ASSESSMENT OF FISH DIVERSITY IN THE SANTA ANA RIVER

By

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ABSTRACT

Diversity, the presence and abundance of different species in a community, can help indicate the health of river ecosystems. In order to determine patterns of diversity in an urban habitat, I examined how fish populations have changed over four years in the Santa Ana River using publicly available data. The goal of this project is to determine how fish diversity in the Santa Ana River changes over time and space. I expect to see that the reaches with the lowest diversity levels have a greater number of invasive species or have been more heavily impacted by human activity. In order to address this hypothesis, I determined Shannon and Simpson's diversity across multiple reaches. Then, I examined possible causes including the number of invasive species and nearby human activity, and used available literature to see what might be impacting the fish populations. I did in fact find that two of the lowest diversity levels were in close proximity to the Martha McLean-Anza Narrows park. An ANOVA statistical analysis showed that metrics of fish diversity across multiple reaches and over time did not significantly change. This project provides a foundation for further addressing how wastewater discharge impacts ecological diversity in urban freshwater habitats. These findings may also help other researchers who study water quality, ecosystem health, or climate change impacts within lotic systems.

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Introduction

The Santa Ana River stretches from Big Bear Lake in the San Bernardino Mountains and empties into the Pacific Ocean at Huntington Beach. When taking into account all of the streams that compile into the river, the Santa Ana River becomes the largest coastal stream system in Southern California (Surbeck et al., 2006). The Santa Ana River Trail is found alongside this river and is a common recreational activity that individuals, including myself, spend time walking and biking. Also, this river water is processed and used as a clean source of water for many inhabitants of Southern California. There are multiple water treatment methods used along the Santa Ana River, from water treatment wetlands in Orange County to the water treatment facilities in the Inland Empire (Mitchell 2006).In order to preserve the positive influence and benefits given by this large coastal watershed, it is of the utmost importance to ensure that an ecosystem that has such a profound impact over its region is taken care of through river health assessments.

Biodiversity is the presence and abundance of species within a community. The value of biodiversity in an ecosystem is intrinsic, anthropocentric, aesthetic, and scientific (Alho 2008). Wildlife's intrinsic value arises due to its very existence because species are the result of many years of evolutionary development and they have a right to be conserved (Alho 2008). In addition, biodiversity impacts humans directly and indirectly. Biodiversity plays a role in nutrient recycling, water quality, and climate regulation (Alho 2008). Humans also benefit from biodiversity from its aesthetic value. Individuals escape urbanized areas in search of more pleasing natural scenery (Alho 2008). Lastly, the scientific value of biodiversity relates to the unknown benefits that the scientific community has yet to discover. For example, unearthed pharmaceuticals may never be found due to the rapid deterioration of natural habitat (Alho

2008). It has been shown that with an increase in anthropogenic pressure, biodiversity will then decrease (Portugal et al., 2016). In fact, largely due to human activity, the world is facing a decrease in biodiversity (Villeger et al., 2011). As the human population continues to grow and the more water is used for economic development purposes, the more river ecosystems will deteriorate (Dekisiss et al., 2003). In order to measure the effects that urbanization has on the overall ecosystem health, fish have proven to be an appropriate bioindicator (Levin et al., 2019). Factors identified as causing the decrease in biodiversity include invasive species, overfishing, and reduced water quality (Nijru et al., 2010).

There are many ways to determine the health of a river. However, in an attempt to focus my efforts, I propose to focus my attention on analyzing the fish community as an indicator of the river's biotic quality. Such an assessment takes into account factors of the river that respond to changes in water quality. (Nandi et al., 2016). Fish are useful bioindicators of the state of an environment because they are sensitive to changes in water and habitat quality (Pont et al., 2006). Thus, if there were to be a change in the presence and abundance of fish species, it indicates that there could be a substantial change in their environment.

Habitat degradation is, unfortunately, bringing about a decrease in fish biodiversity (Alexander et al., 2014). In fact, habitat degradation is one of the leading causes of a loss in fish diversity (Alexander et al., 2014). Urbanization, for example, likely leads to water contamination (Bashir et al., 2020). After contamination, the waterways will become degraded (Bashir et al., 2020). With the world population growing, the addition of treated wastewater to streams is becoming more prevalent (Hamdhani et al., 2020). The flow of the river can be restored and aquatic habitats are able to maintain water flow in areas where there is less water available (Hamdhani et al., 2020). However, water and ecological communities' quality can decrease (Hamdhani et al., 2020). The range of possibilities varies, so record-keeping and research are needed to track aquatic changes.

Throughout the entire world, habitat degradation negatively impacts fish populations (Thompson et al., 2010). So much so that native species including the Santa Ana Sucker are federally threatened (Thompson et al., 2010). Unfortunately, over the last several decades the Santa Ana River has been modified by humans due to urbanization, agriculture, water conservation, and channelization (Thompson et al., 2010). Because of these disruptions, water flow and fish movement have been affected (Thompson et al., 2010). Northern regions of the Santa Ana River are relatively unaffected compared to the Southern regions because it is farther away from human development (Fraga et al., 2013). Interestingly, an unpublished study has found that the Santa Ana Sucker was not randomly distributed throughout the river (Thompson et al., 2010). Instead, they were clumped in certain microhabitats where they can find the cobble and gravel substrate that they favor (Thompson et al., 2010). Furthermore, by maintaining and building on the current habitat of the Santa Ana sucker, there will be an increase in the likelihood of its survival in the Santa Ana River (Thompson et al., 2010). This is because whenever a change occurs in the habitat conditions, the population and communities that live in a freshwater system are influenced by the change (Thomspson et al., 2010). Thus, it is important to preserve the particular areas that native fish like the Santa Ana Sucker favor in order to prevent further harm (Thompson et al., 2010).

Native populations of Arroyo Chub in Southern California have been found to decline over the past several years (Benjamin et al., 2016). The greatest threats facing the Arroyo Chub are habitat degradation and loss, fragmentation, and invasive species (Benjamin et al., 2016). Arroyo Chub populations display differentiation in abundance and genetic material along native drainages (Benjamin et al., 2016). Differences in the population structures are likely due to disruptions in gene flow through dams and watershed boundaries (Benjamin et al., 2016). Luckily this native population has a high level of diversity despite factors that hinder it including invasive species and habitat loss from urbanization (Benjamin et al., 2016). When considering which areas to restore, it would be most fruitful to focus on places that are the least disturbed by human activities because other streams that have been more impacted by humans may be permanently damaged (Benjamin et al., 2016).

Invasive species have the ability to pose considerable harm to native biodiversity (Tobin 2018). I would anticipate seeing that the reach with the highest number of invasive species will also have one of the lowest biodiversity levels. I will see if my lowest biodiversity level matches the expected result. I would also expect to see that there is greater diversity in areas with fewer human activities. Or perhaps even if a human disturbance is nearer to certain reaches, I can expect there to be a lower diversity level there than at a reach that is farther away from human activity. An example of an anthropogenic factor that I plan to look for includes parks. The end goal of my project is to provide further evidence of the environmental impacts that humans have as well as what other agents lessen biodiversity in urban habitats. Additionally, this capstone project will hopefully prove useful to other researchers who are doing a more in-depth look at water quality, ecosystem health, or the impact of climate change in Southern California.

Methods

The data that I used was collected by the United States Geological Survey (USGS) during annual native fish surveys carried out in the Santa Ana River. From 2015-2018 USGS and their collaborators surveyed a variety of river reaches from the urban headwaters of the Santa Ana River to the Prado Dam Reservoir, which constitutes the extant range of Santa Ana sucker in the river during this time period. Every year 8-10 river reaches of biological importance to Santa Ana sucker and Arroyo chub are surveyed. Surveys are completed by cordoning off a 50-meter reach using block nets and fish are collected using a 3-pass depletion survey using electrofishers, dip nets, and seines. Once fish are collected they are identified by a biologist, weighed, and measured. Once surveys are completed the data is uploaded to ScienceBase where it was downloaded and cleaned for use in my analyses (Wulff et al., 2017, 2017b, 2018, 2019).

From the collected data set I extracted the counts of native and invasive fishes. Pertinent data relating to the fish that I have access to are the different types of species, the total species count, the location of the fish surveyed, as well as the length and weight of all collected individuals. Data connected to the environment include the channel width and depth, velocity of water, cover, substrate, and canopy. The most important data for calculating the biodiversity are the location of the fish when they were surveyed and the count of each species in that location. Although the other information is important, it was not used in this study. Instead, this other information can be used to help explain why there might be a change in biodiversity rather than if there is a change.

The publicly available data were analyzed in multiple different ways. I cleaned the data using R software. Using the plyr, dply and janitor packages I cleaned the data. I organized the data by the total count of fish at each reach. I separated the fish counts into invasive and native species. Although, I did not use every fish that was collected in the surveys. Some of the fish that were non-native were not included because their numbers were so small. These species have not been able to establish themselves in the Santa Ana River. Lastly, I looked at how the general trends of the invasive and native fish counts changed. I calculated the Shannon and Simpson diversity through R to determine biodiversity across sampled river reaches. To test for statistical significance, I used the ANOVA statistical test to see if the fish diversity levels changed over time. I chose to use this type of statistical test because I am checking to see if there is a difference in the means of different groups within multiple categorical variables (reaches of water). Lastly, I examined if there was enough statistical power from the data I have to claim that the fish diversity changed from 2015 to 2018.

Results

ANOVA statistical analysis revealed that there was not a significant change in the fish diversity over the course of four years at the sites analyzed.The p-value from Simpson diversity data is 0.741. The p-value from the Shannon diversity is 0.588. Both of these are quite above the standard p-value of 0.05. Therefore, I fail to reject the null hypothesis and conclude that there is not enough evidence to support the idea that fish diversity significantly changed from 2015 to 2018. The f value for the Shannon diversity is 0.306. While the f value for Simpson diversity is 0.113. These f values are rather low and this indicates that there is not a lot of differences between the means of the groups.

After examining the three highest and lowest diversity values I looked at the proportion of invasive species at each of these sites. First, I will share the results for the three highest reaches. The proportion of invasive fish in the SAR RIX confluence to the southern bank and South channel are 0.05921053 and 0.0176565, respectively. The proportion of invasive species in the reach with the highest fish diversity, Middle Channel to Riverside Drive, is 0.007371913. Now, I will share the proportion of invasive species in the reaches with the lowest amounts of diversity. The lowest fish diversity was found at Anza with a proportion of 0.04964539 species being invasive. The other two sites are SAR Riverside Dr. to Mission Blvd. Below Hwy. 60 and Van Buren had proportions of 0.1529412 and 0, respectively. These last two reaches' ratios have the biggest difference from one another.

DiversitybySite

Site	Shannon	Simpson	Year
Rialto Drain	0.6261775	0.2883539	2015
SAR Confluence of Rialto Drain to RIX Confluence	0.5783842	0.2766922	2015
SAR Riverside Dr to Mission Blvd Below Hwy 60	0.3702799	0.1453077	2015
SAR Riverside Dr to Mission Blvd Below Riverside Dr	0.4999518	0.2356072	2015
SAR RIX confluence to southern bank	0.9168662	0.46778	2015
SAR Southside channel to Riverside Drive	0.4738708	0.2230616	2015
Confluence to RIX	0.6749116	0.3878018	2016
Crossover Channel	0.7747099	0.4122183	2016
Crossover Channel to Riverside Drive	0.3784323	0.1677143	2016
Rialto Drain to Confluence	0.7130762	0.3788948	2016
Riverside Drive to Market Street	0.5176957	0.2255416	2016
Riverside Drive to Mission Inn Ave	0.498656	0.2071762	2016
RIX to Crossover Channel	0.3930443	0.1646612	2016
Middle Channel to Riverside Drive	1.0885196	0.6430966	2017
North Channel	0.4401821	0.1959501	2017
South Channel	0.7766216	0.4095835	2017
Anza	0.3110345	0.1305623	2018
North Channel to Riverside Drive	0.4878999	0.2072591	2018
Van Buren	0.3781599	0.1728473	2018

Figure 1: This shows the Shannon and Simpson Diversity level of each reach surveyed between 2015 and 2018.

I did not test between any differences of diversity because I am just focusing on which reaches show the highest and lowest diversity levels. Our highest values of Simpson and

Shannon diversity value were found at the Middle Channel to Riverside Dr., SAR RIX Confluence to Southern Bank, and South Channel reaches (Figure 1). The lowest values of Simpson and Shannon Diversity are found at Anza, SAR Riverside Dr. to Mission Blvd. Below Hwy. 60, and Van Buren (Figure 1). Two out of the three highest diversity values are found in 2017 while the other is in 2015 (Figure 1). Two of the lowest diversity values are found in 2018, with the other found in 2015 (Figure 1).

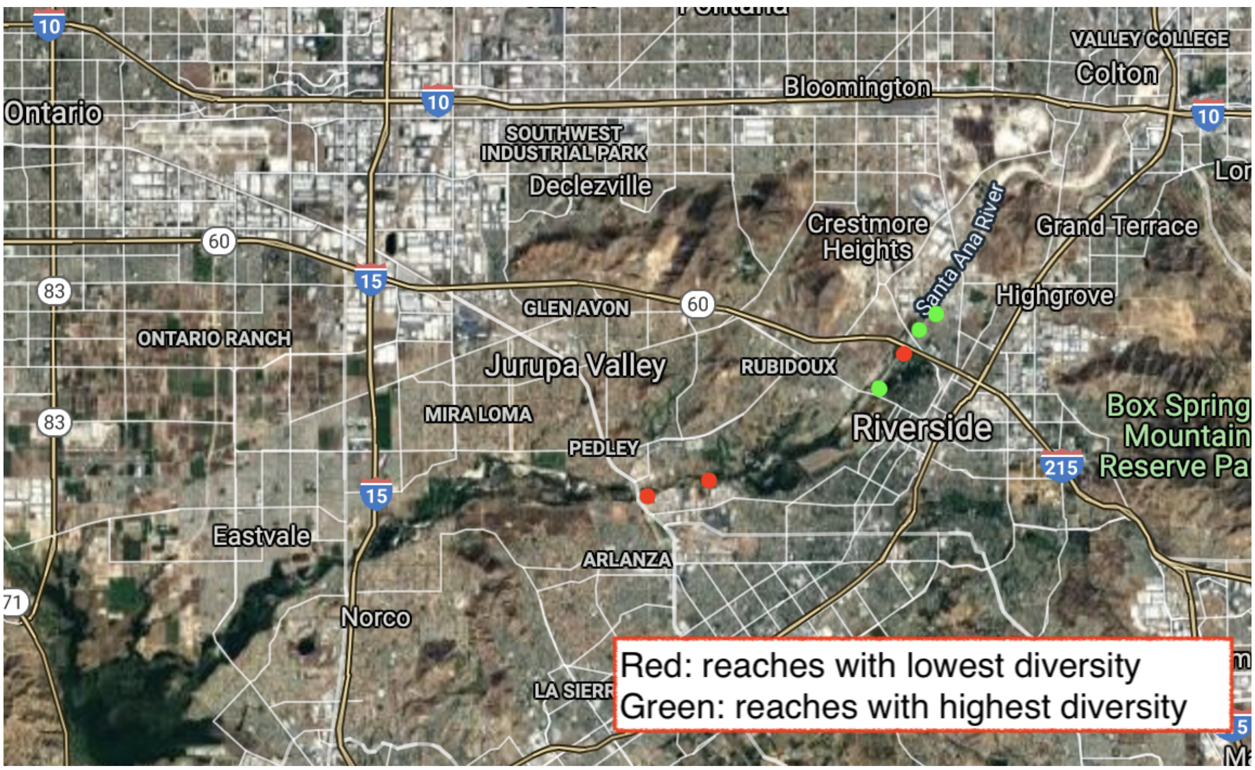

Figure 2: Here I have marked the reaches with the highest and lowest diversity levels so that we can see where they are located on a map. I have marked the three reaches with the lowest diversity in red and the three reaches with the highest diversity levels in green.

Two of the sites with the lowest diversity are clumped together while all three of the sites with the highest diversity are also relatively close (Figure 2). There does seem to be an outlier with SAR Riverside Dr. to Mission Blvd. Below Hwy. 60 being among the reaches with the highest diversity while having one of the lowest diversity levels (Figure 2).

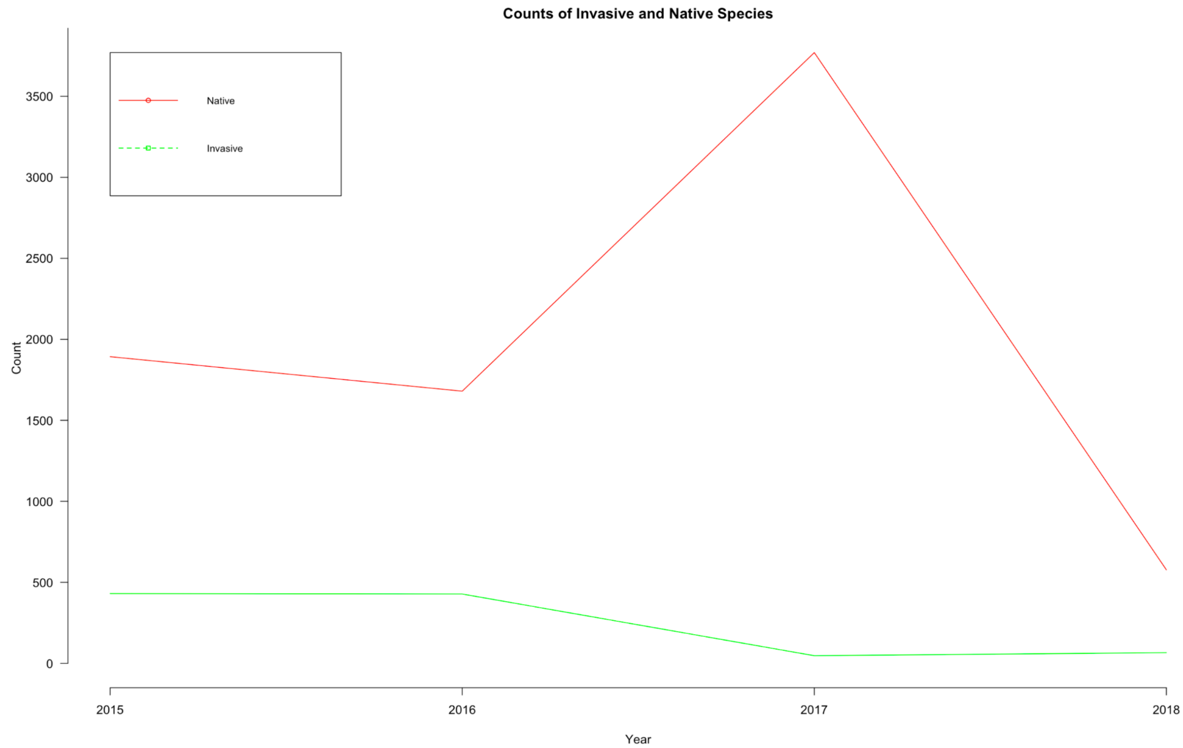

Figure 3: This plot is the overall counts of invasive and native fish collected. Native fish include the Santa Ana Sucker and the Arroyo Chub. Invasive fish include Sunfish, Largemouth Bass, Yellow Bullhead, and Bluegill.

The native fish populations are higher than the invasive species from the data I analyzed (Figure 3). However, I should reiterate that the data collected here is not representative of the entire river nor are the same sites being taken into account each year. A feature of the graph that I wanted to emphasize is that in 2018 the number of invasive and native species are not far apart (Figure 3). Furthermore, the sites that were surveyed in 2017 have the greatest amount of native fish, with a quite low proportion of the fish there being invasive (Figure 3). Further research is required here to determine what mechanisms are causing the large proportion of native fish in 2017 and the smaller proportion of these fish in 2018.

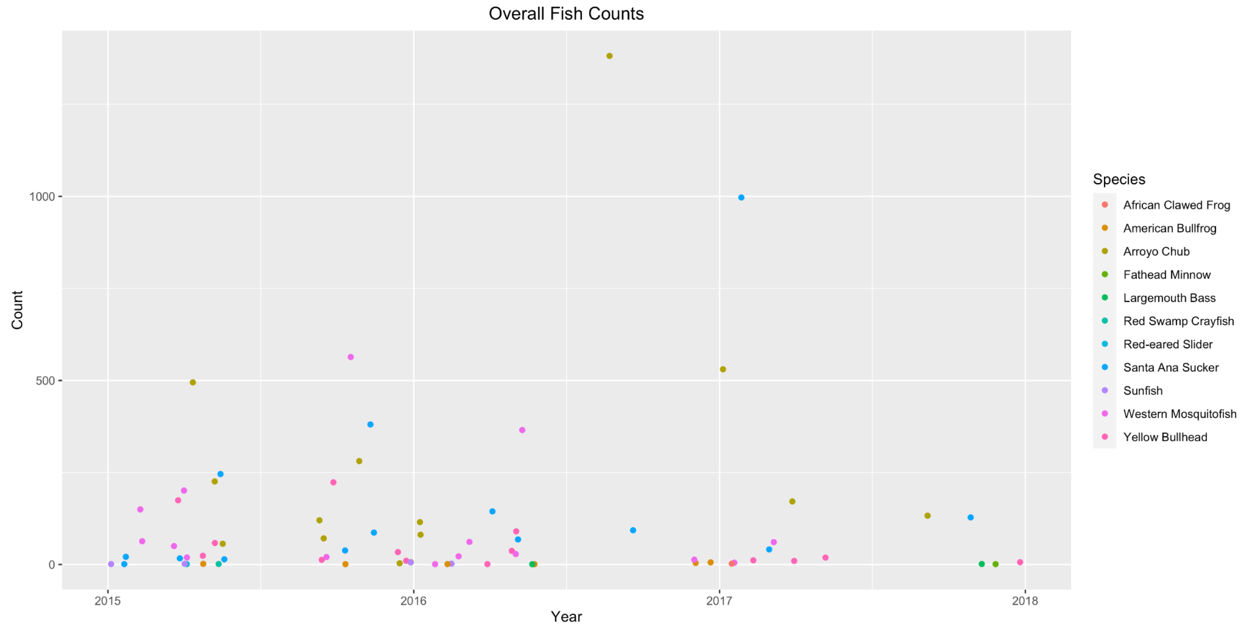

Figure 4: This plot shows the different species that were captured each year as well as the total count.

The greatest amount of fish collected at a site was the Arroyo Chub (Figure 4). This fish is native to the Santa Ana River. The majority of the fish that are collected are less than two hundred and fifty (Figure 4). Many of the species are only collected on a few or perhaps even just one instance (Figure 4). A few of the more uncommon species include the Sunfish, Fathead Minnow, and the Red Swamp Crayfish. We also see that in 2018 surveys there seems to be a much lower amount of fish and sites than the other year (Figure 4). This is due to the amount of data that was cleaned and processed for this project.

Discussion/Conclusion

I found that there is an overall higher abundance of native fish each year through plotting the invasive and native species (Figure 3). I did not include all of the species in the graph. For example, if there were only a few of a certain type of fish then I did not include them in the graph. Those species are not the species that are impacting the native populations the most. Throughout the years the sites that I analyzed did not remain constant, but we are still able to get an idea of the makeup of the fish in the Santa Ana River. ANOVA statistical tests revealed that there has not been a significant change in diversity in the data the USGS collected. This indicates that the conditions in the water have not greatly been altered from 2015 to 2018. This seems to make sense since the majority of the water that feeds the Santa Ana River is wastewater (Luthy et al., 2015). Therefore, the majority of the water that feeds the river flows from one type of source throughout the time this data was analyzed.

Two of the sites with the lowest diversity were both found near the Martha McLean-Anza Narrows Park (Figure 2). I would suggest that perhaps future research would continue to happen here. It is important to have a reference point of how the diversity level was in the past (Shahnawaz et al., 2009). This way researchers get an idea of whether the diversity levels are increasing or decreasing over time. Unfortunately, with these reaches being so close to the park, I find it likely that these reaches have been impacted by this park. If there is a disturbance upstream, then the areas below that will likely have a decrease in fish diversity (Lawrence et al., 2011). Parks are a lovely way to spend some leisure time, but unfortunately, it appears as though that something, or many things, from this park, may be altering the conditions of the water to make it of lower quality. It is imperative to keep an eye on these reaches because of their low amount of diversity and with a change in water quality, fish diversity tends to change with it (Guo et al., 2019). In order to prevent change in the water quality, a course of action that seems plausible includes greater enforcement near the waterway (Swartz et al., 2008). Local enforcement has the potential to preserve and contribute to the increase of fish diversity (Sartz et al., 2008). If the number of humans entering, fishing, and polluting the water decrease then the water quality will no longer fluctuate as much and we would hopefully see an increase in fish diversity.

I find it interesting that some of the most and least diverse sites are found within the same year (Figure 1). There are a variety of reasons why this might be. Examples include changes in river network connectivity, invasive species, and other human activities (Shao et al., 2019). This goes to show that sometimes the overall trends of fish in a year may not accurately represent the diversity of specific sites within a particular year. A year could have an increase in diversity despite the fact that one of the reaches along the river is not all that diverse. Furthermore, one of the reaches with the lowest fish diversity can be found among those with the highest. It does appear that SAR Riverside Dr. to Mission Blvd Below Hwy. 60 is closer to the freeway than the other sites with higher diversity (Figure 2). The close proximity may be impacting the fish diversity at this site (Gilarranz et al., 2016). However, it does seem contradictory to have one of the lowest levels of diversity so close to the reaches with the highest. A possible reason that the reach with the highest and lowest fish diversity are in such close proximity has to do with the time of year the survey was taken (Loures & Pompeu, 2019). Another contributing factor might be that the fish do not move very much, so poor conditions in one location are localized.

The relative proportions of invasive species at the three sites with the highest and lowest diversity are notable. When we look at what percent of the fish species within a reach are invasive, we are seeing how established these fish are compared to other regions. Thus, if there is a greater proportion of invasive fish then it would logically follow that there would be more resources that the native species have to compete for. I expected there to be the largest proportion of invasive fish at the sites with the lowest amount of diversity. My reasoning was that if there are a lot of these established non-native fish then that would take up the resources of the native fish. Then, with more resources the invasive fish would dominate the reach, preventing other species from thriving. This would lower the diversity. When I was calculating the proportions of the invasive species I found that my results were mixed. This is likely because there are a lot of other factors that go into determining the fish diversity of particular reaches (Rahim et al., 2008). I found that one reach, Van Buren, during the survey that particular year did not have any invasive species, so the proportion was 0. This site in particular seems to be odd because it had one of the lowest fish diversity levels, this goes against what I would expect. I cannot help but wonder if this is because of the water conditions in this area. Perhaps they are not favorable for the invasive species. Further research is needed here in order to determine what might be causing this.

Conversely, the reach with the highest fish diversity did have the lowest proportion of invasive species. The invasive species are present here but did not seem to establish themselves as much compared to the other reaches. The proportion at the Middle Channel to Riverside Drive reach is 0.007371913. Although I know there are other factors that have impacted the fish's presence and abundance, this outcome still happens to match my prediction. A lower proportion of invasive fish would have more overall fish diversity in that reach. The low diversity sites that I calculated the proportion of have an overlap with the high diversity sites. The portion of invasive fish in SAR RIX confluence to southern bank's and South channel are 0.05921053 and 0.0176565, respectively. The other two lowest fish diversity levels had unexpected results. The reach with the lowest fish diversity was found at Anza with a proportion of 0.04964539 species being invasive. This is in between the proportions of the reaches with the highest diversity. SAR Riverside Dr. to Mission Blvd. Below Hwy. 60 proportion is 0.1529412. This is slightly below the proportion of invasive fish found in the South Channel where the fish Shannon's diversity is about double. The interpretation I have done here does not seem to provide enough evidence of a correlation between the proportion of invasive species and the diversity level here.

The methods used for this project are applicable to other freshwater systems. A potential application of my findings is that future research will be able to compare the biodiversity level of fish from the years I analyzed to those in future years. Another application of my findings is that I hope to compare what human activities are going on in areas where the fish diversity is the lowest. Other researchers can compare the human activity I note in these areas to the human activity in theirs and see if they also have lower levels of diversity near these particular anthropogenic scenes.

Without a doubt, urbanization impacts natural environments (Grimmond, 2007). It seems to me that urbanization might be inevitable because humans have the urge to always build. I would not say that this tendency is intrinsically evil. Instead, I would say that it is best to pursue a path that allows for human innovation and growth while also responsibly recognizing the impacts it has on nature. I believe that balance is possible. There are countless researchers who dedicate hours of their lives to the pursuit of knowledge and learn what steps are necessary to hopefully make an improvement in this world. When we start losing our native biodiversity, we start losing a bit of the overall value of an ecosystem. Biodiversity impacts the overall ecosystem health which in turn impacts those who live within the ecosystem, including humans. There are so many healthy ecosystems to go to, so I believe that it is best to preserve and care for what we have now.

While I reflect on the work I did towards this capstone, there are a few different approaches I would have taken. First, I would have used data that was a little more continuous. I did not have data that showed all of the same reaches each year. Also, there were some misunderstandings with the naming of which reaches earlier on in the project. If I were to plan out the data collection, I would have been more familiar with the process. Second, if we were not in a pandemic, I would have enjoyed collecting my own data. Although it would not have been as comprehensive as four years of fieldwork, it would have been more fitting to the project I had in mind. The data I used was collected over the course of four years. However, it would have been more appropriate to use all of the same sites to see how the diversity changed. A positive outcome though was that I was able to assess the diversity in more reaches of the river. Lastly, I would have liked to work a little bit more with the USGS. If I were to do this, I would have learned more about their data collection methods and gained a new perspective on tracking different fish populations.

Works Cited

Alexander, M. E., Kaiser, H., Weyl, O. L. F., & Dick, J. T. A. (2014, May 11). *Habitat simplification increases the impact of a freshwater invasive fish - environmental biology of fishes*. SpringerLink. Retrieved March 2, 2022, from https://link.springer.com/article/10.1007/s10641-014-0278-z

Alho C. J. (2008). The value of biodiversity. *Brazilian journal of biology = Revista brasleira de biologia*, *68*(4 Suppl), 1115–1118. https://doi.org/10.1590/s1519-69842008000500018

Bashir, I., Lone, F. A., Bhat, R. A., Mir, S. A., Dar, Z. A., & Dar, S. A. (2020, January 27). *Concerns and threats of contamination on aquatic ecosystems*. Bioremediation and Biotechnology: Sustainable Approaches to Pollution Degradation. Retrieved March 2, 2022, from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7121614/

Cunningham, C., & Gharipour, M. (2018, January 30). *Pipe dreams: Urban wastewater treatment for biodiversity protection*. MDPI. Retrieved November 8, 2021, from https://www.mdpi.com/2413-8851/2/1/10/htm.

Deksissa, T., Ashton, p. J., & Vanrolleghem, P. A. (2003). Control options for river water quality improvement: A case study of TDS and inorganic nitrogen in the Crocodile River (South Africa). *Water* SA, 29(2), 209-18.

Fraga, N. S., Gross, L. R., Bell, D., Mistretta, O., Wood, J., & Stoughton, T. (2013, January). *The vascular flora of the upper santa ana river watershed ...* Research Gate. Retrieved January 31, 2022, from https://www.researchgate.net/publication/281748553_THE_VASCULAR_FLORA_OF_THE_UPPER_SANTA_ANA_RIVER_WATERSHED_SAN_BERNARDINO_MOUNTAINS_CALIFORNIA

Gilarranz, L. J., Mora, C., & Bascompte, J. (2016, February 12). *Anthropogenic effects are associated with a lower persistence of marine food webs*. Nature News. Retrieved February 17, 2022, from https://www.nature.com/articles/ncomms10737

Grimmond, S. (2007, January). *Urbanization and global environmental change: local effects of urban warming*. Retrieved March 8, 2022, from https://rgs-ibg.onlinelibrary.wiley.com/doi/epdf/10.1111/j.1475-4959.2007.232_3.x

Guo, C., Chen, Y., Liu, H., Lu, Y., Qu, X., Yuan, H., Lek, S., & Xie, S. (2019, February 5). *Modelling fish communities in relation to water quality in the impounded lakes of China's south-to-north water diversion project*. Ecological Modelling. Retrieved February 17, 2022, from https://www.sciencedirect.com/science/article/pii/S0304380019300298?casa_token=oL9utHsmcBcAAAAA%3A7SLeoeGN2csFw0zc8tGmEf-vhguaapaEGy26L_bi4BWKiYN-iLOzBzJ1CsRw0dERHIJH_z1pmuI

Guy, C. S., Cox, T. L., Williams, J. R., Brown, C. D., Eckelbecker, R. W., Glassic, H. C., Lewis, M. C., Maskill, P. A. C., McGarvey, L. M., & Siemiantkowski, M. J. (2021). A paradoxical knowledge gap in science for critically endangered fishes and game fishes during the sixth mass extinction. Scientific Reports, 11(1), 1–9. https://doi.org/10.1038/s41598-021-87871-y

Hamdhani, H., Eppehimer, D. E., & Bogan, M. T. (2020, May 18). *Release of treated effluent into streams: A global review of ecological impacts with a consideration of its potential use for environmental flows*. Wiley Online Library. Retrieved February 1, 2022, from https://onlinelibrary.wiley.com/doi/full/10.1111/fwb.13519

Kuklina, I., Kouba, A., & Kozák, P. (2012, October 7). *Real-time monitoring of water quality using fish and crayfish as bio-indicators: A Review*. Environmental Monitoring and Assessment. Retrieved November 4, 2021, from https://link.springer.com/article/10.1007/s10661-012-2924-2#citeas.

Lawrence, D. J., Larson, E. R., Liermann, C. A. R., Mims, M. C., Pool, T. K., & Olden, J. D. (2011, June 7). *National Parks as protected areas for U.S. freshwater fish diversity*. Society for Conservation Biology. Retrieved February 17, 2022, from https://conbio.onlinelibrary.wiley.com/doi/full/10.1111/j.1755-263X.2011.00185.x

Levin, J. C., Woodford, D. J., & Snow, G. C. (2019). Evaluating the effectiveness of freshwater fishes as bio-indicators for urban impacts in the Crocodile (West) catchment, South Africa. *Water SA*, *45*(3), 477–486. https://doi.org/10.17159/wsa/2019.v45.i3.6745

Loures, R. C., & Pompeu, P. S. (2019, July 26). *Temporal changes in fish diversity in lotic and lentic environments along a reservoir cascade*. Wiley Online Library. Retrieved February 17, 2022, from https://onlinelibrary.wiley.com/doi/abs/10.1111/fwb.13372?casa_token=3OHVLCvtoRUAAAAA%3ABVJscZh48wgFCTP_HiaXFoaWz7ZRwyIG7iNmSN2sbOVTyUWgAwhNo06azngXndMrfFOQF71TYkGEJYV4

Luthy, R. G., Sedlak, D. L., Plumlee, M. H., Austin, D., & Resh, V. H. (2015, November 1). *Wastewater effluent dominated streams as ecosystem management tools in a drier climate*. The Ecological Society of America. Retrieved February 17, 2022, from https://esajournals.onlinelibrary.wiley.com/doi/10.1890/150038

Mitchell, P. (2006). *Santa Ana River Guide: From crest to coast -- 110 miles along Southern California's largest river system*. Wilderness Press.

Nandi, I., Tewari, A., & Shah, K. (2016). Evolving human dimensions and the need for continuous health assessment of Indian rivers. *Current Science (00113891)*, *111*(2), 263–271. https://doi.org/10.18520/cs/v111/i2/263-271

Njiru, M., Mkumbo, O. C., & van der Knaap, M. (2010). Some possible factors leading to decline in fish species in Lake Victoria. *Aquatic Ecosystem Health & Management*, *13*(1), 3–10. https://doi.org/10.1080/14634980903566253

Pont, D., Hugueny, B., Beier, U., Goffaux, D., Melcher, A., Noble, R., Rogers, C., Roset, N., & Schmutz, S. (2006). Assessing river biotic condition at a continental scale: a European approach using functional metrics and fish assemblages. *Journal of Applied Ecology*, *43*(1), 70–80. https://doi.org/10.1111/j.1365-2664.2005.01126.x

Portugal, A. B., Carvalho, F. L., de Macedo Carneiro, P. B., Rossi, S., & de Oliveira Soares, M. (2016). Increased anthropogenic pressure decreases species richness in tropical intertidal reefs. *Marine Environmental Research*, *120*, 44–54. https://doi.org/10.1016/j.marenvres.2016.07.005

Shahnawaz, A., Venkateshwarlu, M., Somashekar, D. S., & Santosh, K. (2009, January 30). *Fish diversity with relation to water quality of Bhadra River of western ghats (India) - environmental monitoring and assessment*. SpringerLink. Retrieved February 17, 2022, from https://link.springer.com/article/10.1007/s10661-008-0729-0

Shao, X., Fang, Y., Jawitz, J. W., Yan, J., & Cui, B. (2019, June 24). *River network connectivity and Fish Diversity*. Science of The Total Environment. Retrieved March 2, 2022, from https://www.sciencedirect.com/science/article/pii/S0048969719329134?casa_token=uxwnWlI3i3sAAAAA%3Au-Q8Ya-WjVY44qKDDeYyd5cfQ-G3J_sHUiiwODgyHJxlbw9lHt4nh5QMXE2vP_GI3WLIBI6Wvfg

Surbeck, C. Q., Jiang, S. C., Long Ho Ahn, & Grant, S. B. (2006). Flow Fingerprinting Fecal Pollution and Suspended Solids in Stormwater Runoff from an Urban Coastal Watershed. *Environmental Science & Technology*, *40*(14), 4435–4441. https://doi.org/10.1021/es060701h

Thompson, A. R., Baskin, J. N., Swift, C. C., Haglund, T. R., & Nagel, R. J. (2010, February 20). *Influence of habitat dynamics on the distribution and abundance of the federally threatened Santa Ana Sucker, Catostomus Santaanae, in the Santa Ana River - environmental biology of fishes*. SpringerLink. Retrieved January 31, 2022, from https://link.springer.com/article/10.1007/s10641-010-9604-2

Tobin, P. C. (2018, October 23). *Managing invasive species*. NCBI. Retrieved January 17, 2022, from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6206619/

Villéger, S., Blanchet, S., Beauchard, O., Oberdorff, T., & Brosse, S. (2011). Homogenization patterns of the world's freshwater fish faunas. *Proceedings of the National Academy of Sciences of the United States of America*, *108*(44), 18003–18008. https://doi.org/10.1073/pnas.1107614108

Wulff, M.L., Brown, L.R., and May, J.T., 2017, Native Fish Population and Habitat Study, Santa Ana River, California, 2015: U.S. Geological Survey data release, http://dx.doi.org/10.5066/F72B8W48.

Wulff, M.L., Brown, L.R., and May, J.T., 2017b, Native Fish Population and Habitat Study, Santa Ana River, California, 2016 (ver. 2.0, August 2017): U.S. Geological Survey data release, https://doi.org/10.5066/F7K072H3.

Wulff, M.L., Brown, L.R., May, J.T., and Gusto, E., 2018, Native fish population and habitat study, Santa Ana River, California, 2017: U.S. Geological Survey data release, https://doi.org/10.5066/F7CJ8CR0.

Wulff, M.L., Brown, L.R., May, J.T., and Gusto, E., 2020, Native Fish Population and Habitat Study, Santa Ana and San Gabriel Rivers, California, 2018: U.S. Geological Survey data release, https://doi.org/10.5066/P9FTPCMO.

Xin Deng, Carney, M., Hinton, D. E., Lyon, S., Woodside, G., Duong, C. N., Sang-Don Kim, & Schlenk, D. (2008). Biomonitoring Recycled Water in the Santa Ana River Basin in Southern California. *Journal of Toxicology & Environmental Health: Part A*, *71*(2), 109–118. https://doi.org/10.1080/15287390701613017

Yates, A. G., Culp, J. M., Armanini, D. G., Baird, D. J., Jardine, T. D., & Orlofske, J. M. (2019). Enhancing bioassessment approaches: development of a river services assessment framework. *Freshwater Science*, *38*(1), 12–22. https://doi.org/10.1086/701674