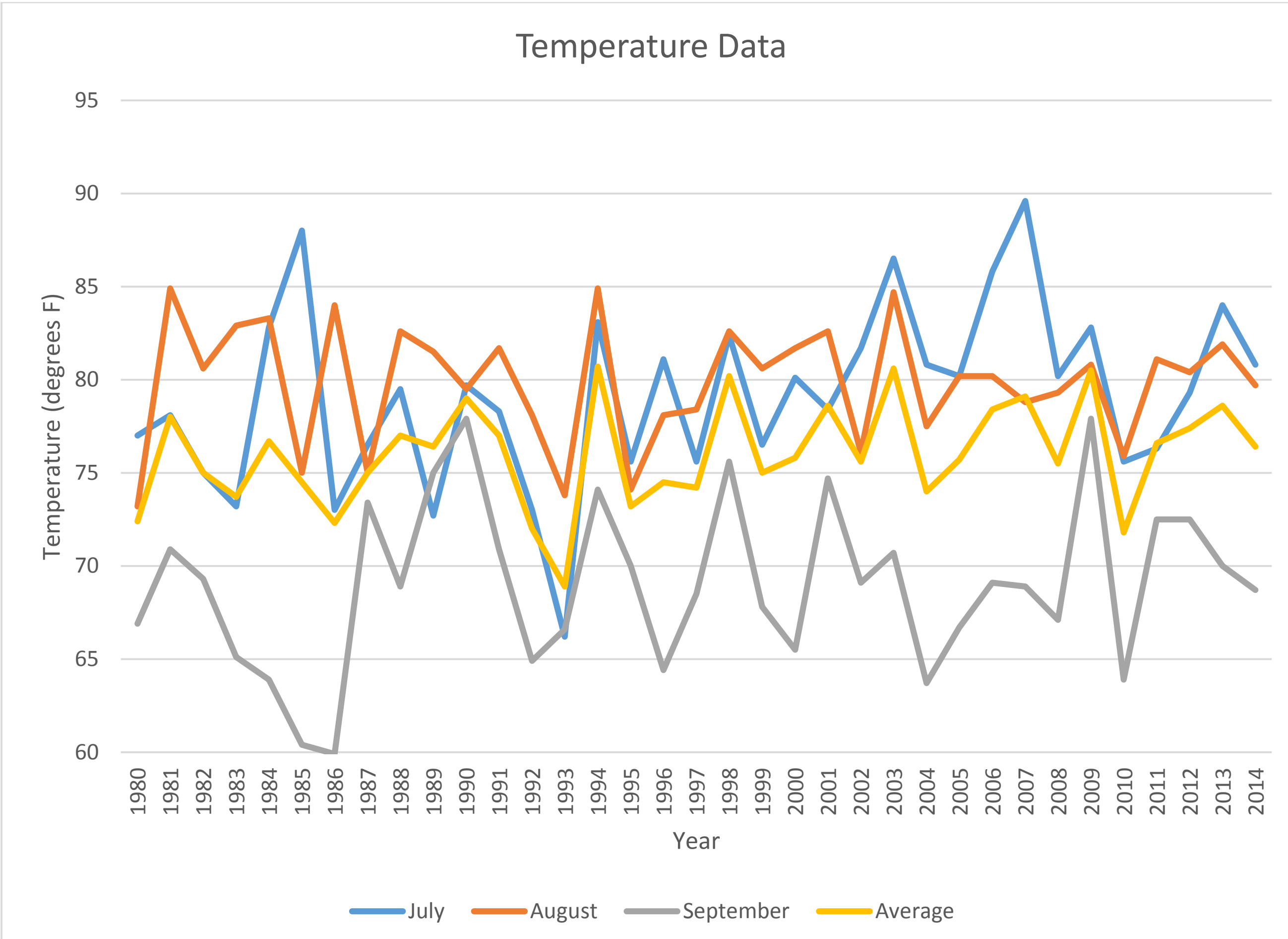
Coinciding with the aforementioned trend, one last small trend that presented itself amongst this climate data was a progressive decrease in the difference in temperature between the months of August and September. To acquire this data, I took the difference in recorded temperature from August and September, for every year. I then took the averages of these results in both time period one and time period two, and discovered an average difference of 11.14 degrees Fahrenheit in time period one, and 10.5 degrees Fahrenheit in time period two, which represents a drop of 0.64 degrees Fahrenheit. This phenomenon can also be indicative of shifting seasons and an expanding summer season, as the temperature difference between months (at least, the months of August and September) seems to be decreasing, albeit at a melodic pace.

After reviewing past articles on climate change and comparing them alongside data gathered from the NOAA, it is evident that climate-induced changes in temperature and precipitation patterns will occur in Western Montana. Now that we have solidified these age old claims, it is next important to determine how these changes will impact trout populations in the region, and ultimately what this tells us for aquatic ecosystems as a whole. Table 3 (below) depicts the raw climate data gathered, and table 4 depicts the most important data points that were summarized above.

Table 3

	1980-1997 (Time Period 1)	1998-2014 (Time Period 2)	T-test P-values @ 5% confidence interval
Average temperature for months of July, August, and September	75.03° Fahrenheit Std. Dev.= 2.91	77.05° Fahrenheit Std. Dev.= 2.44	P=0.0191
Instances/Years in which average temperature for July, August, and September was recorded above 75° Fahrenheit	7 Instances (1 month at 75° Fahrenheit exactly)	14 Instances (1 month at 75° Fahrenheit exactly)	N/A
Average July Temperature	77.1° Fahrenheit Std. Dev= 5.07	81.2° Fahrenheit Std. Dev= 3.74	P=0.0028
Average September Temperature	68.4° Fahrenheit Std. Dev= 5.05	69.7° Fahrenheit Std. Dev= 3.98	P=0.2023
Average August Temperature	79.5° Fahrenheit Std. Dev= 4.11	80.2° Fahrenheit Std. Dev= 2.29	P=0.3165
Average difference in temperature from August to September	11.14° Fahrenheit	10.5° Fahrenheit	N/A

Table 4



Different Trout Species

In order to best understand the impact that changing patterns of temperature and precipitation will have on trout populations, it is first important to distinguish trout by species, as each species has the ability to serve a slightly different niche, and as a result they have slightly different preferences. This is especially true when looking at the suitable thermal habitat for trout, as each species varies in thermal preference for adults, thermal preference for spawning, thermal maxima, etc. (Selong et al. 2001). In general, bull trout, lake trout, and cutthroat trout occupy the coldest niche, brown trout and rainbow trout prefer warmer waters (comparatively), and brook trout reside somewhere in the middle (Selong et al. 2001, Wenger et al. 2011, Fredenberg 2014). bull trout are of particular importance because they are a native salmonid species that is considered as threatened throughout much of its range in western Montana (USFWS 1998), and because temperature appears especially important in defining suitable habitat for bull trout. In this article review, I will focus on comparing rainbow trout (a non-native species in flathead county) and bull trout (native to flathead county), because they prefer opposite ends of the thermal spectrum. Doing this may allow us to determine 1) how climate change will have an impact on each individual species, and 2) to what degree this impact will differ between species. It is important to remember, however, that other species of trout (i.e. brown trout) do exist in western Montana, but for the purposes of this paper I will use rainbow trout as a representative for trout that occupy a wider variety of thermal conditions, and bull trout as a representative for trout that occupy a much narrower (and generally colder) thermal conditions.

As mentioned previously, bull trout are of extreme significance in this article review because they are native to the region and because they are very particular about their suitable thermal habitat. Peak growth in bull trout, as estimated by regression analysis, occurred at 13.28°C (95% confidence interval, 10.9–15.48°C). Feed consumption declined significantly at temperatures greater than 16.8°C, and fish held at temperatures of 22.8°C and above did not feed. "All fish died prior to reaching 28.8°C; the time to 100% mortality was 24 hours at 26.8°C, 10 days at 24.8°C, and 38 d at 22.8°C. Bull trout survival over 60 days at 20.8°C was 79%" (Selong et al. 2001). It is important to note that this data was gathered in a lab and may not be completely representative of their natural environment, but it is still significant because it tells us a multitude of things. First, it tells us the temperature of peak growth for bull trout, but it also shows us that bull trout cannot physically survive in water temperatures above 22.8 degrees Celsius. It also indicates that bull trout may have a difficult time surviving in water temperatures greater than 16.8 degrees Celsius, as a significant decline in the consumption of food could be detrimental to survival rates. This statement is solidified by Fraley and Shepard, when they claim that bull trout are typically rare where water temperatures exceed 15 degrees Celsius (Fraley and Shepard 1989). Ultimately, temperatures above 15–16.8°C are unlikely to be suitable for long-term survival (Selong et al. 2001) because there appears to be a decline in food consumption above these temperatures.

Studies that directly compare thermal suitable habitat between rainbow trout and bull trout are rare, but rainbow trout in particular have been studied in detail. As a result, they have been compared to other species of trout (i.e. Westslope cutthroat trout). Rainbow trout is a potential nonnative competitor for many species of native trout in the western United States, and studies have even shown that it now occupies much of the former range of westslope cutthroat trout (Bear et al 2005). That being said, it is also entirely possible for the same phenomenon to occur in the range of bull trout, as bull trout and cutthroat trout have comparable suitable thermal habitats. This is likely a result of rainbow trout's comparatively wider growth range and their higher upper temperature tolerance. For example, according to Bear's study, the ultimate upper incipient lethal temperature (temperature at which 50% of the population survives for 60 days) of rainbow trout (24.2°C; 95% CI, 20.3 - 24.2°C) was 4°C higher than that of westslope cutthroat trout (19.7°C; 95% CI, 19.1 - 20.3°C) (Bear et al 2005). This means that it is also **at least** 2°C higher than that of bull trout as well, because 0% of the bull trout population survived at temperatures of 22.8°C. While this is true, rainbow trout showed an optical growth temperature quite similar to Westslope cutthroat trout, as their optimum growth temperature determined by regression analysis was 13.6 degrees Celsius, compared to 13.1 degrees Celsius for Westslope cutthroat trout and 13.2 degrees Celsius for bull trout. However, rainbow trout had a wider predicted growth range and grew significantly faster than Westslope cutthroat trout at temperatures less than 6.8°C and temperatures greater than 20.8°C (Bear et al. 2005). It is important to keep in mind that only 79% of bull trout survived over 60 days at temperatures of 20.8 degrees Celsius, as rainbow trout are still able to grow and thrive at this temperature.

Although this study involving Westslope cutthroat trout does not directly include bull trout, it still holds value for this article review because it is possible to insert data on thermal preferences for bull trout alongside the data for rainbow trout and Westslope cutthroat trout. The results of this data have shown that thermal preferences for bull trout are indeed similar to those of Westslope cutthroat trout. As such, it will be possible to apply the findings of this study to the relationship between rainbow trout and bull trout. It is also important to note that this study is significant because it provides extremely profitable information on rainbow trout, which is the other species of importance for this article review.

Ultimately, this data proves that rainbow trout have a greater tolerance for extreme temperatures than other species of trout, which makes them more adaptable and allows them to inhabit a wider range of waters. This allows them to intrude upon the waters that many native fish across the western United States call home, and bull trout are no exception. Next, it is important to look at the impact that changing climate and precipitation may have on these trout.

Impact of Changing Climate: Precipitation

The data that was gathered in Creston, MT affirms the authenticity of past climate literature that claims of rapidly changing patterns of precipitation in this region, but what exactly does this mean for trout in western Montana? According to the data gathered in Creston, overall precipitation seems to be chronically decreasing, but patterns of precipitation seem to be shifting so that we can expect to experience more precipitation in the fall/winter months (Wenger et al. 2011), which can pose as problematic for fall spawning trout. For example, in a model created in Wenger et al's "Flow regime, temperature, and biotic interactions drive differential declines of trout species under climate change", projected declines of one species (brown trout) were driven by increasing frequency of winter high flows. The projected shift in flow regime also negatively affected brook trout, which like brown trout is a fall-spawning species (Wenger et al 2011). Although this analysis did not include bull trout, it may be applicable to the species because like brook trout and brown trout, bull trout are a fall-spawning species. Bull trout in the Flathead River Basin commence spawning migrations (up to 250 km) from May through July, and spawn in second to fourth-order streams (i.e. smaller tributaries) primarily during September and October (Jones 2012). This tells us that native bull trout populations in western Montana could suffer as a result of changing flow regimes driven by increasing frequency of winter flood conditions that could severely alter smaller tributaries. Alternatively, rainbow trout showed a modest negative response and a strong positive response, respectively, to winter high flows, according to Wenger et al's model. Rainbow trout's positive response likely reflects preadaptation to this changing flow regime, which is actually representative of much of the species' native range along the west coast (Wenger et al. 2011). Subsequently, we can expect a stabilization in the population of rainbow trout, and a decrease in the population of bull trout as a result of changing climate-induced patterns of precipitation.

It is also important to remember that along with these comparatively warmer, rainier winters that will result in reduced snowpack (Magnuson 2002), we can expect western Montana to experience dryer summers. These dryer summers may be detrimental to adult bull trout that are spawning and juvenile bull trout that are rearing, as dryer summers coupled with the lack in spring flow due to earlier runoff and warmer winters (Magnuson 2002) may result in extremely low stream flow levels during the summer. Ultimately, without high spring flows that the region is accustomed to, the stream systems may experience lower minimum flows (Nijssen et al. 2001).

In fact, mean August discharge rates measured at two USGS flow gages in the Flathead and West Glacier between the years 1950-2008 show significant declines in stream discharge and increasing frequency of low flow events (Leppi et al. 2011). All of this is important, because this is when bull trout begin to make the trek to lower-tier streams in order to spawn (Jones 2012), as they “rely on a patchwork of natal headwater habitats across river networks in order to spawn” (Rieman et al. 2007). Rearing juvenile bull trout rely on these networks because they rear in natal spawning and rearing streams for 1 to 4 years, and then make complex movements (primarily during high spring flows) to the mainstream rivers or lakes where they grow to maturity (Muhlfeld and Marotz 2005). Less snow runoff in the spring coupled with extremely low amounts of precipitation in the fall may result in stream discharge levels low enough to impede bull trout spawning and rearing patterns. These natal headwater habitats are critical to bull trout spawning and survival, so a loss in connectivity of these patches has the potential to be detrimental for bull trout populations. If these trends continue as projected, we can expect bull trout populations in the region to suffer as a result. Furthermore, rainbow trout have the ability to adapt to changing flow regimes that are experienced in their native waters, so their populations will still continue to remain relatively stable as a result. Ultimately, though, extreme changes in variability could select for generalist species or those with the ability to rapidly colonize habitats (Poff et al. 2001). Although rainbow trout are more resistant to variable conditions comparable to bull trout, not even they can be considered as a generalist species, as they still ultimately succumb to very extreme temperatures.

Impact of Changing Climate: Temperature

Alongside changing patterns in precipitation, we can presume that changing patterns in air temperature will also distort trout populations. This is chiefly a result of the fact that water temperature is strongly correlated with air temperature. In general, stream temperatures are strongly related to geomorphic (elevation and slope), climatic (air temperature), and lake warming covariates. These covariates explained 82% of the variation in August mean stream temperatures (Jones 2012). According to the data gathered in Creston, trends of warming air temperature are occurring, and we can continue to expect these patterns in the future. Model predictions suggest that a warming climate will result in warmer water temperatures in western Montana, which could prove to be detrimental for trout populations. Remember, trout are considered a cold-water species, and they are extremely sensitive to thermal fluctuations (Wenger et al. 2011). However, it is important to remember that their temperature preferences and sensitivities vary by species (Wenger et al. 2011). Bull trout in particular are extremely susceptible to fluctuating water temperatures and periods of warming, as they start to see significant mortality rates when exposed to temperatures over 20 degrees Celsius (Selong et al. 2001). Furthermore, it is important to remember that their food consumption rates take a dive when exposed to waters warmer than 16.8 degrees Celsius. Essentially, extreme periods of warming water temperatures can directly decrease bull trout populations simply because they occupy the coldest thermal niche out of all salmonids (Jones 2012). Rainbow trout, on the other hand, will likely be more resistant to these imminent periods of warming water, as they can survive in temperatures surpassing 24 degrees Celsius (Selong et al. 2001). Additionally, it is important to remember that rainbow trout have a wider predicted growth range and grew comparatively faster than other trout at temperatures less than 6.8°C and temperatures greater than 20.8°C (Bear et al. 2005). Ultimately, this may mean that climate change has a greater negative impact on bull trout populations than on rainbow trout populations, and that we can continue to expect rainbow trout to invade upon the range in which bull trout currently reside.

Bull trout in particular are also extremely vulnerable to climate change because spawning and early rearing are constrained by cold water temperatures creating a patchwork of natal headwater habitats across river networks (Rieman et al. 2007). If trends in air temperature continue to warm as projected by the data gathered in Creston, then we can expect stream temperatures in the region to warm up as a result. This could prove detrimental for bull trout populations that depend on cold water stream networks for rearing and spawning, and warming trend for these stream networks could ultimately result in the absence of spawning and rearing in extreme cases. Because the size and connectivity of these cold patches also appear to influence local populations, projected climate warming in the region will likely lead to increasing fragmentation of remaining habitats, and ultimately the accelerated decline of bull trout as a species (Rieman et al. 2007). Again, rainbow trout populations will remain relatively stable because they are far more resistant to periods of warming, and they do not rely on these cold water stream networks as heavily as bull trout do.

It is important to recognize that along with overall warming trends, shifts in periods of warming can have adverse impacts on trout populations as well. This is especially true for the elongated periods of warming that are beginning to present themselves, as seen by the data gathered from Creston, MT. This is primarily because bull trout spawning will occur when water temperatures fall below 9 degrees Celsius (Fraley and Shepard 1989). If climate change generates warmer summers that turn into elongated periods of warmth, as the data gathered from Creston suggest, then it may be difficult for bull trout to recognize when to spawn. Best case scenario, this will ultimately result in later spawning periods, but even this could be unfavorable to bull trout populations if projected higher winter flood rates result in shifting flow regimes that create damaging spawning conditions. This is because watersheds must have specific physical characteristics (alongside temperature requirements) to provide the necessary habitat requirements for bull trout spawning and rearing, as the preferred spawning habitat of bull trout consists of low-gradient stream reaches with loose, clean gravel (Fraley and Shepard 1989). Rainbow trout will not suffer from these elongated periods of warmth, however, because they are a spring-spawning species. But, even if they were a fall-spawning species, they would not be as susceptible to the projected elongated summers because they have a higher tolerance for warm water temperatures.

What does all of this climate data mean for trout populations?

Ultimately, it seems as if future bull trout populations are at risk as a result of climate change, but it is important to understand that this is not necessarily representative for all species of trout. For example, rainbow trout populations seem to be much less affected by the variables that will damage bull trout populations. This may even benefit rainbow trout populations, as it will enable rainbow trout to successfully invade ranges that were once primarily dominated by bull trout, as competition amongst species would no longer be present. So, while these trends in precipitation and temperature seem to pose an immediate threat to bull trout, rainbow trout may initially thrive as a result of the slightly warmer waters that currently act as a stressor to bull trout populations. Remember, bull trout grow significantly slower than rainbow trout at higher temperatures (McMahon 2007), which can ultimately result in smaller, weaker bull trout populations. It is also important to remember that bull trout have much lower feeding rates at higher temperatures comparative to other trout such as rainbow trout (McMahon 2007), which will enable rainbow trout to outcompete the native bull trout in the future. With decreased motivation to feed, bull trout will not have a chance in competing with rainbow trout for food resources. As a result of all this, rainbow trout will have a marked size and growth advantage over bull trout at the warmer temperatures (McMahon 2007) that we can expect to see in the future. When you couple this with the higher rates of aggression that are being experienced at higher temperatures by other trout such as rainbow trout, it is inevitable that this warming climate will result in conditions in western Montana that are prime for an invasion of rainbow trout. We can also expect to experience interbreeding between native bull trout and other species of trout (i.e. rainbow trout), and this hybridization can ultimately harm genetic integrity (Kitano 2004). In some extreme cases, the stocking of hatchery rainbow trout in rivers can even lead to the introduction of whirling disease in stream bodies in western Montana (Kitano 2004), which also has the potential to be detrimental to bull trout populations. Ultimately, this competition and interaction between introduced rainbow trout and native bull trout adds yet another significant set of stressors to the many existing ones that will limit, and potentially decimate, bull trout populations in the future.

So, while it seems like we can expect to see an initial increase in rainbow trout populations that will replace the inevitably vanishing bull trout populations in western Montana, it is important to realize that these immediate benefits to rainbow trout will not last if these seemingly exponential trends in warmth continue far into the future. If we continue to see a spike in average temperature of 2 degrees Fahrenheit every 17 year period, as the data gathered from Creston suggests, then eventually water temperatures will rise high enough to directly impact rainbow trout populations on both a local and global scale. Even rainbow trout have their limits when it pertains to changing patterns of temperature and precipitation, and while their limits are not quite as severe and immediate as those of bull trout, they will eventually be reached.

Impacts to entire aquatic ecosystems

Aquatic ecosystems have been increasingly threatened by global climate change (Poff 2002), and this is especially prevalent when considering the repercussions that will be felt by trout populations. Trout are considered by ecologists to be a ‘keystone’ species for many of the watersheds they inhabit (California Trout, Inc 1999), and the Flathead River Basin is no exception. Keystone species are those that have the potential to leave critical and irreparable gaps upon their disappearance. This is particularly true for trout in aquatic ecosystems, as they act as important predators that feed on aquatic insects, frogs, smaller fish, etc., but they also act as an important prey species for larger megafauna such bears and larger birds of prey (California Trout, Inc 1999). In this article review, I will discuss the ecological impacts we can expect to experience in western Montana in two different scenarios that were mentioned earlier. First, I will focus on a scenario that we are likely to experience far into the future, in which all trout populations are struggling to survive as a result of increasing temperatures and severe precipitation patterns (I will label this *scenario 1*). Then, I will focus on a scenario in which bull trout populations are replaced by the much more resistant rainbow trout populations, which is something western Montana may experience in the very near/immediate future (I will label this *scenario 2).*

Scenario 1

Far into the future, we can expect to see a decline in total trout populations in western Montana. This is particularly true for this region, as it is one that is susceptible to fluctuating patterns of precipitation and temperature, patterns that are becoming extremely unfavorable for these cold-water species (Tobey at al. 1992), as proven by the data gathered from the NOAA. But, what exactly does this overall decline mean for ecosystems as a whole? One of the largest impacts we may see is an initial spike in aquatic insect populations, as they as a significant prey species for all species of trout that reside in the region (California Trout, Inc 1999). As a result, without adequate trout populations to prey on insects and keep their numbers in check, we can expect to see a significant increase in population for aquatic insects in the future. Although small and seemingly non-impactful on the surface, these aquatic insects have the ability to feed on aquatic vegetation (California Trout, Inc 1999). Given an increase in their population, they have the potential to destroy aquatic vegetation, and this depletion of aquatic vegetation would result in a loss of habitat for any other organisms that reside in the same aquatic ecosystems. This loss of habitat could ultimately result in a decline of other fish species and organisms that would initially benefit from the disappearance of trout due to the initial void in competition left by their disappearance. Also, plant species coexistence is thought to be the result of niche partitioning, which refers to the difference in resource requirements among species. As a result, a more diverse plant community should be able to use resources more completely, and thus be more productive (Fridley 2001). Ultimately, trout act as an important "keystone" predator in the aquatic ecosystems they reside in, as they occupy an important niche as predators that enables them to keep entire aquatic ecosystems in balance.

It is also important to recognize that one of the qualities that make trout a "keystone species" is their designation as an important prey species. Trout act as a prey species to large, charismatic megafauna such as large birds of prey and brown bears, and a significant decline in trout population would result in the disappearance of a significant food source for these apex predators (California Trout, Inc 1999). An apex predator can simply be defined as any predator that sits at the top of their respective food chains. Furthermore, these predators (large birds of prey especially) would need to compensate for their lack of nutrition, and as a result they could ultimately overconsume and threaten another species (i.e. snakes and small mammals). This illustrates how a decrease of trout populations could ultimately have impacts that would be felt in terrestrial ecosystems alongside the impacts that will be felt in aquatic ecosystems. It further solidifies the "keystone species" label that has been given to trout, as their absence has the ability to impact ecosystems that they do not even reside in. Essentially, trout occupy the middle of the trophic system in many aquatic environments, and as a result their disappearance would be felt up and down the food chain, and even across ecosystems.

Lastly, salmonids such as trout have an indirect impact on the ecosystem that is often overlooked. Salmonids in particular are a species that are greatly desired by humans for consumption and for sport, the latter of which is particularly true for the region of western Montana. As such, humans will go to great measures in order to benefit their populations. A common strategy is to modify land-use practices and to eliminate human intervention amongst streams in which a healthy population of salmonids are known to exist. This includes managing the development of urban and suburban areas that are interested in industrial, residential and business uses (Knight 2009). A prime example can be seen when looking at agricultural producers that allow for animal access to natural waterways. This exposure to livestock can result in bank erosion and nutrient loading thus harming water quality and habitat structure for salmonids such as trout, but also for all other species (both fauna and flora) that reside in the enclosed aquatic ecosystem (Knight 2009). Because these practices pose a threat to salmonid populations in particular, efforts are put into place in order to curb this contamination by fencing off livestock and not allowing them within a certain distance of the water source. It is likely that these same efforts would not be applied to streams that contained less charismatic species such as frogs, insects, or fishes that are not as significant to human interests (Quinn 2011). This illustrates the importance of trout and other salmonids to human culture. As a result, efforts are put into place that are meant to benefit their populations, but these efforts also benefit aquatic ecosystems as a whole. With this information, we can conclude that this may actually result in a positive impact on aquatic ecosystems. If trout populations continue to struggle as predicted, it is likely that human efforts to improve their habitat will heighten, and ultimately aquatic ecosystems will benefit from these increased efforts. However, it is important to note that if trout populations decline as a result of the projected climate models introduced earlier, then the adverse impacts that will be felt throughout the different trophic levels of the ecosystem will likely outweigh the positive impacts that would result from modified land-use practices.

Ultimately, trout act as a “keystone species” to the ecosystems they reside in, and they have the ability to do so in both direct and indirect manners. It would be near impossible and far too time consuming to identify all of the ecological impacts that will be experienced as a result of rapidly declining trout populations. These are just a few examples that highlight the severity of the ecological impacts that would result from a disappearance of trout populations. It is important to note that *Scenario 1* relies on the assumption that increases in air temperature are directly correlated with increases in water temperature, but the time with which it would take these correlations to occur were not studied in this paper.

Scenario 2

Whereas *Scenario 1* predicts for a complete fallout of trout populations that would be experienced somewhat far into the future, *Scenario 2* anticipates for a condition in the near future. This scenario calls for an escalation of rainbow trout populations comparative to bull trout populations in western Montana. Rainbow trout have the ability to eat a wide variety of prey; they can decimate larger prey populations (i.e. frogs and smaller fish), but they can also survive on smaller plankton (California Trout, Inc 1999). This could be extremely consequential for species residing in the same aquatic ecosystems, as a large population of rainbow trout have the ability to outcompete most other species, including other fishes. This out competition can ultimately result in even higher rainbow trout populations and lower levels of ecological diversity.

This low level of ecological diversity is can be harmful for multiple reasons. First, it is important to recognize that the more divergent species in an ecosystem are when considering their ecosystem processes, the smaller the number required to buffer an ecosystem against change. This means that a dangerously low level of diversity can limit the *Insurance effect* that is felt in most ecosystems, which states that an ecosystem that contains more species will have a greater likelihood of containing redundant stabilizing species, and it will have a greater number of species that will have the ability to respond to natural and unnatural perturbations in different ways. This will enhance an ecosystem's ability to buffer perturbations, and thus remain both stable and functional (Naeem 1997). On the same token, an ecosystem that is dominated by one species has a much greater risk of facilitating the spread of diseases that are carried by those specific species. Essentially, an excessive population of rainbow trout as compared to other species can result in highly unstable aquatic ecosystems, as a significant perturbation that would harm rainbow trout would result in the decimation of the entire ecosystem. It is important to note that ecosystems have the ability to recover long-term, but entire species and relationships could disappear in the process before recovery.

Along with the aforementioned *Insurance effect*, biodiversity in aquatic ecosystems also provides for a resistance to invasion from outside species. Consequently, a decrease in biodiversity as a result of the dominance of rainbow trout populations will allow for conditions that are favorable to potentially invasive species. This is because diverse communities may use resources more completely than simple communities due to the concept of complementarity (different resource requirements for different species). Thus, invaders may have greater success in non-diverse ecosystems because there are greater amount of vacant niches waiting to be filled. Hence, there may be a greater likelihood that an invading species will introduce a new property or process to an aquatic ecosystem that is lacking diversity (Elton 1958). This could prove detrimental to an ecosystem that is not ecologically diverse, because new properties and processes that would be introduced via invasive species could potentially harm the already existent species. If the already existent species are small in number (i.e. largely dominated by rainbow trout), this could ultimately restructure entire aquatic ecosystems so that they are supportive of invasive species. This is yet another example of how a dominance of rainbow trout populations can result in less than ideal conditions for aquatic ecosystems as a whole.

Ultimately, past climate trends and future climate projections call for conditions that are more favorable for rainbow trout than any other species of trout (particularly bull trout) in western Montana. As a result, in the immediate future we can expect a large increase in rainbow trout populations comparative to other trout populations. This has the ability to result in ecosystems that lack ecological diversity, which could consequently harm the stability of aquatic ecosystems as a whole in western Montana.

Socio-economic impacts

While impacts on entire aquatic ecosystems are more immediately palpable, it is important to understand that fluctuating trout populations will also have adverse socio-economic impacts. This is particularly true for the fly-fishing industry in western Montana, where climate and precipitation patterns are projected to fluctuate enough to impact trout populations. However, it is important to recognize that transformations in the fly-fishing industry will vary from *scenario 1* to *scenario 2,* and these variations will ultimately be indicative of changes (for better or for worse) in the fly-fishing culture.

Scenario 1

It is important to remember that in Scenario 1, we experience a decline in total trout populations in western Montana as a result of projected temperature and precipitation patterns far into the future. This will immediately have adverse socio-economic impacts western Montana, as this rocky mountain region is home to the largest percentage of sales in the fly fishing industry, accounting for about 31.5% of total sales nationwide (Frank 2013). This indicates that fly-fishing is popular in this region, more so than in any other region, so we can expect that it will be most affected by a decrease in sales. Also, it is important to realize that fly fishing can already be considered a small-market, “niche endeavor”, as total sales of all fly fishing products (this includes rods, reels, flies, and any other gear that is necessary for a typical fly fishing outing) amount to just under $750 million (Field and Stream 2012). As a means of comparison, this accounts for less total sales than some individual brands of candy bars (Field and Stream 2012). Because it is such a small market to begin with, even somewhat small fluctuations or changes in consumption of fly-fishing products has the ability to severely impact the entire industry. In fact, the total number of license buyers in western Montana was recorded as 389,534 in 2006, compared to just 363,175 in 2012 (USFWS 2014). This illustrates how interest in the sport may already be declining, and it will continue to do so if we experience declines in total trout populations in the future, as interest in the sport likely directly coincide with harvest rates.

Alongside this general data, it is important to take into account the time of year when fly fishing industry makes most of its sales. 36.3% of national fly fishing sales occur between the months of July and September (Angling Trade 2012), suggesting that the sport is most popular during these summer months. This may pose as problematic for the fly fishing industry in the future, because according to the climate trends explored earlier in this article (sections titled “precipitation data” and “climate data”), we can expect to see warmer summer months alongside abnormal patterns of precipitation in the region of western Montana. It is also important to remember that all species of trout, even the usually resistant rainbow trout, are less likely to feed at higher water temperatures. This means that if climate warming during the summer continues as projected in this region, we can expect that the temperature threshold at which trout will no longer feed will be reached, which means that we can expect a decline in total trout populations (as a result of malnutrition) during summer months that are critical for the fly-fishing industry. More importantly, though, this could directly result in decreased total catch as a result of the trout’s lack of interest in the flies that fishermen are presenting to them. After all, fly fishing success depends on the fisherman’s ability to make the fly they are using as artificial bait look like a realistic and enticing food item to the trout. If trout no longer have the desire to consume food as a result of increasing temperatures, it is likely that fly fishermen will catch fewer trout, because even their best attempts at artificial representation will fail to entice the trout. This could result in a lack of interest in the fly-fishing industry during these summer months when it relies on most of its production and sales, which has the ability to even further damage the already small-scale industry.

Much interest around fly-fishing in western Montana relies on healthy, wild trout populations, as much of Montana manages most of its rivers for wild trout, which means that hatchery born fish are not introduced into these rivers (Big Sky Fishing 2015). This makes western Montana a popular choice for many anglers, as many (myself included) pride themselves on being able to outwit much more timid populations of native trout. However, because this region does make for such a desirable angling location, we can expect an extremely significant impact on the fly-fishing industry here. It is also important to realize that because the waters of western Montana rely almost exclusively on these wild trout populations, future trout populations may be relatively lower than a region that allows the implementation of fish-hatcheries in order to sustain populations. Regions that rely on fish hatcheries have a greater ability to instill desirable trout populations, so the absence of such hatcheries could be problematic in western Montana. Ultimately, the popularity of fly-fishing in western Montana, coupled with its largely native populations of trout, will likely result in a greater impact on the sport-fishing industry given the projected outcomes in *scenario 1* hold true for the future.

Surprisingly, increased interest in warm water fishing may allow for resistance amongst the fly fishing industry. For example, the south accounts for 27.3% of all sales associated with the fly-fishing industry. This is significant to western Montana, because much of this fly-fishing in the south targets warm water species of fish such as bass and carp, as opposed to trout (Frank 2013). In fact, most of the potential for growth in the fly-fishing industry are the warm water industries in the south, and it is possible that fishermen in the south aim for bass and carp as fishermen in the west aim for trout. This gives hope to the fly fishing industry in western Montana, as it shows us that in general, fishermen will target just about any species that is available to them. This could mean that fishermen in western Montana revert to targeting a different species in the absence of trout as a result of warming temperatures, a species that will be more accustomed to the warming temperatures that we may expect to see far into the future. As long as the interest is there, the interest in the sport (and therefore the industry as a whole) will continue to grow, even in the absence of trout. While this may seem favorable at first, it is important to recognize that as a result, the culture of trout fishing will begin to rapidly vanish. As an avid fly fisherman myself, there is something to be said about waking up in the early hours of a crisp fall morning to catch the dawn feeding session that trout so regularly participate in. Many fishermen would argue that there is nothing quite comparable to experiencing a "take" (the act of a trout surfacing to feed on the fly you are presenting) on the calm waters that are almost always present during the early morning hours.

Ultimately, while the fly-fishing industry has the ability to survive in the absence of trout, the culture and aesthetic pleasure that allowed the sport to become popular and thrive in the first place will vanish alongside these beautiful salmonids. This would result in a new age of fly-fishing that already seems to be taking hold in warmer regions of the country; one in which targeting warm water species such as bass and carp becomes the new trend. This may eventually completely displace the once desirable wild trout that so many fishermen prided themselves on landing.

Scenario 2

In *scenario 2*, we can expect to experience a decrease in bull trout populations that directly coincides with an increase in rainbow trout populations in western Montana. It is important to remember that in this scenario (one much nearer in the future as compared to *scenario 1*), rainbow trout populations increase comparatively to bull trout populations. While this initial increase in rainbow trout populations may eventually prove detrimental for aquatic ecosystems, such a spike can initially benefit the fly fishing industry.

It is important to understand that if western Montana experienced a decline in bull trout populations, the fly-fishing industry would not be as severely impacted as we may initially think. This is because, except for three exceptions (Hungry Horse Reservoir, Lake Kookanusa, and Swan Lake) targeting bull trout is illegal because of their ESA (Endangered Species Act) status as threatened. It still occurs regularly and is difficult to enforce, because nobody who is aware of this designation would admit they are targeting bull trout (Fredenberg 2015). However, it is important to understand that in general, trout fishermen do not prefer a specific species of trout, but rather they simply fish for trout in general (Fredenberg 2015). In short; 1) most fly fishermen are perfectly content with catching rainbow trout, and 2) fishing for bull trout is extremely uncommon because in most instances, it is illegal. As a result, the absence of bull trout (along with a rise in rainbow trout) will not negatively impact the fly-fishing industry; in fact, such an occurrence may even give this micro-economy a boost. Also, because rainbow trout compete directly with other trout species (such as bull trout), we can attempt to curb their spread by introducing them to the sport fishing environment at times when bull trout spawning rates are high. This would result in less competition, allowing bull trout populations to endure. It would also be possible to incentivize harvests of rainbow trout year round, and doing so may exterminate enough of the rainbow trout population to allow bull trout populations to make a comeback. In essence, an initial increase in rainbow trout populations (as predicted in *scenario 2*) can give the fly fishing industry a much needed boost along with giving it the opportunity to assist in bull trout reintroduction. For these reasons, *scenario 2* may be exactly what the fly fishing industry needs.

An increase in rainbow trout harvest in the event that *scenario 2* becomes a reality will also allow for entire ecosystem benefits. Remember a lack of ecological diversity as a result of increased rainbow trout populations has the ability to have adverse impacts on entire aquatic ecosystems. As such, introducing policies to allow for increased rainbow trout harvest can ultimately eliminate the dominance of rainbow trout populations that may be experienced under *scenario 2*. This will result in both increased sales for the fly fishing industry and more stable ecosystems, creating a positive feedback loop between the fly fishing industry and aquatic ecosystems that can be repeated until a balance in the ecosystem is reached.

However, it is important to understand that introducing rainbow trout populations to increased rates of harvest only acts as a solution to disappearing bull trout populations as long as water conditions remain agreeable to the thermal requirements that bull trout possess. If temperature and precipitation patterns begin to approach what is predicted in *scenario 1*, then reducing the competition for bull trout will not matter, as their thermal limits will have been breached. If such a policy (i.e. incentivizing increased catch of rainbow trout) is implemented, then, it is important to recognize at what point it will no longer benefit native bull trout populations. It is also important to remember that with warming that approaches conditions predicted in *scenario 2*, we may experience decreases in rainbow trout populations, so incentivizing increased harvest of rainbow trout is only a viable solution so long as their thermal limits are not violated.

Fish Hatcheries as a Solution?

The implementation of fish hatcheries may seem like a viable solution to these socio-economic and ecological crises that stem from a decline in trout populations, but it is important to recognize the ecological dangers of implementing such hatcheries. In order to fully comprehend said dangers, it is first important to understand how fish hatcheries work. “A typical salmonid fish hatchery includes propagation facilities such as holding ponds for the adult fish to spawn, incubators, rearing tanks and raceways as required to rear young to release size. The major operation requirements are water supply, fish loading facilities, feeding equipment and cleaning equipment” (Liao 1970). This illustrates both the close capacity with which these hatchery fish are raised, and their artificially acquired dependence on human intervention for sources of food. The future release of hatchery fish may pose problematic for fish populations as a whole, because reduced rearing densities (density and proximity of young fish that are growing to adulthood) can facilitate the development of behavioral life skills in captive animals, thereby increasing their contribution to natural production. Some of these life skills include food search ability, anti-predator response, and the ability to forage on novel prey, all of which act as critical behavioral skills important for surviving in the wild (Brockmark et al. 2010). Fishes that are raised in hatcheries with close proximities, then, may lack these life skills critical to survival. This can prove to be precarious in the event that hatchery fish interbreed with native fish, as the wild gene pool will be introduced to the much weaker captive gene pool. This is especially dangerous for bull trout in western Montana, as it is a native population that is already extremely low in number, so any interbreeding with captive fish could result in a genetically and numerically depleted population of bull trout. Ultimately, when considering fish hatcheries as a solution to declining trout populations, it is important to understand the impacts such implementations may have on future trout populations. We must be sure that the destructive effects of anthropogenic production do not exceed the productive ones, as it may result in destroying wild trout populations faster than they can regenerate themselves.

Along with the genetic dangers of fish hatcheries, it is important to comprehend that their initial success and the continued survival of trout populations will be dictated by future water temperature and precipitation patterns. No matter how successful the introduction of domesticated trout may be, these efforts will not matter if western Montana experiences the changes in climate that are projected. This is because water temperatures will breach the threshold at which trout can survive (*scenario 1* applies to all species of trout, *scenario 2* applies to bull trout), so even artificially producing trout populations via fish hatcheries would not yield any success, as hatchery raised fish have the same thermal limits as their native counterparts. As a result, it seems as if fish hatcheries would only prove as a viable method of trout population reintroduction in regions that will not experience the severe fluctuations in climate and precipitation that are projected to strike western Montana in the future. That being said, it is still important to comprehend the risks that these hatcheries pose to genetic integrity.

One potential strategy for achieving fish hatchery success could be to raise populations of sterilized fish (Hindar et al. 1991), as doing so would allow for the prevention of interbreeding between native and captive populations that would result in genetically compromised populations. It is important to note, however, that this would result in an increased dependency on hatchery bred fish populations. Another solution may be modifying the points of rearing and release of hatchery fish so as to avoid interbreeding (Hindar et al. 1991). These strategies may indeed pose as viable solutions for regions that will maintain climates suitable for trout survival, as this would allow for an increase population of trout while maintaining relatively genetically capable wild populations. This could also act as a solution to the struggles that may be experienced by the fly fishing industries in many region, as most fishermen will maintain continued interest in the sport so long as they are catching fish. Even if they are catching artificially stocked populations, many fisherman 1) cannot tell the difference between a wild and domesticated trout, or 2) they simply do not have a preference as to what category of trout they catch, so long as they are catching trout. As a result, fish hatcheries that instill practices that attempt to avoid the interbreeding between wild and domesticated trout may prove fruitful for both the fly fishing industry and ecosystems as a whole, as wild populations will remain strong while fishermen continue to catch fish. However, it is important to remember that these benefits may not be experienced in the region of western Montana, as it is likely that this region will experience future temperature and precipitation patterns that do not provide habitat conditions suitable for trout (both hatchery raised and wild) survivability.

Larger Implications?

From all of this information, we can conclude that western Montana will experience ecological and socio-economic impacts as a result of climate-induced fluctuations in trout populations. Next, it is important to explore larger implications and determine how applicable these findings may be across different cultural and geographic regions.

First, we must remember that the region of western Montana will be ecologically and socio-economically impacted in these manners because of 1) their vulnerability to temperature and precipitation changes, and 2) the abundance of trout populations in this region. *Scenario 2* (disappearance of native bull trout populations) is one that will be unique to western Montana, as this is one of the few regions where native bull trout populations still reside. *Scenario 1*, however, will be far more applicable across regions, as rainbow trout are a species that is common in many regions of the world, persisting in approximately 100 countries worldwide (Rai et al. 2005). So, a region that houses a viable rainbow trout population along with projected climatic changes similar to western Montana will likely experience very similar ecological impacts (as trout act as a keystone species in any ecosystem they reside in), but socio-economic impacts will be much more challenging to apply. This is because the significance of both trout and aquatic ecosystems vary from region to region, depending on socio-economic status. For example, in western Montana, trout are of great importance to the fly-fishing industry because of their revered status amongst many fishermen, which gives them a recreational and slightly cultural significance. However, in a less developed region with similar ecosystems, trout may be of great nutritional or economic importance, to the point where human survivability is reliant on the species. For example, in Nepal (a mountainous region relatively similar to western Montana), fish consumption is presently very low and the people residing in these mountainous terrains need a good source of protein that can be achieved via abundant trout populations and successful aquaculture production of trout populations (Rai et al. 2005). This illustrates the nutritional significance that trout hold in this region, and it also sheds light on the economic significance of trout to these peoples, as farm-raised trout are a significant source of income for people in this region (Rai et al. 2005). If Nepal were to experience changes in climate similar to that projected in western Montana, then we can expect the livelihood of many to be threatened. In this scenario, the socio-economic impacts of trout population decline are far more severe than those that may be experienced in western Montana, which will experience socio-economic impacts largely limited to the fly fishing industry. In the case of a less developed region such as Nepal, individuals and families will be affected. This example reveals how socio-economic impacts as a result of climate-induced fluctuations to trout populations will vary in different regions worldwide. Some (i.e. western Montana) will experience adverse effects to recreational economies, while others (i.e. Nepal) may experience impacts that are far more severe to everyday life and survivability.

Furthermore, it is important to remember that regions that house warm-water species of fish may even ecologically and socio-economically benefit from future increases in water temperature as a result of climate change. For example, in the mid-west, warm water fishes such as muskie, smallmouth bass, and bluegill are expected to benefit from climate change, as they have the ability to replace the cold-water fish that will disappear as a result of climate change (US EPA 2015). This could lead to increased productivity in the socio-economic realm, as according to the *Ames Tribune,* the sport-fishing industry in this region largely depends on an abundance of bass, as many anglers in the region like to focus their attention on bass, particularly during the fall. It is also important to remember that many species of trout (i.e. bull trout, brown trout, etc) spawn in the fall, so the negative impact on their populations as a result of warming temperatures will create favorable conditions for competing bass, and ultimately for the sport-fishing industry in this region that thrives on large bass populations. This illustrates how regions that are home to warm water fish will be able to adapt (socio-economically) to climate change, as anglers' interest in warm water species of fish such as bass will largely be able to mask the disappearance of cold water fish.

Conclusion

It is safe to conclude that the region of western Montana is expected to experience changes in temperature and precipitation that may impact both native (i.e. bull trout) and non-native (i.e. rainbow trout) trout populations. These fluctuating trout populations have the ability to adversely affect ecological and socio-economic processes in the region. However, it is important to keep in mind that although these impacts seem gloomy, they are not applicable to every region worldwide. Fundamentally, ecological and socio-economic impacts that stem from the interplay of climate change and aquatic ecosystems will vary depending on both aquatic species and climate present from region to region. Mid-latitude regions that harbor cold-water ecosystems will likely be impacted the most, but even then the severity of these impacts will largely depend on the socio-economic processes that occur in the region. Ultimately, it is important to comprehend that environmental problems are largely associated with cultural and socio-economic processes, so much so that their varying scales of severity are largely dictated by said processes. Climate-induced fluctuations to trout populations that result in adverse ecological and socio-economic impacts in western Montana serves as a great example that illustrates the diverse and complex relationships that exist between ecological and socio-economic realms.

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