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Fish Populations in a Changing World

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Abstract:

Freshwater ecosystems in North America face many threats including habitat degradation, fragmentation, and hydrological changes to the river system. This is especially obvious in Southern Appalachia region, which is a hotspot for freshwater biodiversity. Large inputs of sediment from coal mining and nutrients from agriculture degrade water quality. Dams and other stream modifications have led to changes in the habitat and hinder migration. Numerous native and endemic species have small isolated populations that are threatened by extinction. Recovery rates of species depend on numerous factors, including abiotic and biotic ecosystem factors and the natural history of the species. Species like the Yellowfin Madtom, Kentucky Arrow Darter, and Blackside Dace are increasing in population size and range due to the help from numerous organizations.

Keywords: fish, recovery, Appalachia, freshwater, ecology, dam, homogenization

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Introduction

In recent years, attention and concern for protecting vulnerable and biodiverse habitats have increased. People all over the world support the protection of coral reefs and the rainforest. However, many are unaware of the diversity inland or in more temperate areas, including North America. As the biodiversity and unique species in freshwater North America are not as well known, the public is less aware and protective of these resources. The United States is ranked 7th in worldwide fish diversity containing 10% of all known fish species (Stein et al. 1998). Furthermore, the unique freshwater habitat of the United States aquatic system hosts the largest diversity of freshwater mussels, snails, crayfish, mayflies, stoneflies, and caddisflies worldwide (Stein et al. 1998). These groups are particularly sensitive to habitat degradation, and the insect orders with the greatest diversity are actually used to determine water quality due to their sensitivity. This diversity is threatened by multiple factors, predominantly habitat degradation, fragmentation, and changes in natural hydrology (Jelks et al. 2008). These factors affect freshwater diversity on a global scale. All over the globe, governments and independent organizations work to combat these factors to preserve fish populations and native diversity, with varying degrees of success. Across Europe there have been major efforts to increase the water quality in river systems, yet there are continued declines in native species (Aarts et al. 2003). The United States faces a similar situation and although there have been increasing efforts to correct these factors, populations are still in decline. In 1998, 37% of the United States fish species were at risk of extinction (Stein et al. 1998). Today that number has risen to 39% with only 6% of species showing improvement in their status since 1989 (Jelks et al. 2008).

The largest contributor to the decline of fish populations is habitat degradation, mostly due to pollution and stream disturbance or modification (Warren et al. 2000). Habitat degradation leads to decreased ranges as habitats fail to meet species-specific requirements. This in turn leads to fragmentation and isolation of populations as ranges are shortened and pocket populations are left behind. Habitat degradation impacts sensitive or specialized fish populations at a drastic level and leads to a slow recovery process. In some areas sensitive species populations have yet to recover from chronic pollution twenty years after water quality improvements were made (Ryon 2011). Even more tolerant species, like game fish have faced declines due to pollution. This decline effects both commercial fisheries and recreational areas (Hughes 2015).

Habitat degradation in turn leads to homogenization; which is the loss of this unique habitat as conditions degrade with increased pollution, sediment, and temperature levels (Scott and Helfman 2001). The loss of unique ecosystems has led to sharp declines in endemic fish species. Endemic species have a very specific and narrow native range and species may only exist in one river system or a handful of headwaters within a single area. As these conditions degrade, endemic fish lose the habitat they need; furthermore, more tolerant fish have seen massive increases in their range. These more tolerant newcomers have changed the community structure in many unique ecosystems. The changes in community structure have ripple effects throughout the food chain leading to further declines in already imperiled species. Even species that might be native to a specific watershed (connected river systems) will move into areas they do not naturally occupy as conditions degrade. Furthermore, homogenization of fish species has increased due to stocking of commercial and sport fish throughout the nation adding to the changes in community structure and loss of unique ecosystem interactions (Rahel 2000). Both invasive and native fish that have expanded their range have cascading effects in the food web and interfere with natural species interactions, increasing the decline of native populations. An example that falls under both categories is the bluegill sunfish, which has a natural range along the eastern United States but now can be found over the majority of the nation, due to the homogenization of the environment and the stocking of game fish (Scott and Helfman 2001).

Hydrological changes to the river systems are also extensive influences in the decrease of native fish populations. Hydrological modifications include major habitat impacts like damming, wetland draining, and other ‘smaller’ changes to the natural water drainage. Dams all over the globe decline fish populations by restricting water connectivity; the Southeastern United States only has about 41% of its water unobstructed by damming (Liermann et al. 2012). Dams also cause habitat homogenization as lotic (fast-moving) water becomes lentic (still) (Liermann et al. 2012). This drastic change in habitat causes declines in native populations and allows for nonnative species to further increase their populations. Dams form a barrier to migration between fish populations, increasing fragmentation and keeping fish from nesting habitat

(Tullos et al. 2016). However removing a dam is not necessarily the best solution. Not only is dam removal expensive and time consuming, but the results are not guaranteed to be positive for native fish. Removing dams releases a vast amount of sediment downstream and allows invasive species to easily migrate (Tullos et al. 2016). It might not even provide the natural habitat it once did for the species after the dam is removed if too many environmental conditions have been changed.

Habitat fragmentation can be caused by habitat degradation or hydraulic changes as both can separate populations from the metapopulation, or populations of the same species that exchange genetic material. Without the ability to migrate, genetic diversity and population elasticity decreases, increasing the likelihood that a population will be extirpated, local extinction, from a system, (Warren et al. 2000. Local extinctions can be caused by a number of events such as: poor recruitment (individuals in younger generations), continued habitat degradation, predation, and catastrophic events like a major drought (Black et al. 2013). The Blotchside Logperch (*Percina burtoni*) in the Tennessee and Cumberland drainages is one such species that could face extirpation. Its population densities are low and highly fragmented (George et al. 2006). The populations show low genetic diversity and specialized alleles, which poses problems for researchers. On one hand, genetic diversity should be increased to ensure a more stable population, but introducing a lot of new alleles into an area could lead to the decline in specialized traits that would lead to a later decline in the population.

There is a lot of work going into removing pollutants in systems (Fausch et al. 2002) and restoring connectivity to reduce fragmentation. Many recovery projects work by focusing on these two major components: ensuring that a species has the habitat to survive and providing direct assistance to increasing populations (Fausch et al. 2002; Shute et al. 1994). Captive breeding is used to help recover fish populations that have declined or reintroduce natural species. This not only provides an increase in fish numbers but an opportunity to study the species itself (Rakes et al. 1999). These recovery plans tend to be highly specialized based on the species and the habitat needed and the genetic diversity present in a local population. As fish tend to act as indicators of regional conditions, even if improvements are made locally, diversity will often remain low and recovery slow as they are affected by a wider area (Freund and Petty 2007). This makes it even harder to properly gauge the effect recovery efforts have on a fish population. This paper seeks to inform how these major forces in decline combined with other factors such as invasive species have led to the decline of fish diversity in the Southern Appalachian area and how different management regimes have been created to assist in the recovery of these populations and their successes and failures.

The Southeastern United States contains a large percentage of the nations' diversity and threatened species. Considered a major hotspot in biodiversity for freshwater fish, around 75% of these fish populations are considered jeopardized or declining to some extent with 28% federally listed (Warren et al. 2000). This number has increased to 39% listed as of 2011 (Jelks et al. 2008). Fish species in the southeast in general are vulnerable due to very specific habitat requirements, isolated populations, and their endemic nature (Warren et al. 2000). The Appalachian area specifically has a large concentration of this diversity. Southern Appalachia has about half of the fish species found in the United States and Canada (Morone 2012). This region provides unique habitat that has allowed for specialized species to appear. This has led to a large amount of endemic species. As of 2002 14% of Southern Appalachia's species were considered endemic (Butler 2002). Many of these species are only found in one watershed, or within a handful of headwater streams. A watershed refers to a drainage of one river system; these areas are connected and share water sources. As these species are highly specific and specialized, they face the greatest danger from declining habitat, fragmentation, and hydrological changes to the river system (Jelks et al. 2008).

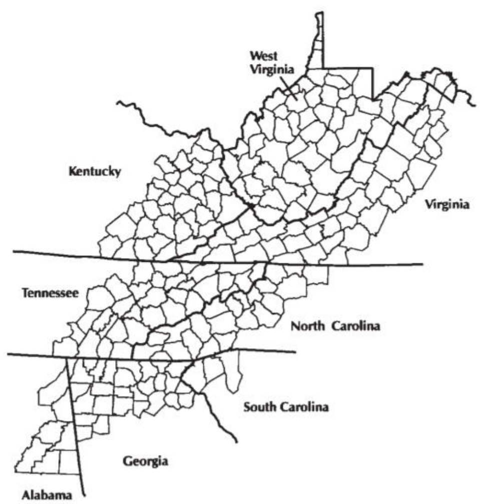

Figure 1. Shows the counties that generally fall under the Southern Appalachian range. (Image from Yarnell 1998.)

The actual Southern Appalachian range varies greatly between groups depending on the focus, however Figure 1 provides a visual of areas that generally fall into the Southern Appalachian range (Yarnell 1998). The mountain range itself is extremely old, dating back 570 million years to the Pre-Cambrian era (Butler 2002). The relatively stable conditions and the sanctuary it provided from glaciers helped ensure that freshwater ecosystems had a relatively long time to evolve, leading to specialized species (Yarnell 1998). The Southern Appalachians host many unique species of fish and other organisms that have formed unique communities and species interdependence (Butler 2002). For example, a few species of mussels have developed mantles that act as fish lures, this allows these species to successively deliver their parasitic larva to host fish species (Haag 2015). Some of these lures attract a wide range of species but others are species specific; therefore, occasionally the loss of one fish species in a system would lead to the loss of a mussel species. The loss of species and decreasing wildlife has been a concern for many years (Yarnell 1998). It was the concern for this area from locals, tourists, and biologists in the late 19^{th} century that led to the creation of the American Forestry Association (AFA) in 1875, which became the Division of Forestry under the Department of Agriculture in 1881. This led to some of the early conservation bills that allowed the government to buy and protect land.

With the increased rate of extinction at 2.4% it is projected that 10% of the Southeast's fish species will be extinct by 2050 (Warren et al. 2000). With increasing population growth, water use, climate change, fertilizer use, invasive species, combined with the major factors species will continue to decline (Strayer and Dudgeon 2010). The amount of changes seen in the river systems is suspected to have caused an 'extinction debt' as species have reached a point where recovery is not possible in the system and populations will simply drop until the species becomes extinct. If there are not massive changes brought to these systems extinction rates will simply continue to increase exponentially. This has led to increased studies of native fish species and stream ecology in order to help reverse the effects and increase and bring back native fish populations. Multiple organizations at the national, state, and local levels have taken to working on finding ways to improve native fish populations and aid in stream restoration. This often starts with identifying and analyzing the problems an area faces, collecting data on declining fish species, and finding solutions that can be tested to show levels of improvement.

Discussion

Stream modification

Loss of connectivity between river systems was identified as the reason species were not recovering in cleaner rivers across Europe (Aarts et al. 2003) and this holds true for Southeastern America.

Streams and water resources are utilized in multiple ways to benefit society including dams, channelization, and other stream modifications. These modifications to waterways assistance people in a number of different ways including recreation opportunities and irrigation. Currently the Southern United States is over pumping water from major aquifers that feed aquatic habitats (Warren et al. 2000) in order to meet human needs. However this strongly affects the fish species that live there in multiple ways. Not only do stream changes directly change the habitat of the stream, they block migration paths for fish. Migration barriers were listed as a major factor in decline for the majority of species listed in Kentucky, increasing in frequency with higher levels of endangerment (Cucherousset and Olden 2011). Losing the ability to migrate these populations are fragmented and isolated. Without being able to interact with the metapopulations, extirpation, local extinctions from an area, becomes much more likely (Warren et at. 2000).

It is also not easy to change these areas back to their natural habitat. It is expensive and time-consuming with results that are not guaranteed as often completely undoing large changes (Pegg and Chick 2010). Removing dams releases a vast amount of sediment downstream that has built up over time. Dam removal also allows for movement of any invasive species between the separated water bodies. Then even after a dam has been removed the area may still not provide the desired natural habitat. One study found the effect of restoring natural flow was less beneficial than removing nonnative fish, which is considerably cheaper to do (Marks 2010). The removal of non-native fish had 20 times more of the effect on improving native fish populations than the removal of the dam. While the combination of impediment and non-native doubled the decline. Even the long term benefits of converting the stream to more native habitat is not expected to pay off. Then the restoration did not cause a decrease in exotic fish so native populations were not able to easily recover due to the strain placed on them during their recovery. This must be weighed against the need for species migration for spawning events (Stanley and Doyle 2003). There are many papers that argue the improvement of native fish populations after dam removal and the recovery of native diversity by the return of more natural habitat. On the other hand, studies that focus on nonnative fish show that their populations are vastly improved and are able to easily spread throughout a system, which is not the desired effect of dam removal (Kanehl et al. 1997). Removing a dam will help native populations migrate and interact, but it will also lead to the spread and increase of nonnative fish. The age of a dam also has to be considered, because while older dams do have a lot more sediment buildup many of them are in a state of disrepair and are not heavily relied on (Stanley and Doyle 2003). Overall dam removal is expensive and does not necessarily offer the best solution for improving native fish populations. Each site has to undergo its own evaluation in risk assessment (Tullos et al. 2016). Currently many are working on making small corridors that allow for slight movement between impediments and tracking fish movement to find the best impediments to work on removing.

Habitat Degradation

The Appalachian region has such high diversity due in part to the unique and heterogeneous habitat it provides. These systems offer water that is cool, low in sediment, and non-polluted. As these conditions degrade, endemic fish lose the habitat they need; additionally, more tolerant fish have seen massive increases in their range. The loss of the Appalachian's unique ecosystem has led to sharp declines in endemic fish species. Homogenization is the loss of this unique habitat as conditions degrade with increased pollution, sediment, and temperature. Temperature is increasing due to climate change and the loss of forest shade caused by logging or urbanization (Rahel 2000; Scott 2001. Urbanization is linked directly to homogenization in a number of ways, including the loss of riparian (vegetation around the riverbanks) and the increase of pollution from runoff (Scott and Helfman 2001). The loss of surrounding forested land is linked to a decrease in spawning for multiple species of fish, specifically those that rely on gravel or sediment for reproduction (Sutherland et al. 2002). Deforestation is known to affect stream ecology but the exact percentage loss is not known. Even with 95% forest cover there can be a decrease in sensitive fish populations like sculpins, benthic minnows, and darters, while more tolerant fish like sunfish increase in abundance (Jones et al. 1999). This is mostly attributed to the decrease of habitat diversity due to the increase in sediment. The riparian removal causes major shifts in community in favor for more tolerant species increasing the predation and competition that sensitive species face (Jones et al. 1999). Furthermore, homogenization results in tolerant fish utilizing different areas in a system, causing changing the community structure as their range expands to include new areas of a river system (Rahel 2000; Scott and Helfman 2001. Homogenization is also linked to the stocking of food and sport fish throughout the nation increasing the occurrence of these species and the loss of unique species communities that echoes throughout the food chain (Rahel 2000).

The number one pollutant in most freshwater streams is sedimentation. In the Appalachian area sedimentation has been increased mostly by strip mining, but any disturbance of the stream leads to increased sedimentation (Sutherland et al. 2002). In only one year the sediment released from a strip mine can drastically change energy input and species composition for a river, and reduce the downstream fish population by half (Lotrich 1973). Sediment in some ways is a two edged sword, as it stores other pollutants like heavy metals. Causing a disturbance in a stream then will not only lead to increased sedimentation but will also release any pollutants the sediment contains. (Sutherland et al. 2002).

A main contributor to pollution of Appalachian areas is coal mining. Not only does coal mining produce numerous toxins, it drastically increases the amount of sediment in the stream. Effects can be seen quickly as declines in populations appear less than a year into contamination. The fastest effects are seen in individuals that eat aquatic invertebrates, including the younger generations of many species and often smaller fish (Lotrich 1973). A study from 1973 looked at the difference a year of mining operations had on a relatively pristine stream in the Cumberland Plateau. After only one year of mining, drastic changes from sedimentation and other pollutants affected energy input and species composition. Reliance on terrestrial invertebrate energy and detritus naturally decreased with increasing stream order. Stream order refers to the size of the stream, first order are extremely small or headwaters streams, where two meet they form a second order stream which increases in size, and so on. Therefore, as a stream increases in size it has less dependence on terrestrial input and relies more on aquatic primary production and aquatic invertebrates. Although, with increasing size, the majority of energy in a food web comes from the river itself and there is still a heavy reliance on the riparian areas as that overall energy input increases. This is because larger stream orders typically contain more organisms and require the higher energy input. Before mining, fish species overlap between the 2^{nd} and 3^{rd} order stream and increase in species going up in order. The community of both rely heavily on sensitive invertebrates including Plecoptera, Ephemeroptera, and Trichoptera. Feeding habits correspond with different emergence times leading to changes in diet in both orders that changed seasonally. The third order was made up of larger and older fish that preyed on crayfish instead of the almost complete reliance on insects in the second order. However, species composition differ drastically between the orders, for example in the second order stream Creek Chub made up 66% while in the third order stream it was only 21%. This shows although they have similar species these communities are very different. After the mining event there are drastic affects in the orders. The increase in competition within species caused major decreases in growth rate in both streams, and third order fish populations were reduced by half. The stream is considered to be somewhat resistant to change though as all of the species were still present, but the composition changes show the initial stages of the ‘breakdown’ in the stream community. Mined communities continue to degrade as mining remains, further damaging the system which takes years to recover. As fish tend to act as regional indicators mined areas cause regional effects, as even in areas that have undergone restoration efforts show fish populations have inhibited recovery (Freand and Petty 2007).

Previously there was little restriction on pollution and many felt that fish would simply migrate into better habitat and return when the area was restored (Carey 1992). This very hands off approach did not account for the decrease in connectivity caused by man-made barriers and varying habitat that sensitive species could not cross. It did not focus on how these moving populations would affect areas they migrated to. There have been major efforts to clean up the waterways under pressure from the Clean Water Act since its creation. A report from 2015 shows that overall health of Eastern Kentucky streams is on the rise (KYDEP 2015). Surprisingly, this is not just driven by the need for clean drinking water, but to meet the needs of endangered or threatened species of invertebrates or vertebrates, which led to the protection and cleanup of water systems. A major shift of the previous view is the recognition of the importance of fish and the knowledge of their response to water quality degradation. However, Kentucky is still not at a desirable condition as recent years saw a 10% decrease in river ability to support aquatic life, leaving less than half of the waterways able to fully support aquatic life (KYDEP 2012). Furthermore, contrasting views on the overall improvement is not uncommon, as not all areas are actually covered in water quality reports as it is limited by funding (Joice 2014; KYDEP 2015). The general consensus is that Eastern Kentucky's largest problem to stream health is sediment (KYDEP 2012; Joice 2014). The largest contributor to sedimentation is strip mining, but most types of disturbance leads to sedimentation (Sutherland et al. 2002). Any amount of disturbance in streams will significantly increase sedimentation (Sutherland et al. 2002; Weaver and Garman 1994).

Sediment retains pollutants so when sediment is disturbed, contaminants will be released into the environment (Sutherland et al. 2002). Pollutants from agriculture, like fertilizers, are second only to coal mining effects, but this is closely followed by unknown source pollutants, which are linked typically to urban development (KYDEP 2012; Joice 2014).

Even low level urbanization will cause long term changes in small streams (Walters et al. 2005; Weaver and Garman 1994). Roads, bridges, commercial and residential development, and decreasing riparian over the course of 38 years in a small community caused significant decreases in stream diversity. Without any non-native fish to increase pressure and decline of native populations, the urban development was held mostly responsible for the sharp decline in diversity and fish populations (Weaver and Garman 1994).

Meeting water quality standards for pollutants will not always lead to a recovery due to synergistic effects of multiple stressors (Freund and Petty 2007). One study looked at how low levels of different stressors like acid mine drainage and increased temperatures drastically decreased macroinvertebrate communities, changing the foundation of the food chain for populations in non-recoverable ways (Merovich and Petty 2007).

There is a large amount of variation in how systems and species recover from pollution with recovery dependent on the specific ecosystem and the extent of degradation. A long-term study surveyed a system in Tennessee over 20 years to map out expected recovery rates (Ryon 2011). The study demonstrated fast recovery downstream with short term stressors, like chemical spills, as they have little effect on the overall system, and populations recover within a year. Chemical spills and pollutants, over time, caused chronic effects leading to problems with bioaccumulation and more progressive decline. The recovery of the system depended on the amount and degree of pollution and on the species in question. Sensitive species' richness and density have yet to fully recover even after 20 years. These results lead to the conclusion that single incident recoveries can be seen short term (year or two), while multiple stressors or chronic stressors require much more time (Ryon 2011). Today most systems face chronic stressors as they have been continuously polluted over years due to factories, agriculture, or mining. Because it is hard to remove pollutants this has led to a focus on less vulnerable watersheds as expected recovery rates will be low and costly (Freund and Petty 2007). The cost and payoff have also lead to an even larger focus on restoring connectivity between populations.

Fragmentation

Fragmentation can be caused by dams, large differences in habitat, and pollution. Sensitive and small fish species can be separated from close populations if smaller cleaner streams are separated by larger and more polluted sections. As they can either not withstand the water quality conditions or face too much predation to easily cross between sections. Many isolated species are endemic and already extremely vulnerable (Warren et al. 2000) and without migration these populations become fragmented and isolated. This lack of interaction with the metapopulations increases the chances of a population facing extirpation (Warren et al. 2000. Isolated populations can undergo local extinctions by a number of events, such as poor recruitment (reproduction), drought, increased predation, and continued habitat degradation (Black et al. 2013). Low genetic diversity is also dangerous within todays changing environments. Without a large gene pool to increase the amount of mutations and differences between individuals, adaptation ability is greatly decreased. Adaptations are possible due to the different traits individuals possess in a population. Then if a population sharply declines not only will it be more susceptible to disease and environmental change, but inbreeding as well.

Invasive species

Nonnative and invasive species can be found at all trophic levels from zooplankton to mammals in the ecosystem and have brought changes to the community composition and the way species interact (Cucherousset and Olden 2011; Mahala 2008). Nonnative and invasive species have been shown to have synergistic effects with habitat degradation, fragmentation, hydraulic alteration, climate change, overexploitation, and pollution. Species like Asian Carp can outcompete native fish species causing changes in behavior, food web, community structure and composition (Mahala 2008). All of these increase the chances of extinctions.

There are different management strategies that work to control these species with containment and limiting harm; although, they are often difficult, costly, and have varying success (Mahala 2008; Hughes 2015). Some of these species are even native to an area but are expanding their ranges due to introduction and homogenization. One such species is the red shiner (*Cyprinella lutrensis*). Bait bucket, the pet trade, and increasing homogenization have led to the massive spread of this species (Nico et al. 2017). Its vast range has increased dramatically partly due to it being one of the most thermally-tolerant cyprinids in the United States (Hassan-Williams and Bonner 2013), its aggressive nature (Nico et al. 2017), hybridization of native *Cyprinella*, and rapid reproduction. The expanded range of the red shiner has changed native species abundance and composition leading to ‘trophic cascades’ in ecosystems (McCormick et al. 2010) and was labeled in 1997 as the second biggest threat to indigenous Southern fish species (Nico et al. 2017).

The red shiner has had a serious impact on the decreasing populations of the native blue shiner (*Cyprinella caerulea*) along the Appalachian Blue Ridge (DeVivo 1995). The red shiner outcompetes its native counterpart with its overaggressive nature and quick reproduction. The amount of the blue shiner’s decline has led to some organizations in Georgia to list the red shiner as 19^{th} in the most concerning invasive fish of the state (Georgia Invasive Species Task Force). It also has brought massive changes to the genetics of the blue shiner through hybridization resulting in changes in the frequency of derived alleles (George et al. 2003). Currently there are conservation efforts to increase connectivity in native blue shiner populations to increase native gene flow.

There is a great amount of concern over the spread of some of the most devastating invasive fish throughout the Appalachians. Once these invasive species have a foothold, massive changes to the community will result and even diligent efforts will struggle to combat these invasive species with little effect. The Round Goby eats practically everything including native mussel larvae, small native fish, invertebrates, and other fish species eggs. They are highly aggressive and will take away nesting sites from native fish. They also spawn rapidly and repeatedly and can quickly establish populations where they enter. For similar reasons the snakehead is also one for major concern as it is hardy and adaptable allowing it to outcompete and eat many native species (Mahala 2008). The snakehead can quickly overtake an area due to its high reproduction rate.

Moving Forward

General problems occurring with management of rivers is the need for large scale data, in both geographic ranges and long term studies, which demands a hefty amount of time and money (Fausch et al. 2002). There is also the issue of good historic data, as no one really knows the true pristine habitat ranges for any fish and older data can be spotty or missing. Confusion and gaps can also occur when species are split and guesses have to be made on each of the species historical native range. Recovery takes a collaborated effort of multiple agencies and companies. These groups work together to fund, collect data, and plan and execute recovery efforts. Many of these are governmentally funded but there are also numerous nonprofit and educational groups that work to improve and preserve fish species (Shute et al. 1994). These include the National Park Service, Conservation Fisheries Inc., the Southern River Counsel (Shute et al. 1994), and many local colleges like Eastern Kentucky University.

Originally management was mostly driven by economic and recreational purposes which led to the large amount of stocking of nonnative and even native game species in numerous watersheds (Shute et al. 1994). These stocking practices had effects on native fish before proper data recording was even done on native populations. Harvest was much less regulated and overharvest from commercial and educational purposes often posed a problem. However, as stream ecology started to become more developed, the attention shifted to more native species and management of an ecosystem. Though game and commercial fisheries are still important to society and are managed with that population in mind. There is a lot of work going into removing pollutants in systems. The focus of these projects is placed on areas that have the best risk assessment to maximize the amount of recovery seen on a larger scale (Fausch et al. 2002). A larger focus and effort is being made to restore connectivity to reduce fragmentation, as this is seen as one of the largest problem to recovering populations (Fausch et al. 2002; Shute et al. 1994). Captive breeding has been utilized for years to replenish declining populations and reintroduce extirpated taxa and give insight into their natural history while in captivity (Rakes et al. 1999). It provides a chance to test water quality ranges, influences on breeding habit, and other questions researchers have. The organization Conservation Fisheries, Inc. (CFI), has been very active in reintroducing and studying native species' life history using Captive breeding for years (Rakes et al. 1999).

Moving forward in recovery, managers have set some broad new goals to achieve. Future management is focusing how climate changes will affect aquatic systems (Strayer and Dudgeon 2010). Managers hope to increase cooperation between experts that work in freshwater ecology and conservation biology. Additionally, management is emphasizing the importance of communication an education of stakeholders (the public). Management of native species has improved due to these trends and a better understanding of fish, stream ecology, and the importance of the sites' ecological history. The lack of large scale data, both geographically and chronologically, causes uncertainty in many management decisions (Fausch et al. 2002). However the increase in shared data through different websites and the increase in published papers have helped modern managers combat this problem. Management has improved with increased knowledge of streams' heterogeneous nature and the increase of local data collection.

Recovery depends a lot on the species in question and the specific watershed. Recovery rates can be affected by barriers to migration especially between source populations (Detenbeck et al. 1992) and the level of disturbance and the natural tolerance of a species. Even when the natural habitat might be available the recovery rate is also strongly affected by the local community structure with faster recovery when there is decreased predation and lowered competition. These factors allow a recovering population to get a better foothold in an ecosystem. Full recovery of an ecosystem is simply not possible, as there have been too many changes and the cost is too high, but different species have seen slow improvement. Although fixing these problems is a slow ongoing process, efforts continue to be made to better the ecosystem and protect the sensitive species found there. Most efforts are focused on improving water quality, species specific needs, and restocking of native populations.

Discovering specific species needs takes time and often multiple studies before an effective recovery strategy can be created. It also takes a long time to establish native breeding populations with stocking (Rakes et al. 1999). Stocking for four listed species started in 1986 at Abrams Creek in Tennessee for the Smoky Madtom (*Noturus baileyi*), Yellowfin Madtom (*Noturus flavipinnis*), Duskytail Darter (*Etheostoma percnurum*), and Spotfin Chub (*Erimonax monachus*) (Shute et al. 2005). The sudden decreased populations were blamed on the building of a dam in 1957 and the trout fishery. It was suspected that 64 species were extirpated from the stream; although, researchers felt that some species did return. Researchers believed the stream was mostly uncontaminated because it was located mostly within the Great Smoky Mountain National Park. It appeared that it would be a relatively easy recovery by reintroducing the lost fish species. Therefore, efforts focused mostly on simply restocking species with side efforts on improving water quality. It took the stocking of thousands of fish and almost 15 years for any of the introduced fish populations to start to stabilize. In general the fish communities seemed to be approaching native composition when compared to similar river systems. The improvement was attributed to the increased health of the overall ecosystem and improving threatened populations. This study in a lot of ways pioneered how to properly work on restocking fish. Further studies have improved on the outline that was set. Now stocking includes close examination of genetic similarities in order to preserve specialized alleles, like the recovery efforts of the Blotchside Logperch (*Percina burtoni*) (George et al. 2006). Intensive research on the genetic grouping of populations is necessary to maximize the effectiveness. This does increase recovery time and increases the cost of this method. Without this knowledge, local specialized genes could be lost, decreasing the specific adaptions the population has for an area. Specialized adaptations could be lost with a large influx of nonspecialized individuals, so although there would be more individuals they would be less adapted for the area. This would cause a sudden boom and then bust in the population as individuals without specialized adaptations died off leading to population decline. The recovery of the species mentioned previously and a few other species are detailed further in the next section.

Recovery Efforts

Vulnerable Fish Species

Blotchside Logperch *(Percina burtoni)*

Figure 2. The Blotchside Logperch seen above is a vulnerable fish species found in a very limited range in the Tennessee and Cumberland Drainages. (Photo by J.R. Shute.)

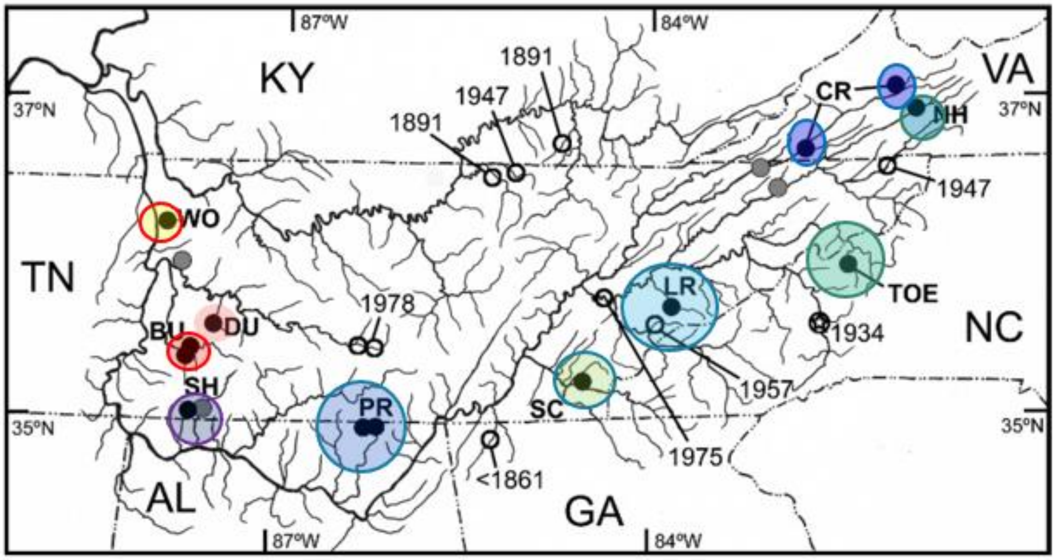

Figure 3. Map of the distribution of Blotchside Logperch in the Tennessee and Cumberland Drainages. Colored circles are located around current population that were sampled for genetic analysis. (Edited image, original within George et al. 2006.)

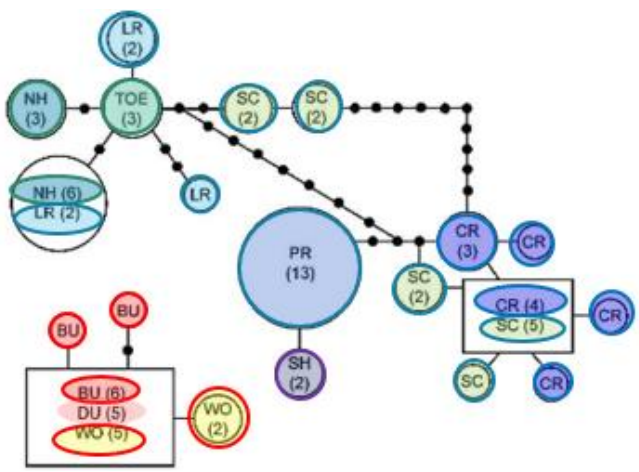

Figure 4. Shows the haplotype network from the genetic analysis of the Blotchside Logperch populations colors and names respond to populations labeled in Figure 3. The size of the figure reflects the frequency of the haplotype and the number the amount of individuals with the haplotype. Solid lines represent a mutation even and the small black circles represent a theoretical haplotype. Shows that location does not correlate with the amount of genetic similarity shared between populations. (Edited image, original within George et al. 2006.)

The Blotchside Logperch (Figure 2) has numerous isolated populations in the Tennessee and Cumberland Drainages and in order to maximize stocking effectiveness researchers wanted to understand which populations shared the closest genetics (George et al. 2006). Their populations show low genetic diversity and specialized alleles, which poses problems for researchers. After analyzing numerous specimens from each population (Figure 3), they were able to map out key differences and similarities between the populations. The genetic analysis involved the relationship of different groups of genes or haplotypes in the populations (Figure 4). . The figure demonstrates that there are two distinct clades, or two ancestral populations that led to distinct groups. This can be seen in the differentiation between the cool colors (TOE, LR, NH, SC, Cr, and PR) versus the warm colors (BU, DU, and WO). These clades have been separated for a long time and differ greatly from one another genetically. There were significant differences within the clades as well. The straight lines between each section represent a mutation, and the small black circles a hypothetical grouping of genes that represent the change. The greater amount of mutations between populations the greater they differ genetically from one another. Many populations within the larger clade differ significantly from one another and some show more genetic diversity than others, SC for example. The genetic analysis was extremely important because the population CR (shown in purple) and the closest neighboring population NH (shown in blue green) differ drastically from one another. When creating genetically diverse captive populations for restocking populations these groups should not be mixed. Although they are located geographically close to one another they have very different adaptations for their areas. On one hand, genetic diversity should be increased to ensure a more stable population, but introducing several new alleles into an area could lead to the decline in specialized traits that would lead to a later decline in the population. The conclusion then was to maximize diversity and minimize the loss of specialized traits by grouping together the most similar populations using these groups as a basis for captive breeding and restocking.

Threatened Fish Species

Yellowfin Madtom (*Noturus flavipinnis*)

Figure 5. Yellowfin Madtom seen above is a threatened fish species that was stocked in Abrams Creek.

(Photo by B. M. Burr)

The Yellowfin Madtom (Figure 5) is a threatened fish species found in the Tennessee and Cumberland Drainages, and is one of the four species that was stocked in Abrams Creek in 1986 (Shute et al. 2005). It was once widespread but was presumed extinct before three geographically isolated populations were found in the late-1970's and early-1980's. Figure 6 shows the relationship with stocked fish and the estimated population since stocking began in 2003. This species had a relatively high survivorship of reintroduced individuals and although it has not quite reached native population levels the population continues to increase.

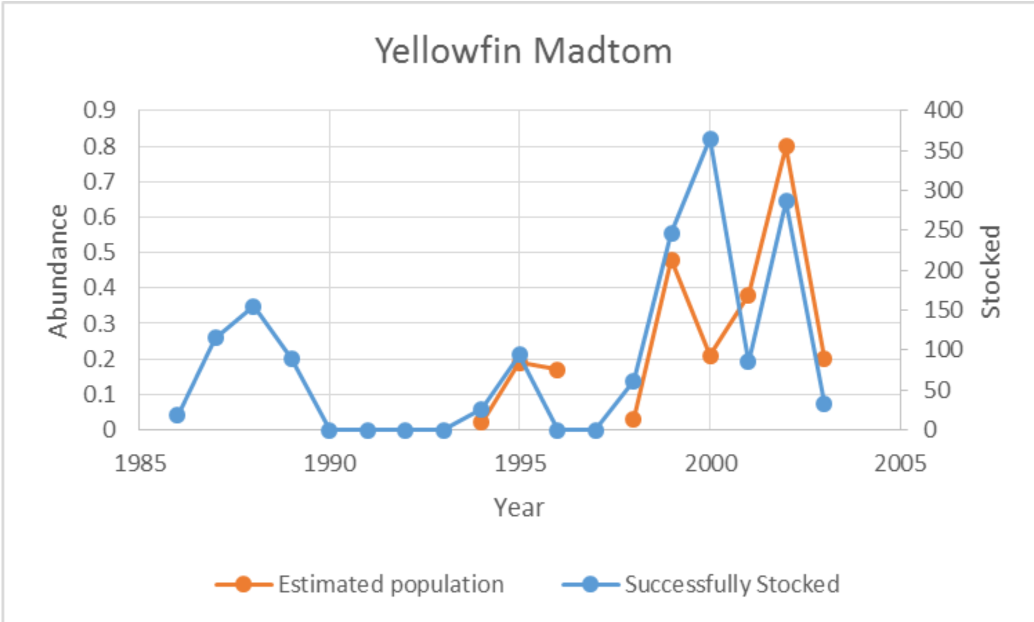

Figure 6. The graph of Yellowfin Madtom shows the relationship between successfully stocked fish and the estimated population. This figure shows an improvement of the yellowfin population from stocking efforts. (Graph based on table and graph estimates in Shute et al. 2005.)

Spotfin Chub (*Erimonax monachus*)

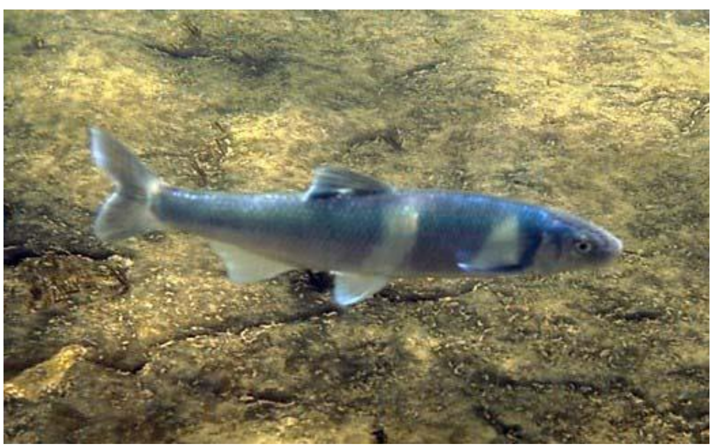

Figure 7. The Spotfin Chub is a threatened fish species. It is the only fish of the four reintroduced into Abrams Creek that did not show any recovery. (Photo from North Carolina Wildlife Resource Commission.)

The Spotfin Chub (Figure 7) is a threatened fish that has a relatively large range, the largest range of the four imperiled fish species that were stocked in Abrams Creek (Shute et al. 2005). Although it was successfully introduced back into some parts of the

Great Smoky Mountains National Park (Rakes et al 1999) the project started at Abrams Creek in 1986 was unsuccessful (Shute et al. 2005). Figure 8 demonstrates that stocking events did not help reintroduce this population. This could be due to a variety of reasons. Originally this species unlike the other three was simply stocked from a nearby population instead of a large genetically diverse captive breed population. Spotfin Chub's also tend to school with other species which makes them extremely hard to identify. As little information is currently known about this fish it is possible that the species moved to smaller tributaries and have stable populations in areas not surveyed. It also thought that the Spotfin Chub needs more connectivity between larger and smaller river systems, and Abrams Creek cannot provide the connectivity or diverse habitat the species needs.

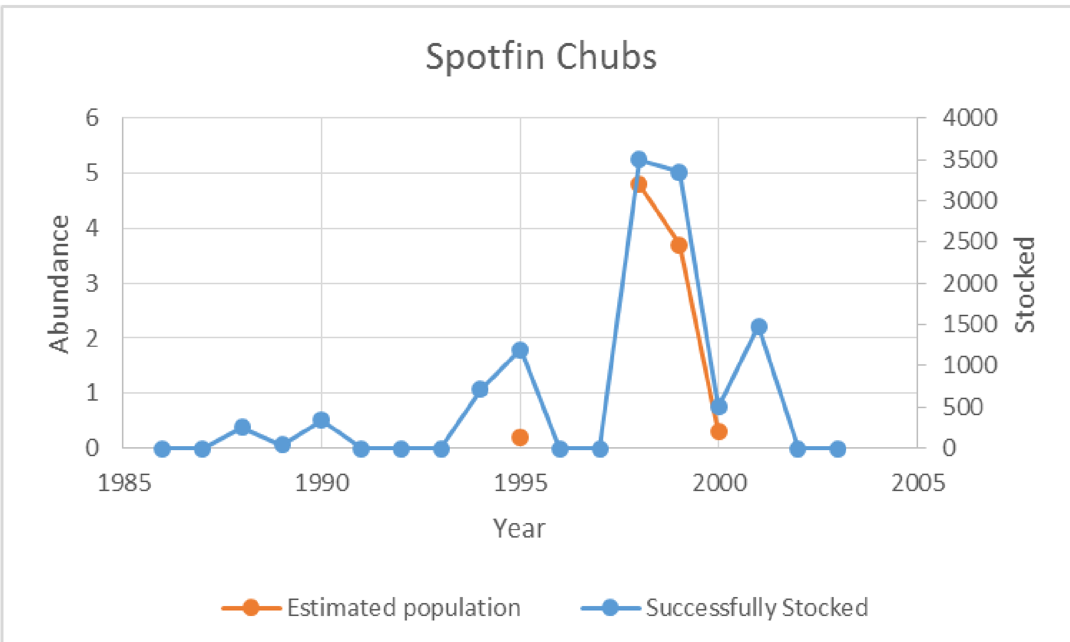

Figure 8. The graph of the Spotfin Chubs shows that stocking efforts were not able to help reestablish a population in Abrams Creek. (Graph based on table and graph estimates in Shute et al. 2005.)

Kentucky Arrow Darter *(Etheostoma spilotum)*

Figure 9. The Kentucky Arrow Darter a threatened fish found in small headwaters. (Photo by Dr. Matthew R. Thomas.)

The Kentucky Arrow Darter is a native darter mostly found in headwaters (Kentucky Department Fish and Wildlife 2013). It is a sensitive fish that mostly eats on mayflies, (Floyd 2014) which are a sensitive aquatic invertebrate themselves. It faces multiple problems including increased sediment, conductivity, bank erosion, logging wastewater, and runoff from the city and agriculture (Kentucky Department Fish and Wildlife 2013). The greatest threat it faces is coal mining pollution, specifically the acidification caused by mining pollution (Kentucky Department Fish and Wildlife 2013). They had a much greater range in 60's but are currently found in only half of their historic streams, and less than half of the specific sites where they were recorded (Floyd 2014). Recovery efforts focused on bank restoration and improving water quality. Many places saw increased populations; although, there were some areas that failed to show recovery. The largest failure led to an entire watershed to be abandoned due to lack of positive response so efforts could be focused on more recoverable streams. However this species still requires ongoing effort to continue to improve. Currently there are studies into tracking their movements in order to help establish connectivity. There is also a large movement to inform private land owners who were unaware that this species was found near their property.

Blackside Dace *(Chrosomus cumberlandensis)*

Figure 10. The Blackside Dace is threatened species that is the focus of numerous recovery projects. (Photo from Conservation Fisheries.)

The Blackside Dace is another species that has faced a lot of recovery projects and study in the last few years. Originally, the Blackside Dace was thought to be part of another species that looks similar (Black et al. 2013). It was eventually recognized as its own species and in 1987 was listed as threatened. Due to the lack of historical data its real native range is mostly unknown and the possibility that is has been introduced by people into new areas only adds to the confusion (Mattingly et al. 2013). This species is thought to be extirpated from at least 52 streams (Detar et al. 2013) and either missing or almost gone in 66% of its native reaches.

The problems the Blackside Dace faces includes sediment, which hurts spawning and foraging, nonnative predators, and food availability (Floyd et al. 2013). Unfortunately this sensitive species is found in areas with coal and timber resources which both increase sedimentation and temperature. One paper suggested that if mining and increased impairment continued there was a 33% chance that this species would face extinction within 5 years (McAbee et al. 2013). Areas have also suffered recent droughts, which caused further stress on the species, hindering recovery (Detar et al. 2013). The population is heavily fragmented and populations are a great distance from one another (Black et al. 2013) increasing the concern for local extinction (Detar et al. 2013).

Recovery projects worked to improve community structure and migration. Studies worked to monitor genetic diversity, climate change, and the effects of invading species (Mattingly et al. 2013). Although the recovery goal was not met for the Blackside Dace improvement was noted after the removal of migration blockades (Floyd et al. 2013). The project was revaluated and the project timeline extended to further increase the populations. One factor that was mentioned in the lower than projected recovery was the red breasted sunfish which preyed upon them. Continuing work on finding out important migration patterns led to tagging. Preliminary results in tagging found that Blackside Dace traveled large distances and more work is planned for movement corridors (Mattingly et al. 2013).

The Blackside Dace acts as an umbrella species for many other sensitive species, like the Rainbow Darter. Improving conditions for this species increases diversity, evenness and general fish abundance in the area (Floyd et al. 2013; Mattingly et al. 2013). Recovery efforts work on improving water quality and decreasing migration blockades, which improves the quality of the habitat for other species. Every recovery effort made to improve the population of Blackside Dace in turn helps many other sensitive species and improves the overall health of the ecosystem.

Endangered Fish Species

Duskytail Darter (*Etheostoma percnurum*)

Figure 11. The Duskytail Darter is an endangered fish species found in the Tennessee and Cumberland Drainages. (Image from WPClipart.)

The Duskytail Darter was once widespread in the Tennessee and Cumberland Drainages (Shute et al. 2005). When restocking started in 1986 at Abrams Creek the species was found in four geographical isolated populations. Figure 11 shows that the Duskytail Darter's population in Abrams Creek is stabilizing. During surveys, males can be seen defending rock nests, showing the population is successfully reproducing in the stream. Although the population has not reached natural abundance levels, it is hoped that with continued efforts their population will be able to reach recovery goals.

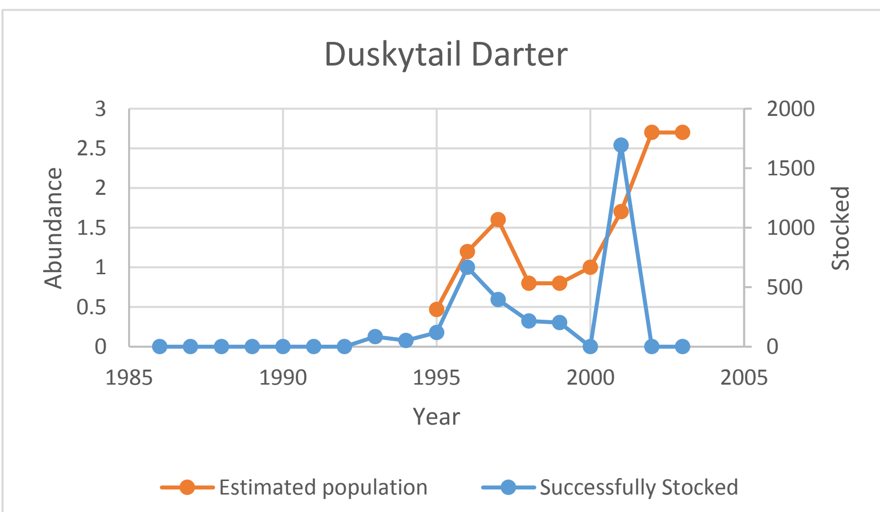

Figure 12. The graph on the Duskytail Darter shows that stocking efforts have been able to reestablish and improve the species population in Abrams Creek. (Graph based on table and graph estimates in Shute et al. 2005.)

Smoky Madtom (*Noturus baileyi*)

Figure 13. The Smoky Madtom is an endangered species that was successfully reintroduced into Abrams Creek. (Picture from Jessica Rager.)

The Smoky Madtom is an endangered species and was thought for a while to be extinct until a few populations were discovered (Shute et al. 2005). It was one of the fish stocked in Abrams Creek starting in 1986. Restocking efforts and population abundance of the Smoky Madtom is shown in Figure 14, which demonstrates that the populations is reestablishing due to restocking efforts. Of the four species stocked in Abrams Creek the Smoky Madtom is the only species thought to have reached its natural level of abundance. The Smoky Madtom has been seen defending nests while surveyors are present confirming that there is an established and reproductive population.

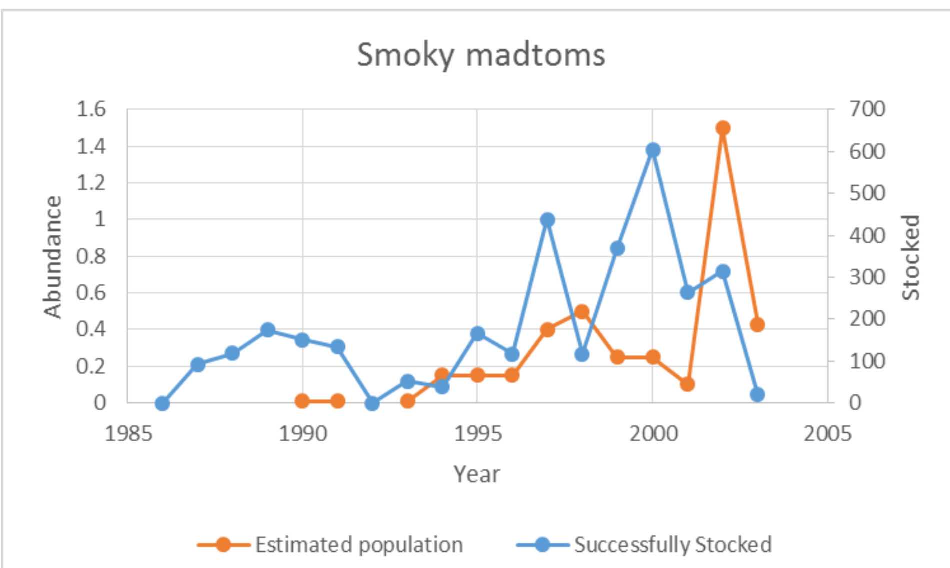

Figure 14. The graph of Smoky Madtoms shows that stocking efforts were able to successfully reestablish a population in Abrams Creek. (Graph based on table and graph estimates in Shute et al. 2005.)

Conclusions

The Southern Appalachian area is a unique and threatened ecosystem that many organizations are working to restore and protect. The greatest threats are from habitat degradation, hydrological modifications, and fragmentation. Species recovery is complex and slow, with multiple factors involved. Understandably water quality and specific habitat needs have to be available for a species before it can recover or reestablish in an area. Efforts like restocking, opening migration corridors, and decreasing invasive species though will increase the rate of recovery and increase the chances of a obtaining a sustainable population. In the species that were successfully reintroduced in Abrams Creek the outcome was contributed to numerous factors (Shute et al. 2005). Such as, the amount of diversity in captive breed population and restoration efforts. By the end of the project researchers had identified current problems and new goals. Although there had been efforts to improve habitat quality it was realized that habitat degradation and agricultural runoff was causing hindrance in species recover. Further projects will then be focused on improving habitat quality by restoring edge vegetation and lowering cattle input. There will be a greater focus on educating the public. In particular, the education of farmers about the importance of keeping their cattle out of streams. The importance of educating the public cannot be understated. For example, many of these fish species in Abrams Creek use rocks to nest and people were building structures or rocks dams, which has been shown to dramatically decline numerous species populations. Part of the success of the reintroduced fish species into Abrams Creed was attributed to the efforts of informing people about the native fish in the stream.

In this case knowing is half the battle. Education is a huge step in people understanding and bringing about change. The people that motivate the changes and management goals are the stakeholders. These stakeholders are the people that are invested in the resource such as people in the community, campers, hikers, commercial fisheries, or recreational fishermen. Furthermore, many vulnerable species can be found on private land and people do not know the vast harm they could unknowingly be doing (Burr 1980). Knowing about this problem and spreading this knowledge helps raise awareness on the native diversity and vulnerability of native populations. To further the cause there are multiple programs and volunteer opportunities to assist in recovery as well as the option to adopt-a-watershed (Shute). The National Wildlife Federation takes donations on restoring the Appalachian Rivers (Monroe 2012). The Appalachian Landscape Conservation Cooperation (LCC) Conservation Planning Atlas (CPA) offers a platform for sharing scientific data and getting involved.

Bibliography

Aarts, B., F. Van Den Brink, and P. Nienhuis 2003. Habitat loss as the main cause of the slow recovery of fish faunas of regulated large rivers in Europe: the transversal floodplain gradient. River Research and Applications 20:3-23.

Black, T., B. Jones, and H. Mattingly. 2013. Development and validation of habitat models for the threatened Blackside Dace, Chrosomus cumberlandensis, at two spatial scales. Southeastern Naturalist 12(4): 27-48.

Burr, B. 1980. A distributional checklist of the fishes of Kentucky. Brimleyana 3: 53-84.

Butler, R. 2002. Imperiled Fishes of the Lower Tennessee Cumberland Ecosystem, with Emphasis on the Non-Federally Listed Fauna. U.S. Fish and Wildlife Service [PDF]. http://www.sefishescouncil.org/articles_abstracts/ltcfishreport.pdf

Carey, D. 1992. Water quality in the Kentucky River Basin. Kentucky Geological Survey.

Cucherousset, J., and J. Olden. 2011. Ecological impacts of nonnative freshwater fishes. Fisheries 36(5): 215-230.

Detar, J., T. Black, and H. Mattingly. 2013. Population densities of the threatened blackside dace, Chrosomus cumberlandensis, in Kentucky and Tennessee. Southeastern Naturalist 12(4):6-26.

Detenbeck, N., P. Devore, G. Niemi, A. Lima. 1992. Recovery of temperate-stream fish communities from disturbance: a review of case studies and synthesis of theory. Environmental Management 16(1): 33-53.

DeVivo, J. 1995. Impact of Introduced Red Shiners, Cyprinella lutrensis, on stream fishes near Atlanta, Georgia. Proceedings of the 1995 Georgia Water Resources Conference: 95-98.

Fausch, K., C. Torgersen, C. Baxter, and H. Li. 2002. Landscapes to riverscapes: bridging the gap between research and conservation of stream fishes a continuous view of the river is needed to understand how processes interacting among scales set the context for stream fishes and their habitat. BioScience 52(6): 483-498.

Floyd, M. 2014. Range-Wide Conservation Strategy for the Kentucky Arrow Darter (Etheostoma spilotum Gilbert).

Floyd, M., S. Harrel, A. Parola, C. Hansen, J. Harrel, and D. Merrill. 2013. Restoration of Stream Habitat for Blackside Dace, Chrosomus cumberlandensis, in Mill Branch, Knox County, Kentucky. Southeastern Naturalist 12(4):129-142

Freund, J., and J. Petty. 2007. Response of fish and macroinvertebrate bioassessment indices to water chemistry in a mined Appalachian watershed. Environmental Management. 39(5): 707-720.

George, A., D. Neely, R. Mayden. 2006. Conservation Genetics of an Imperiled Riverine Fish from Eastern North America, the Blotchside Logperch, Percina Burtoni (Teleostei: Percidae). The American Society of Ichthyologists and Herpetologists (4): 585-594.

George, A., J. Caldieraro, K. Chartrand, and R. Mayden. 2003. Population Genetics of the Blue Shiner, Cyprinella caerulea. Southeastern Naturalist 16: 637-650.

Georgia Invasive Species Task Force. Introduction to Invasive Species. https://www.gainvasives.org/what-is/introduction-to-invasive-species/

Haag, W. 2015. The Hidden and Imperiled Gems of Kentucky's Rivers. Kentucky Woodlands Magazine 10: 16-18.

Hassan-Williams, C., T. Bonner. 2013. Cyprinella lutrensis. In Texas Freshwater Fishes, Texas State University.

Hughes, R. 2015. Recreational fisheries in the USA: economics, management strategies, and ecological threats. Fisheries Science 81(1): 1-9.

Jelks, H., S. Walsh, N. Burkhead, S. Contreras-Balderas, E. Diaz-Pardo, D. Hendrickson, J. Lyons, N. Mandrak, F. McCormick, J. Nelson, S. Platania, B. Porter, C.

Renaud, J. Schmitter-Soto, E. Taylor, & M. Warren. 2008. Conservation Status of Imperiled North American Freshwater and Diadromous Fishes. Fisheries 33(8): 307-304.

Joice, T. 2014. State report shows continued water quality concerns. Kentucky Waterway Alliance.

Jones, E., G. Helfman, J.Harper, and P. Bolstad. 1999. Effects of Riparian Forest Removal on Fish Assemblages in Southern Appalachian Streams. Conservation Biology 13(6): 1454-1465.

Kanehl, P., J. Lyons & J. Nelson. 1997. Changes in the Habitat and Fish Community of the Milwaukee River, Wisconsin, Following Removal of the Woolen Mills Dam. North American Journal of Fisheries Management 17: 387-400.

Kentucky Department of Fish and Wildlife. 2013. Kentucky's Species of Greatest Conservation Need and their statuses. PDF http://fw.ky.gov/WAP/Documents/fish_update.pdf

KYDEP 2012. Kentucky Division of Water 2012 Annual Report. Kentucky Energy and Environment Cabinet. PDF http://water.ky.gov/Documents/AnnualReports/DOW%202012%20Annual%20Report.pdf

KYDEP. 2015. Many of Kentucky’s streams showing improved water quality; New exceptional waters identified. Kentucky Energy and Environment Cabinet.

Liermann, C., C. Nilsson, J. Robertson, and R. Ng 2012. Implications of dam obstruction for global freshwater fish diversity. Bioscience 62: 539-548.

Lotrich, V. 1973. Growth, Production, and Community Composition of Fishes Inhabiting a First- , Second- , and Third- Order Stream of Eastern Kentucky. Ecological Monographs 43(3): 377-397.

Mahala, M.. 2008. Kentucky Aquatic Nuisance Species Management Plan. Kentucky Department of Fish and Wildlife.

Marks, J. 2010. Effects of flow restoration and exotic species removal on recovery of native fish: Lessons from a dam decommissioning. Restoration Ecology, 18: 934-943.

Mattingly, H., and M. Floyd. 2013. Conclusions and Future Directions: Ecology and Conservation of the Threatened Blackside Dace, Chrosomus cumberlandensis. Southeastern Naturalist 12(4):181-188.

McAbee, K., N. Nibbelink, T. Johnson, and H. Mattingly. 2013. Informing recovery management of the threatened Blackside Dace, Chrosomus cumberlandensis, using a Bayesian-belief network model. Southeastern Naturalist 12(4):143-161.

McCormick, F., G. Contreras, and S. Johnson. 2010. Effects of Nonindigenous Invasive Species on Water Quality and Quantity. A Dynamic Invasive Species Research Vision: Opportunities and Priorities: 111-120.

Merovich, G., and J. Petty 2007. Interactive effects of multiple stressors and restoration priorities in a mined Appalachian watershed. Hydrobiologia 575(1): 13-31.

Monroe, J.. 2012. Appalachian Rivers: Streaming with Life: Researchers find that Appalachia's rivers and streams are biological hot spots rich with aquatic species. National Wildlife Federation. https://www.nwf.org/News-and-Magazines/National-Wildlife/Animals/Archives/2012/Appalachian-Rivers.aspx

Nico, L., P. Fuller, and M. Neilson. 2017. Cyprinella lutrensis. USGS Nonindigenous Aquatic Species Database, Gainesville, FL. https://nas.er.usgs.gov/queries/factsheet.aspx?SpeciesID=518

Pegg, M., and J. Chick. 2010. Habitat Improvement in Altered Systems. In W. Hubert and M. Quist (Ed.), Inland Fisheries Management in North America, 3:295-321. American Fisheries Society.

Rahel, F. 2000. Homogenization of fish faunas across the United States. Science 288(5467): 854-856.

Rakes, P., J. Shute, and P. Shute. 1999. Reproductive behavior, captive breeding, and restoration ecology of endangered fishes. Environmental Biology of Fishes 55(1-2): 31-42.

Ryon, M. 2011. Recovery of Fish Communities in a Warm Water Stream Following Pollution Abatement. Environmental Management, 47(6): 1096-1111.

Scott, M., & G. Helfman. 2001. Native Invasions, Homogenization, and the Mismeasure of Integrity of Fish Assemblages, Fisheries, 26(11): 6-15.

Shute, J., J.Rakes, P. Shute. 2005. Reintroduction of Four Imperiled Fishes in Abrams Creek, Tennessee. Southeastern Naturalist 4: 93-110.

Shute, P., R. Biggins, and R. Butler. 1994. Management and conservation of rare aquatic resources: a historical perspective and recommendations for incorporating ecosystem management. Aquatic fauna in peril: the southeastern perspective: 445-466.

Stanley, E., M. Doyle. 2003. Trading off: the ecological effects of dam removal. Frontiers in Ecology and the Environment 1: 15-22.

Stein, B. A. Laurenzi, C. Vaughn. et al. 1998. Rivers of Life: Critical Watersheds for Protecting Freshwater Diversity. Edited L. Master, S. Flack, and B. Stein. Nature Conservancy. Arlington, Virginia.

Strayer, D., and D. Dudgeon. 2010. Freshwater biodiversity conservation: recent progress and future challenges. Journal of the North American Benthological Society, 29:344-358.

Sutherland, A., J. Meyer, and E. Gardiner. 2002. Effects of land cover on sediment regime and fish assemblage structure in four southern Appalachian streams. Freshwater Biology 47(9): 1791-1805.

Tullos, D., M. Collins, J. Bellmore, et al. 2016. Synthesis of Common Management Concerns Associated with Dam Removal. Journal of the American Water Resources Association 52: 1179-1206.

Walters, D., M. Freeman, D. Leigh, B. Freeman, C. Pringle. 2005. Urbanization Effects on Fishes and Habitat Quality in a Southern Piedmont River Basin. American Fisheries Society Symposium: 2-17.

Warren, M., B. Burr, S. Walsh, H. Bart, R. Cashner , D. Etnier. 2000. Diversity, Distribution, and Conservation Status of the Native Freshwater Fishes of the Southern United States. Fisheries 25 (10): 7-31.

Weaver, L., G. Garman. 1994. Urbanization of a Watershed and Historical Changes in a Stream Fish Assemblage. Transactions of the American Fisheries Society 123 (2): 162-172.

Yarnell, S. 1998. The Southern Appalachians: A History of the Landscape. Southern Research Station, Asheville. PDF. https://www.srs.fs.usda.gov/pubs/gtr/gtr_srs018.pdf

Image Bibliography

Burr, B. Yellowfin Madtom. Florida Museum of Natural History. Shown as Figure 5. https://www.floridamuseum.ufl.edu/catfish/ictaluridae/yellowfinmadtom.htm

Conservation Fisheries. The Blackside Dace. Conservation Fisheries. Shown as Figure 9. https://www.conservationfisheries.org/blackside-dace

George, A., D. Neely, R. Mayden. 2006. Conservation Genetics of an Imperiled Riverine Fish from Eastern North America, the Blotchside Logperch, Percina Burtoni (Teleostei: Percidae). Figure 1. The American Society of Ichthyologists and Herpetologists (4): 586. Shown as Figure 3.

George, A., D. Neely, R. Mayden. 2006. Conservation Genetics of an Imperiled Riverine Fish from Eastern North America, the Blotchside Logperch, Percina Burtoni (Teleostei: Percidae). Figure 3. The American Society of Ichthyologists and Herpetologists (4): 589. Shown as Figure 4.

North Carolina Wildlife Resource Commission. Spotfin Chub. Shown as Figure 6. http://www.ncwildlife.org/Learning/Species/Fish/Spotfin-Chub

Rager, J., The Smoky Madtom. Shown as Figure 13. http://smoky-madtom.blogspot.com/

Shute, J. Blotchside logpearch. Conservation Fisheries Inc. Show as Figure 2. http://www.arkive.org/blotchside-logperch/percina-burtoni/

Thomas, M. Dr., Kentucky Arrow Darter. Kentucky Department of Fish and Wildlife Resources. Shown as Figure 8. https://www.biologicaldiversity.org/news/press_releases/2016/kentucky-arrow-darter-10-04-2016.html

WPClipart, The Duskytail. WPClipart. Shown as Figure 10. https://www.wpclipart.com/animals/aquatic/fish/D/darter/Duskytail_darter__Etheostoma_percnurum.jpg.html