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Habitat Selection and Spatiotemporal Patterns of Movement in a Fluvial Population of White Sucker (*Catostomus commersoni*)

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I know a lot of people have been mentioned and I am sure I missed a few others. I have made it to this point with lots of assistance and no words will ever be able to express the magnitude of thanks that I owe to so many people. But in case you are reading this, for whatever reason, thanks.

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Abstract

The responses of fishes to ongoing stream restoration projects throughout the southeastern United States are largely unknown. White suckers are thought to be an important competitor with brook trout, a target restoration species, and their response to canopy cover could be an important predictor of restoration success. Because stream restoration can be lengthy, I simulated future canopy cover by artificially shading five pools (80 to 90%). I then measured the short-term (30 days) responses of white sucker populations in control (un-shaded) and treatment (shaded) pools. After 30 days, white sucker densities (#/100m^2) remained similar in un-shaded (control) pools but were significantly reduced in artificially shaded pools. Recapture rate of tagged white suckers was significantly different between un-shaded (42%) and shaded pools (17%). The percentage change in density was not significantly different between un-shaded and shaded pools after 30 days. Mean total length of captured white suckers was similar among groups and proved not to be a confounding factor. I also followed a small group of white suckers using radio transmitters to monitor non-spawning movements. Radio tagged white suckers were found to be predominantly sedentary with a few long-distance movements interspersed. The largest movement observed for a white sucker in this study was 1,300 m upstream. A preference was not found for either upstream or downstream movement. Estimates of average daily movement for 24 radio tagged white suckers averaged 0 m with no significant differences in average daily movement among the 24 fish. A significant positive correlation was found between daily white sucker movement and average daily stream flow. Instream PIT tag antennas recorded 455 white sucker movements. Movements after sunset accounted for 92% of all records. This project

gathered insightful knowledge of the preferred habitat and movement tendencies of a fluvial population of white sucker. As riparian canopy matures along this restored stream white suckers may chose to leave the study in search of un-shaded pools. A large exodus of white suckers may alter existing fish communities in the study area. The magnitude and direction of these alterations are unknown and monitoring is necessary and will be continued.

Introduction

Human population increases and expansion throughout the landscape have increased aquatic habitat degradation and fragmentation. Throughout the United States many catchments have been impacted by the conversion of native vegetation to agriculture and urban/suburban development (Johnson et al. 2007). Most of the catchments in the mid-Atlantic United States now occur as spatially diverse mosaics of different land-cover types variously affected by human use (Johnson et al. 2007). The need for restoring these degraded ecosystems is great and the United States has already spent billions of dollars on restoration projects (Palmer et al. 2003; Malakoff 2004; Palmer et al. 2005). Restoration of riparian habitats has been widely used to improve ecological condition in streams (Jansson et al. 2007) by recreating complex ecosystems from more simple degraded states (Bradshaw 1983; Jansson et al. 2007).

The Eastern Brook Trout Joint Venture (EBTJV) is a unique partnership among state and federal agencies, regional and local governments, businesses, conservation organizations, academia, scientific societies, and private citizens seeking to protect, restore, and enhance aquatic habitat throughout the range of the eastern brook trout (*Salvelinus fontinalis*). Data produced by the EBTJV identified 1,451 subwatersheds throughout the eastern United States with historically self-sustaining brook trout populations that have been extirpated (EBTJV 2006). The Smith Creek Restoration Project (Rockingham County, VA) is one of the EBTJV’s first attempts at restoration. Monitoring of changes to both terrestrial and aquatic communities will provide insight as to the extent and direction of ecosystem changes resulting from these restoration efforts.

The goal of the Smith Creek Restoration Project is to restore native brook trout to a location they historically inhabited.

I looked in detail at one species of fish inhabiting Smith Creek, the white sucker (*Catostomus commersoni*), which is a potential competitor with brook trout. Understanding the ecology of species found in association with brook trout will improve the ability to restore extirpated populations. The key objectives of this research were: 1) to evaluate the short-term response of white sucker densities and movement to artificially simulated hardwood canopy cover; and 2) evaluate movement and habitat use of white suckers under existing conditions. In essence, I wanted to explore potential changes in white sucker population dynamics that may be forthcoming 20+ years down the road as trees grow, the stream becomes shaded, and water temperatures decrease.

Study Area

Smith Creek is a third order stream within the 5,539 ha Smith Creek subwatershed (Hydrologic Unit Code 510172) in Rockingham County, Virginia. The majority of land use classifications in the subwatershed are either forest (61%) or agriculture (38%) (Thieling 2006). Land uses in riparian areas (100 m each side of stream) within the subwatershed are also predominately forest (56%) and agriculture (42%). My 3.14 km study reach differs from the subwatershed in that it has few riparian trees (113 trees greater than 10 cm in diameter breast height) and is predominately heavily grazed pasture. The subwatershed historically sustained a native brook trout population. Past agricultural practices along Smith Creek have eliminated riparian forests increasing stream temperature and sedimentation in the subwatershed. These habitat changes have altered native fish assemblages.

The privately owned property of Rainbow Hill Farms, on which the study takes place, has been used for agricultural purposes for roughly 225 years. The most recent agricultural use for this property was the grazing of cattle. The cattle had free access to all parts of the property including Smith Creek which flows northward roughly through the center of the property. Stream banks were badly eroded and the stream bottom was heavily impacted by sediment (Figures 1.1 and 1.2).

Figure 1.1. Rainbow Hill Farms Restoration Area 1. A picture taken prior to restoration work. Pasture is heavily grazed and very little riparian vegetation is found near the stream.

Figure 1.2. Rainbow Hill Farms Restoration Area 2. A second picture taken prior to restoration work. Stream banks were badly eroded and extensive sedimentation was ongoing.

In 2005 restoration efforts began on Rainbow Hill Farms using funding from the Conservation Reserve Enhancement Program (CREP) and the EBTJV. Cattle were removed from the property and 65 acres of the floodplain were planted with a total of 12,561 saplings of six different species (white ash *Fraxinus americana*, northern red oak *Quercus rubra*, hackberry *Celtis occidentalis*, red maple *Acer rubrum*, smooth alder *Alnus serrulata*, and American sycamore *Platanus occidentalis*). Restoration efforts on the Rainbow Hill Farms property will return riparian and upland pastures to bottomland and upland forests. When restored Rainbow Hill Farms will provide a connection to the small isolated brook trout population upstream in Mountain Run on protected National Forest land (Figure 1.3).

My study reach on the Rainbow Hills Farm property averaged 7.1 meters in width (range 3.8 to 12.3 m). Discharge averaged 4.3 cfs during the study (range 2.4 to 34.3 cfs) (6 June 2007 to 26 July 2007), with no bankful events (flows ≥ 441 cfs). Stream temperature ranged from 13.9 to 23.6 and averaged 18.6 C during the study (6 June 2007 to 26 July 2007. A map of the study area and the location of the study pools and two instream PIT tag antennas is found in Figure 1.4.

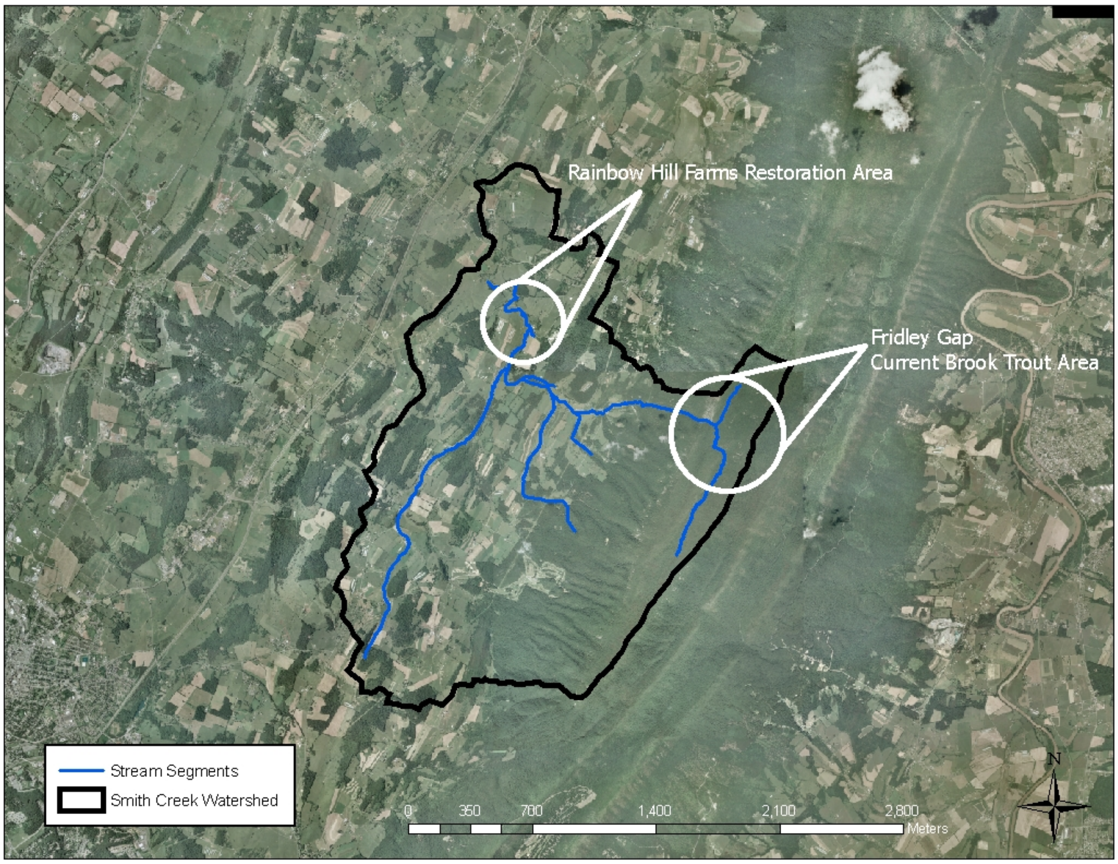


Figure 1.3. Aerial Map of the Smith Creek Subwatershed. Rainbow Hill Farms restoration area is in a part of the subwatershed used extensively for agriculture. Fridley Gap is contained within USDA National Forest property and is protected from agricultural impacts. It currently supports a naturally reproducing brook trout population.

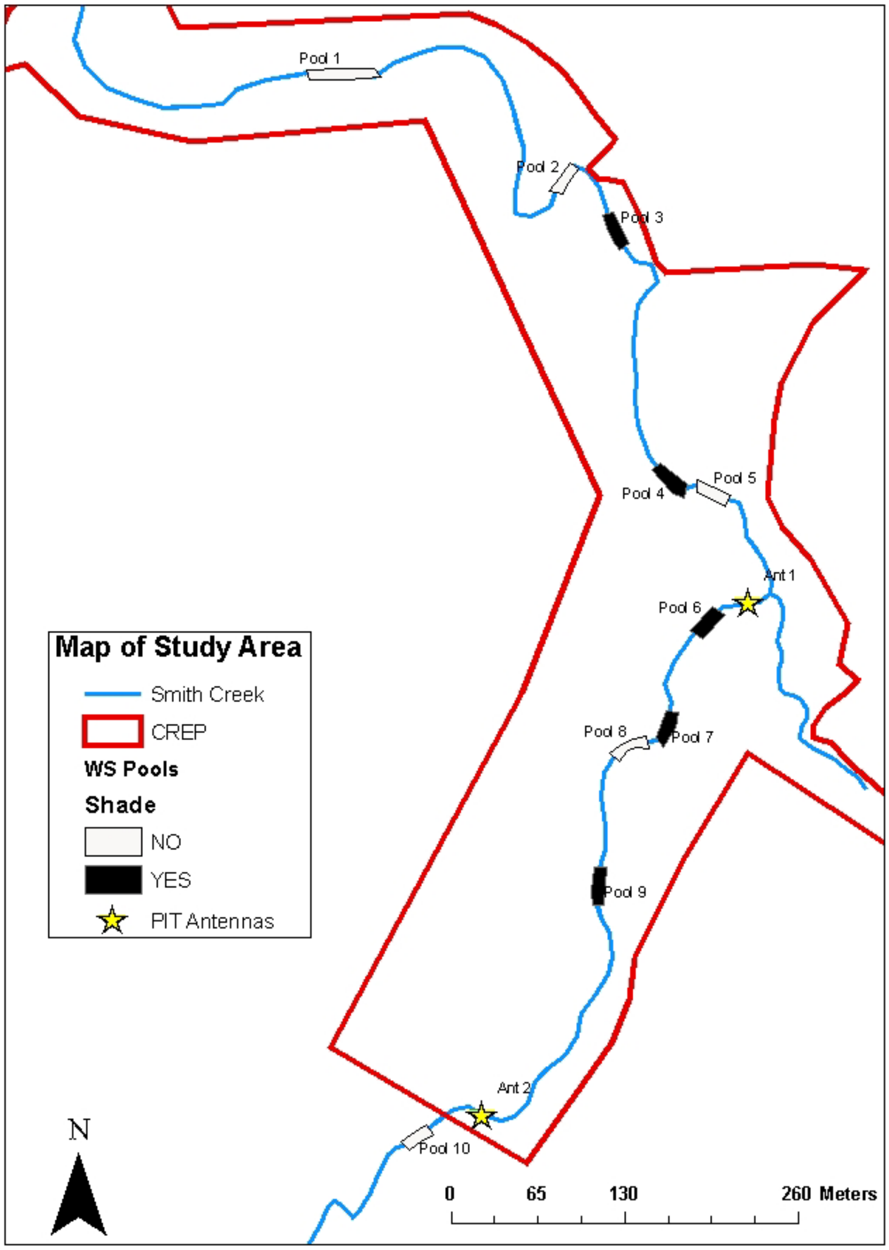


Figure 1.4. Map of Study Area. Study pools are categorized as control (un-shade) or treatment (shade). Location of an instream PIT tag antenna is represented with a star.

Chapter One: White Sucker Response to Artificial Shade

Life History Characteristics

The white sucker is one of the most widely distributed non-game fish in North America. The range of the white sucker stretches north from Arkansas up through Maine into Canada and west to eastern Idaho but not into the Pacific Northwest. It inhabits both lotic and lentic water bodies ranging from headwater streams to large lakes, but typically occurs in small to medium-sized clear, cool streams or rivers (Wakefield and Beckman 2005). The white sucker is potadromous, has a relatively high fecundity, and is an iteroparous early spring spawner (Winemiller and Ross 1992). Since lake dwelling white sucker have received most of the attention given to the species, there is a vast amount of knowledge pertaining to adfluvial populations. Previous literature reports great variation in life history traits such as longevity (7-23 years), maximum length (350-569 mm), age at maturity (2-10 years), and fecundity (2,000-139,000 eggs) (Scott and Crossman 1973).

Researchers have observed much of the spawning migration and the spawning act itself to take place at night (Raney and Webster 1942; Raney 1943; Breder and Rosen 1966; Corbett and Powles 1983). This behavior may be a survival technique that has evolved over time to avoid predation. Barton's (1980) observations facilitate this assumption because he found spawning suckers to be vulnerable to avian and mammalian predation in the clear, shallow waters of the spawning area. Interestingly, Koenst and Smith (1982) found evidence suggesting light intensity may affect growth. When they reared white suckers under shaded conditions they found an average increase in growth of 43% over those white suckers reared in un-shaded conditions. These results suggest that white suckers may need overhead cover or shade to reduce physiological stress and thus increase growth. A shade preference has not been demonstrated for white suckers in a natural setting; therefore, I evaluated the response of white suckers to artificial canopy cover mimicking a mature hardwood forest, which may elucidate a behavioral preference of white suckers for shaded or un-shaded pools.

Methods

An inventory of all riffle, runs, and pools in a 3.14 km segment of Smith Creek was completed. Only pools with less than 15% overhead shade, determined by a spherical densitometer, and less than 5% in stream cover, determined by visual estimation, were considered for this study. After quantification of the above criteria only ten pools were available on the Rainbow Hill Farms property. The ten chosen pools then were further evaluated based on channel width, average thalweg depth, and maximum depth. Study pools were an average of 8.2 m in width (range 6.8 to 12.3 m). Maximum depth in study pools ranged from 0.6 to 1.1 m, while average depth ranged from 0.5 to 0.9 m. The average area of selected pools was 242.1 m^2 (range 431.7 to 165.2 m^2) (Figure 1.5).

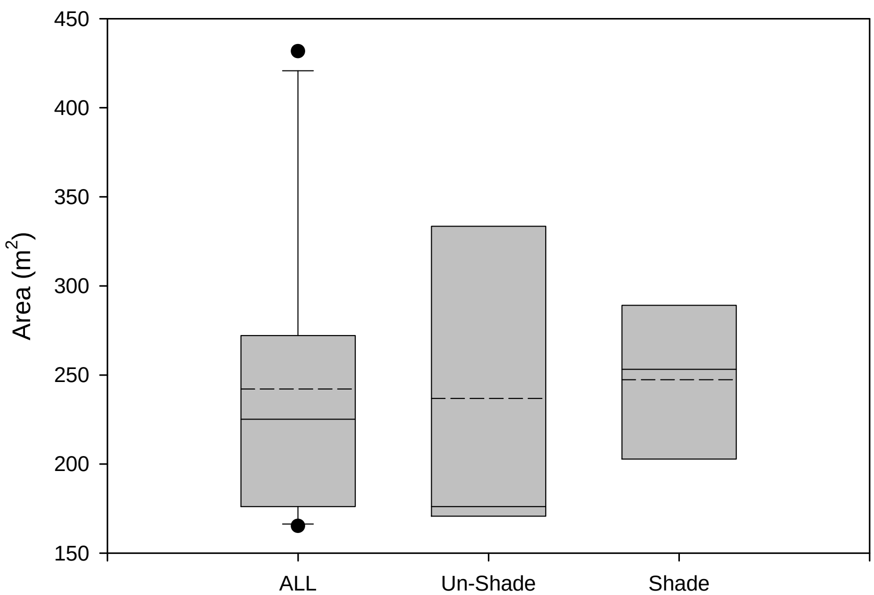


Figure 1.5. Box Plots of Average Area of Study Pools. The ten study pools are grouped together and broken down into their respective treatment group (un-shade and shade). Solid lines represent the median value, and dashed lines represent the mean value for each plot.

Temperature loggers (HOBO Water Temp Pro v2, Onset Computer Corporation, Bourne, MA) were placed in the water at the upstream and downstream end of each pool and set to record every thirty minutes. Temperature loggers were attached to a brick and sunk to the stream bed. A wire was also run to a fixed object on the bank to make sure the loggers were not washed away by a high flow event. Temperature loggers were used to monitor natural stream temperature changes within each pool and those resulting from the addition of a shade canopy. Temperature loggers remained in the stream as long as the shade canopy was in use. At the end of the shade period loggers were removed, downloaded and calibrated. Calibration consisted of placing the loggers in an ice bath for at least 24 hours. After the ice bath, data was downloaded and drift was taken into account. Paired t-tests were used to compare mean daily temperatures for all study pools before and after shade treatment using $\alpha \leq 0.05$ to denote significance.

After classification each pool was randomly assigned to either a control or treatment group. The control group (un-shade $n = 5$) remained un-shaded throughout the experiment. The treatment group (shade $n = 5$) was artificially shaded (Figure 1.4).

Initial fish sampling in control and treatment pools took place from 6 June 2007 to 12 June 2007. Block nets were set at the upstream and downstream bounds of each pool to control fish movement during sampling. A three to four-pass depletion population estimate (Zippin 1958) was conducted for each pool. Two battery powered backpack electrofishing units (LR-24, Smith Root, Inc., Vancouver, WA) were used for sampling. Sampling consisted of two teams of three people each. For each team, one person carried out the electrofishing and held a bucket. The other two team members wielded dip nets. After each pass, fishes were placed in separate live baskets in the stream, but outside of the sampling area, for holding until processing. All white suckers were sorted by total length (TL, mm) and separated from other captured fish. Two groups of white suckers were created, < 225 mm and ≥ 225 mm. Captured white suckers were anesthetized with MS-222 (tricaine methanesulfonate), and given a left pelvic fin clip in Pools 1-5, or a right pelvic fin clip in Pools 6-10. Each white sucker was implanted with a PIT (Passive Integrated Transponder) tag (12.5x2.07 mm, 0.102 g, 134.2 kHz ISO, Biomark, Inc., Boise, ID). PIT tags were injected inside the peritoneal cavity just anterior to the pelvic girdle with a 12-gauge hypodermic needle attached to a syringe (Roghair and Dolloff 2005). Each tag had a unique 15-digit alphanumeric code that allowed individual fish to be identified and followed through time (Gibbons and Andrews 2004). White suckers < 225 mm then were allowed to fully recover in live baskets in the stream prior to release near the point of capture. White suckers ≥ 225 mm were processed in a similar manner except that four fish from each pool in this group were randomly selected, using a random number table, to receive a radio transmitter. The four selected fish were held in 19 liter buckets with aerators until surgery. Concurrent with white sucker processing, technicians measured all other captured fishes to the nearest millimeter in total length, allowed them to recover and released them near the point of capture.

An attempt was made to manage short term behavioral modification resulting from electrofishing by allowing ten days after fish sampling in each study pool before artificial shading. A shade canopy was completed later by driving four inch wooden fence posts on both sides of the stream opposite of one another. The posts were placed 30 feet apart. High tensile wire was strung from one post to another across the stream in straight lines and at 45 degree angles to form an “x” for support (Figure 1.6). Shade cloth (90%)

was purchased from Pak Unlimited, Inc., (Cornelia, GA) in 6.5x18.3 m panels. Each panel was constructed with grommets spaced every 1.5 m around all four sides. Each panel was stretched lengthwise along the side of the stream and the top and bottom (short sides) were fastened to the high tensile wire with zip ties. Ropes were tied to the grommets at each of the four corners and in the middle of each side. We then pulled the ropes opposite of the side we attached the shade cloth to and stretched it across the wire and over the wetted width of the stream. The shade canopy was used to simulate a mature hardwood forest canopy providing approximately 80-90% overhead shade.

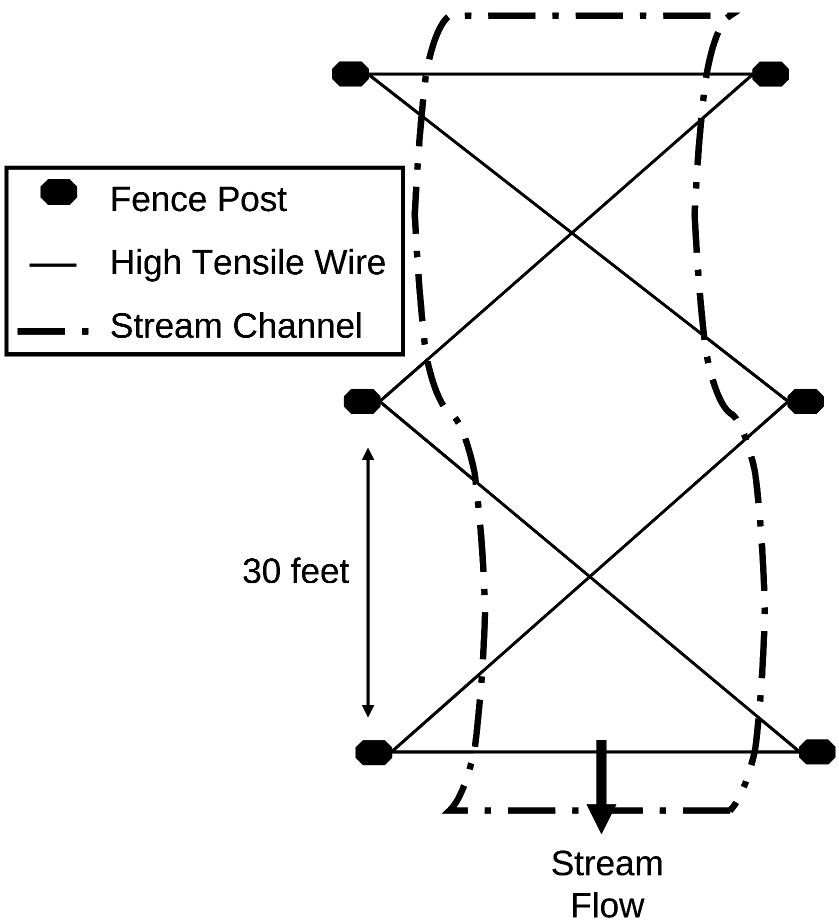


Figure 1.6. Diagram of Shade Canopy Support System. Diagram represents a single section of the support system stretching across the stream.

After 30 days the capture methods outlined previously were repeated in each study pool. All captured fish were measured, allowed to recover, and released near the point of capture. White suckers captured for the first time during the second sampling were not given a new tag or mark at this time. PIT tag numbers from previously tagged white suckers were recorded along with total length and recapture location.

Results

Water Temperature

There were no differences detected in mean daily water temperatures between un-shaded (19.5 C) and shaded pools (19.6 C) (Independent Samples t test, t = -0.726, df = 268, p = 0.468) during the study period. However, pools which were artificially shaded showed a reduction in the variability in water temperature change as it flowed through a pool (i.e. daily rate of change by area of each pool) (Figure 1.7).

White Sucker Density

A total of 703 white suckers were PIT tagged in the ten study pools over the course of this experiment. There were significant differences between white sucker population densities (#/100m^2) after 30 days of shading in treatment pools (Wilcoxon Signed Ranks Test, Z = -2.023, p = 0.043). Density declined in all shaded pools after 30 days. There were no significant differences between white sucker population densities (#/100m^2) after 30 days in un-shaded pools (Wilcoxon Signed Rank Test, Z = -0.135, p = 0.893). Densities both increased and decreased in un-shaded pools after 30 days. There were no significant differences in the percentage change in densities between un-shaded and shaded pools after 30 days (Mann Whitney U test, U = 21, p = 0.1) (Table 1.1). Although not significant (p = 0.1) the trend was for un-shaded pools to have less drastic values for percentage change in density after 30 days. The proportion of white suckers recaptured in un-shaded pools (146 / 344 = 42%) was significantly higher (Pearson's Chi-square, Chi = 29.18, df = 1, $p < 0.001$) than the proportion recaptured in shaded pools (62 / 359 = 17%). The proportion of white suckers that were found in the same un-shaded pool or another un-shaded pool (158 / 344 = 46%) was significantly different (Pearson's Chi-square, Chi = 28.74, $p < 0.001$) from the proportion of white suckers found in the same shaded pool or another shaded pool (70 / 359 = 19%) 30 days following initial tagging.

White Sucker Total Length

There was no difference in mean total length of all white suckers captured initially compared to all white suckers captured 30 days later (t-test, t = 0.701, df = 1,329, p = 0.483) (Figure 1.8). No difference was found between the mean total length of white suckers captured in un-shaded holes initially and after 30 days (t-test, t = 1.527, df = 769, p = 0.127) (Figure 1.9). Additionally, there was no significant difference found between the mean total length of white suckers found in treatment pools initially and those captured in treatment pools 30 days after artificial shading (t-test, t = -0.219, df = 558, p = 0.827) (Figure 1.10). Of the white suckers recaptured after 30 days, there was no significant difference in the mean total length of those found in the pool of initial tagging (stayers) and those found in a different study pool (movers) (t-test, t = -0.284, df = 246, p = 0.776) (Figure 1.11). Finally, no difference was found in the mean total length of recaptured white suckers moving upstream or downstream (t-test, t = -0.316, df = 44, p = 0.754) (Figure 1.12).

White Sucker Movement

There was no significant difference in the proportion of recaptured white suckers that migrated from an un-shaded pool initially into a shaded pool (13 / 344) or from a shaded pool initially into an un-shaded pool (22 / 359) (Pearson's Chi-square, Chi = 1.86, df = 1, p = 0.1731). The proportion of white suckers tagged initially in un-shaded pools that were recaptured in another study pool (18 / 344) was not significantly different from the proportion of white suckers tagged initially in a shaded pool that moved to another study pool (28 / 359) (Pearson's Chi-square, Chi = 1.661, df = 1, p = 0.197).

Table 1.1. White Sucker Density in Study Pools Before and After Treatment.

Group	Pool	#/100m^2 Before	#/100m^2 After	% Change
Un-shaded	1	32	56	71
	2	44	31	-30
	5	38	17	-56
	8	28	23	-16
	10	16	35	116
Shaded	3	45	18	-60
	4	3	2	-50
	6	36	27	-23
	7	28	17	-41
	9	53	8	-84

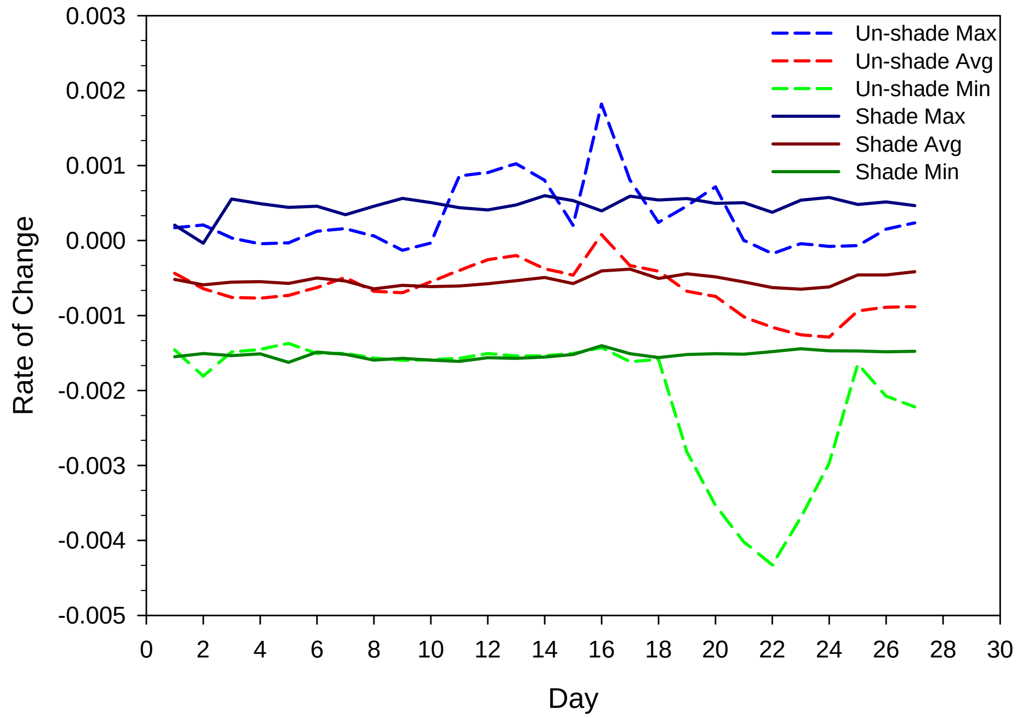


Figure 1.7. Average Daily Rate of Temperature Change by Area. Temperatures were combined by group for un-shaded and shaded pools. The blue line represents daily maximum temperatures, red represents daily average temperatures and green represents daily minimum temperatures. (Day 1 = 6/29/2007)

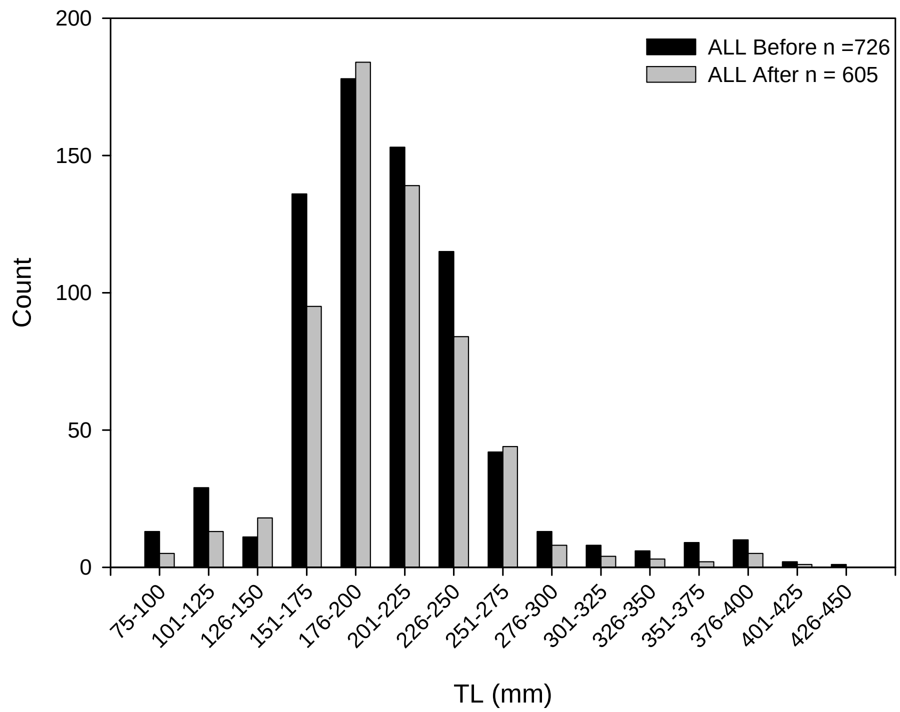


Figure 1.8. Length Frequency Histogram of ALL White Suckers Captured (Mean total length Before = 205 mm, and After = 204). Before data is from initial sampling, after data is 30 days following initial sampling.

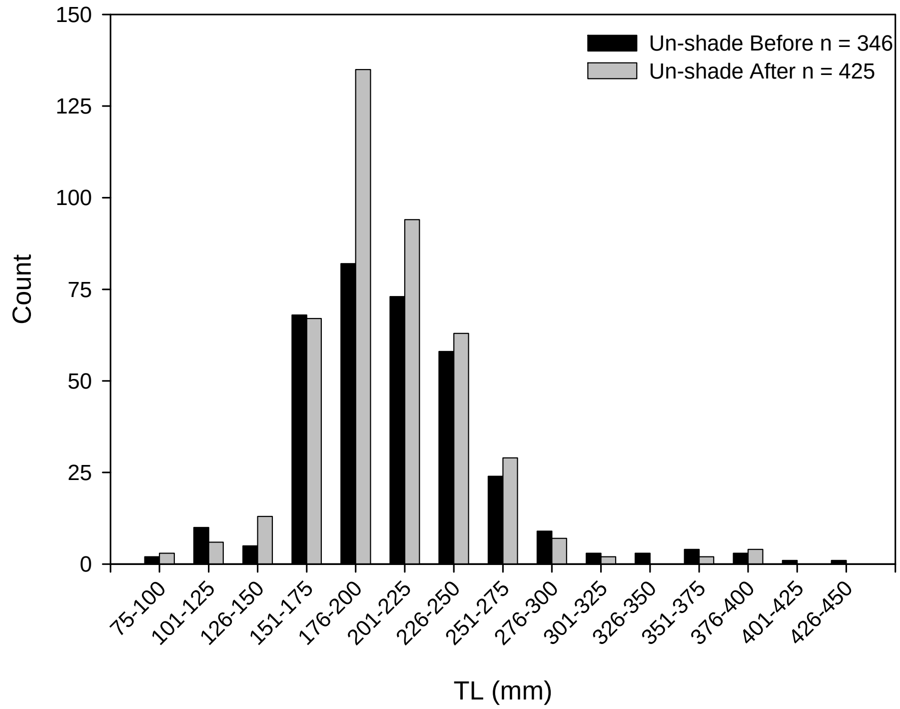


Figure 1.9. Length Frequency Histogram of White Suckers Captured in Un-shaded Pools (Mean total length Before = 209 mm, and After = 204 mm). Before data is from initial sampling, after data is 30 days following initial sampling.

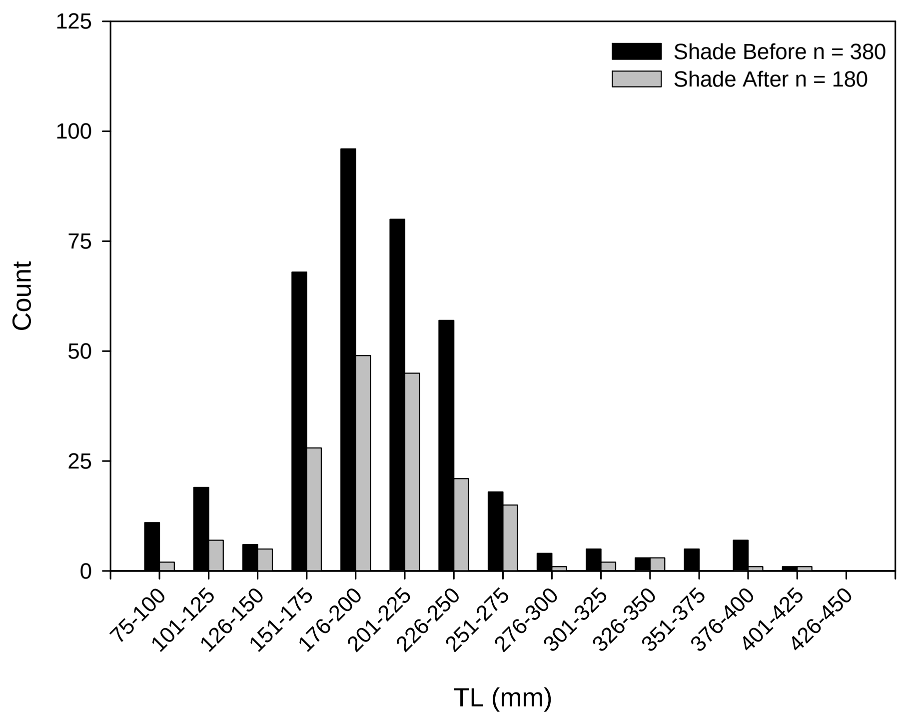


Figure 1.10. Length Frequency Histogram of White Suckers Captured in Shaded Pools (Mean total length Before = 203 mm, and After = 204 mm). Before data is from initial sampling, after data is 30 days following initial sampling.

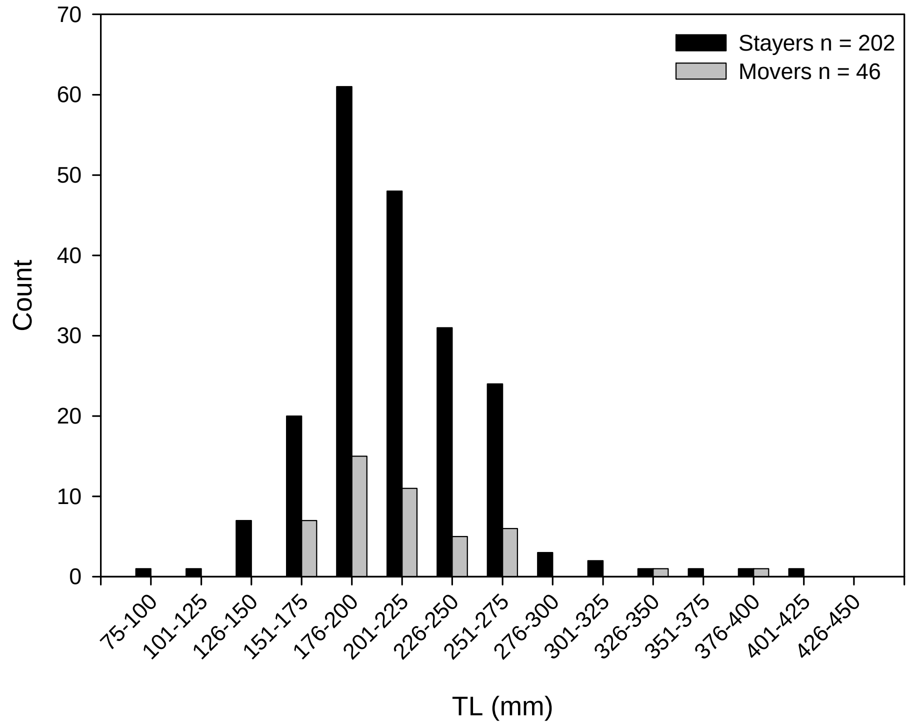
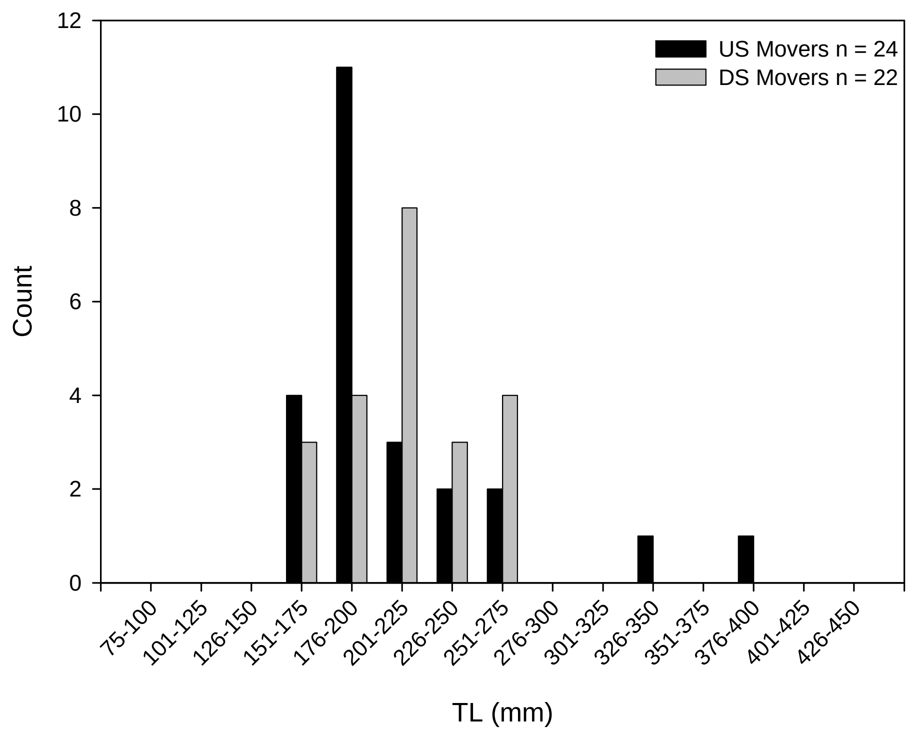


Figure 1.11. Length Frequency Histogram of Recaptured White Suckers. Stayers were found in the pool of initial capture and tagging, movers were found in a different study pool (Mean total length of stayers = 212 mm, and movers = 214 mm).



1.12. Length Frequency Histogram of Recaptured White Suckers That Moved Upstream or Downstream. Direction of movement was determined from the pool of initial capture and tagging (Mean total length of US movers = 212 mm, and DS movers = 216 mm).

Discussion

During 30 days of simulated overhead cover, the tagged white suckers in the Smith Creek study area were given a choice between un-shaded pools and shaded pools. In a laboratory study on white sucker growth, Koenst and Smith (1982) found white suckers cultured in shaded conditions grew up to 43% faster than suckers cultured in un-shaded conditions. This led me to hypothesize that in a natural setting white suckers would behaviorally select shaded habitat thereby allowing for optimum growth. However, during my study white suckers preferentially selected un-shaded pools, which was the exact opposite of what was expected. There are many potential variables other than overhead shade influencing white sucker behavior in Smith Creek. I controlled for confounding variables such as water temperature, instream habitat, and flow. When considered as groups, un-shaded pools and shaded pools were very similar in covariates such as average depth, maximum depth, instream cover and percent of initial overhead shade. This left the presence or absence of overhead cover (artificial shade) as the last remaining variable in question. An attempt was also made to control for movement specific behavior modifications resulting from electrofishing capture by allowing 10 days after sampling prior to artificial shading. Electrofishing mortality and handling stress should theoretically be equal for fish captured in both un-shaded and shaded pools because sampling methods were constant throughout the study. The recapture rate of white suckers in un-shaded pools (42%) was significantly higher than shaded pools (17%) suggesting differences exist between the treatments.

Population densities in un-shaded pools both increased and decreased after 30 days. However, in shaded pools all white sucker population densities declined. No difference was found between the percentage change in white sucker density in un-shaded and shaded pools 30 days after shading, although a trend for un-shaded pools to experience a smaller change than shaded pools was evident ($p = 0.1$). Un-shaded pools retained more than twice the number of tagged white suckers than shaded pools after 30 days. These results in conjunction with the significantly different recapture rates between un-shaded and shaded pools strongly suggest that white suckers prefer un-shaded pools.

A general decline in number of fishes present from June to July in this Smith Creek study area has been documented previously (Hudy, unpublished data). However, we would not expect to see the magnitude of decline that was observed for white suckers in this study. White suckers are a long lived species and natural mortality is not suspected for the decline in white sucker abundance. We also saw a large influx of new (untagged) fish into study pools and a large number of tagged white suckers not recaptured, suggesting the white suckers in Smith Creek demonstrate transient behavior during non-spawning times of the year. It is thought that naturally high rates of movement in this open population acted in conjunction with artificial shade to produce white sucker density decreases in some study pools and increases in others.

A simpler, more obvious explanation for density decreases is the disturbance associated with sampling. When disturbed, fish, similar to most species, tend to move away from the disturbance. Our sampling efforts may have pushed fish out of study pools following electrofishing surveys and 30 days was not a long enough time period for recolonization. Although, the significant difference in recapture rates between un-shaded and shaded pools seems to refute this hypothesis. Another possibility is that given the assumed high rates of natural movement, white suckers not recaptured may have been in transit at the time of initial capture and that specific study pool was not within their typical home range. Sampling was not conducted in habitat between study pools so fish not recaptured may have been anywhere from a few meters to over a kilometer away from a study pool.

The trend seen for shaded pools to reduce the variability in rate of temperature change by area is on a very small scale (Figure 1.7). In the future, as shade encroaches this effect will become more pronounced and potentially demonstrate a greater impact on stream temperature. The reduction of water temperature variability is important for survival if a species of fish is on or near its thermal limit.

As the restoration process at Rainbow Hill Farms progresses stream shade will become permanent. At this point white suckers will not have a choice between un-shaded and shaded pools, unless they chose to move outside of the restoration area completely. Given the preference for un-shaded pools, white suckers may be expected to decline in numbers as the restoration process continues. Currently, white suckers comprise a significant portion of fish biomass in the Smith Creek study area. Future changes in white sucker population structure and abundance may affect other fish species found in the study area. Therefore, continued monitoring of the restoration area through time is necessary to track changes in white sucker population dynamics associated with increasing riparian stream shade.

Chapter Two: White Sucker Movement

Introduction

Fish movement is an often studied aspect of fisheries biology. However, non-game fish such as the white sucker have received relatively little attention compared to sport fishes. While there are numerous reports on life history attributes of white sucker (*Catostomus commersoni*), most white sucker movement studies look only at movement in relation to spawning associated with lakes and their tributaries (Raney and Webster 1942; Corbett and Powles 1983; Quinn and Ross 1985; Trippel and Harvey 1989). Bond (1972) completed a comprehensive study of white sucker life history in the Bigoray River, Alberta but did not address movement outside of spawning migrations. There has been one published work concerning short-term (i.e. daily or weekly) and/or seasonal movements of riverine white sucker outside of spawning. During the winter Brown et al. (2001) found white suckers in the Grand River, Ontario to be relatively stationary except during periods of high water. General information relating to white suckers is relatively commonplace, however, detailed knowledge of potadromous populations in the southern portion of the range is lacking.

Several studies (Stewart 1926; Spoor and Schloemer 1938; Emery 1973) have established that white suckers are inactive in deep water during daylight hours and move to feed at night. Thus, it seemed white suckers were attempting to reduce metabolic rates by staying in cooler water during non-feeding periods (Chen and Harvey 1995) and this was later confirmed in laboratory studies (Reynolds and Casterlin 1978; Kavaliers and Ralph 1980). Taken together these results suggest that short-term movement studies may find diurnal patterns of movement in riverine suckers.

To address the non-spawning movement and habitat use of white suckers inhabiting Smith Creek I made use of radio telemetry and PIT tag technologies. Radio telemetry has proven to be one of the most efficient and correct approximations for determining habitat selection of warmwater stream fishes (Larimore and Garrels 1985; Siegwarth and Pitlo 1999). Pit tag technology allows for passive antennas to continuously record all fish movement past a predetermined location (Zydlewski et al. 2006).

My objective was to monitor non-spawning movement of white suckers in Smith Creek using both active (radio telemetry) and passive (instream PIT tag antenna) methods.

Methods

Telemetry

The four randomly selected white suckers from each of the ten study pools were surgically implanted with a pulse-coded radio transmitter. Radio transmitters with trailing whip antennae (NTC-3-2 and NTC-4-2-L) were obtained from Lotek Wireless, Inc. (New Market, Ontario, Canada). Transmitters had masses of 1.1 and 2.1 grams with estimated battery lives ranging from 124 to 251 days (Table 2.1). Only white suckers greater than 225 mm were given radio transmitters in order to keep the transmitter weight less than or equal to 2% of the fish's body weight (Winter 1983). A length-weight regression analysis determined that all white suckers 225 mm or greater would have a body mass large enough to support the biggest tag.

Table 2.1. Specifications for Radio Transmitters Implanted into White Suckers. Measurements are in millimeters (mm).

Model	Length	Width	Height	Diameter	Weight	Operational Life (days)
NTC-3-2	15.5	6.3	4.5	-	1.1	124
NTC-4-2L	18.3	-	-	8.3	2.1	251

Surgical procedures were adapted from Walsh et al. (2000) and Roghair and Dolloff (2005). White suckers were anesthetized until equilibrium was lost and then placed in a soft rubber cradle ventral side up. Water was gravity fed over the gills during the entire procedure. A small incision, approximately one and a half centimeters long, was made in the abdomen of the fish anterior to the pelvic girdle. The transmitter was inserted and the incision was closed with 2-3 interrupted 3-0 nylon sutures. The transmitter antenna was allowed to exit the body through the original incision. The procedure took approximately 2-3 minutes and white suckers regained equilibrium and were swimming in a bucket less than a minute after the final suture was tied. They were given an additional 15-30 minutes of recovery in a live basket in the stream prior to release near the point of capture.

Tracking equipment consisted of a scanning receiver (SRX-400, Lotek Wireless, Inc.), a three-element folding Yagi antenna, and a GPS unit (Garmin GPS map 76CSx). Signals were transmitted in the 150.000-151.999 MHz range at 6 pulses per minute (ppm). Up to 11 frequencies could be stored in the receiver at one time. The receiver was programmed to scan through each frequency for a given period of time before moving on to the next frequency. When a tag was detected a power bar would appear on the display screen with the signal strength and code for the transmitter detected. Fish were tracked twice weekly from 19 June 2007 to 22 August 2007 and reduced to approximately once weekly from 28 August 2007 to 15 November 2007 because of low rates of movement. Fish were located through basic triangulation. After triangulation the estimated location of the fish was recorded on a data sheet. After the study was completed, GPS coordinates were taken standing in the stream at the locations recorded during previous tracking events. GPS locations then were input into a Geographic Information System (GIS) database for spatial analysis. I calculated absolute distance moved (sum of the distance moved between relocations), displacement (net distance moved, upstream movements were positive), range (distance between the upstream-most and downstream-most relocations), and estimates of minimum daily movement (absolute distance moved between relocations divided by the number of days elapsed) for my non-spawning data set (Grabowski and Isely 2006).

PIT Tag

Additionally, two instream PIT tag antennas were constructed to passively monitor the movement of white suckers with and without radio tags 24 hours a day. The antennas were each anchored in the stream bed and positioned such that the bottom of the antenna was level with the stream bed so as not to cause any obstruction to potential fish movement. At Antenna 1 (Figure 1.4) the receiver was powered by alternating current available on site and at Antenna 2 the receiver was powered by four six-volt deep cycle batteries connected in series and parallel. This power source lasted for approximately 20 days but was changed every two weeks to ensure the antenna remained working.

Once completed the PIT tag antennas detected and recorded the date and time of any fish with a PIT tag that swam through the antennas. Antenna current, or the ability of the antenna to detect a PIT tag, fluctuated through time and regular maintenance was required. Due to the variability of the antenna current a constant efficiency rate for the study period could not be determined. Efficiency was estimated to average 80% and fluctuate between 25 and 90%. Efficiency can theoretically reach 100% but in field situations a large number of variables act to reduce the overall effectiveness of the antenna. We are, however, confident that a majority of the fish passing through the antennas were detected.

Results

Telemetry

A total of 37 transmitters were implanted between 6 June and 12 June 2007. Tagged white suckers averaged 266 mm (range 210-409 mm) at the time transmitters were implanted. An effort was made to tag four fish in each study pool however, only one fish received a radio transmitter in Pool 4 because only one fish ≥ 225 mm was captured. Information for each white sucker implanted with a radio transmitter is provided in Table 2.2.

After accounting for lost tags and tags that were never located, movement data for 24 white suckers were used for analysis. There was a significant difference between the number of white sucker relocations having zero movement since the previous location (374 / 513) and those that moved either upstream or downstream since the previous location (139 / 513) (Pearson's Chi-square, Chi = 73.48, df = 1, $p < 0.001$). The majority of relocations found fish in the same position as the previous relocation. Of the relocations noting movement, either upstream or downstream, there was no preference for one direction over the other (US: 68 / 139, DS: 71 / 139) (Pearson's Chi-square, Chi = 0.0431, df = 1, $p = 0.8354$) (Figure 2.1). Five white suckers had absolute movements greater than 1,000 m. Two fish had a range in excess of 1,000 m. The largest upstream movement was 1,300 m by white sucker #39. The largest downstream movement was 1,260 m by white sucker #73. Average daily movement for all 24 white suckers combined to equal zero and ranged from -21.1 m (downstream) to 19.6 m (upstream). Average daily movement for individual white suckers can be found in Table 2.3 along

Table 2.2. Information for all White Suckers Implanted with Radio Transmitters. Tag location is the study pool in which the fish was tagged initially. Fate corresponds to the status of each transmitter (B = battery failure U = unknown O = operational throughout the study TL = tag lost).

Fish	TL (mm)	Tag Location	Date Implanted	Last Observed	Days of Operation	# of Relocations	Fate
65	239	Hole 1	6/6/2007	10/10/2007	124	20	B
67	246	Hole 1	6/6/2007	6/6/2007	0	0	U
87	371	Hole 1	6/6/2007	11/15/2007	159	23	O
41	271	Hole 1	6/6/2007	10/2/2007	116	19	B
72	251	Hole 2	6/6/2007	6/6/2007	0	0	TL
91	230	Hole 2	6/6/2007	8/9/2007	63	11	TL
83	263	Hole 2	6/6/2007	11/15/2007	159	23	O
89	285	Hole 2	6/6/2007	11/15/2007	159	23	O
39	232	Hole 3	6/7/2007	11/15/2007	158	23	O
80	370	Hole 3	6/7/2007	11/15/2007	158	23	TL
42	246	Hole 3	6/7/2007	11/15/2007	158	23	O
43	247	Hole 3	6/7/2007	7/19/2007	42	8	U
85	351	Hole 4	6/7/2007	11/15/2007	158	23	U
46	254	Hole 5	6/7/2007	10/22/2007	135	21	U
84	231	Hole 5	6/7/2007	11/15/2007	158	23	O
75	331	Hole 5	6/7/2007	6/7/2007	0	0	TL
76	288	Hole 5	6/7/2007	8/9/2007	62	12	TL
86	247	Hole 6	6/8/2007	11/15/2007	157	23	O
79	229	Hole 6	6/8/2007	6/8/2007	0	0	TL
74	255	Hole 6	6/8/2007	6/8/2007	0	0	TL
44	258	Hole 6	6/8/2007	10/22/2007	134	21	U
40	225	Hole 7	6/8/2007	6/8/2007	0	0	TL
66	254	Hole 7	6/8/2007	8/28/2007	80	15	U
90	231	Hole 7	6/8/2007	11/15/2007	157	23	O
69	236	Hole 7	6/8/2007	6/8/2007	0	0	TL
64	251	Hole 8	6/11/2007	6/11/2007	0	0	TL
38	362	Hole 8	6/11/2007	11/15/2007	154	23	O
70	235	Hole 8	6/11/2007	10/2/2007	111	19	U
92	260	Hole 8	6/11/2007	8/14/2007	63	13	TL
37	235	Hole 9	6/11/2007	11/15/2007	154	23	O
82	409	Hole 9	6/11/2007	11/15/2007	154	23	O
93	231	Hole 9	6/11/2007	11/15/2007	154	23	O
81	235	Hole 9	6/11/2007	11/15/2007	154	23	O
68	210	Hole 10	6/12/2007	10/10/2007	118	20	U
73	212	Hole 10	6/12/2007	10/22/2007	130	21	B
78	219	Hole 10	6/12/2007	11/15/2007	153	23	O
48	365	Hole 10	6/12/2007	11/15/2007	153	23	O

with minimum estimates of the absolute distance moved, displacement, and range for each fish. When compared to one another, there were no significant differences in the average daily movements among the 24 radio tagged white suckers (ANOVA, df = 23, F = 0.865, p = 0.646).

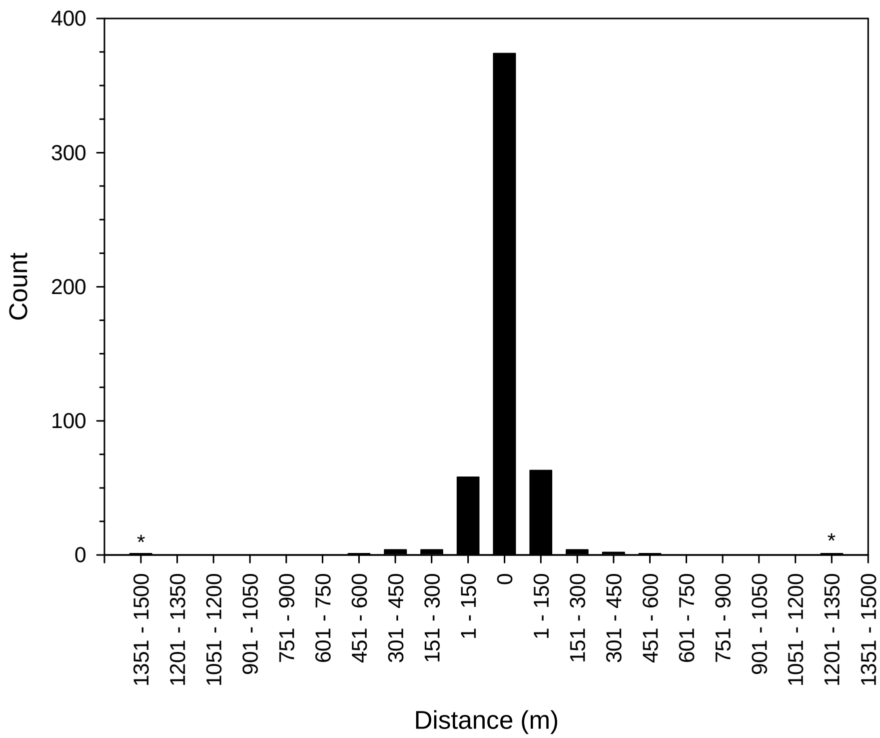


Figure 2.1. Frequency Histogram of the Direction of Total Movement of White Suckers Between Relocations. Relocation events for all 24 white suckers were pooled. An asterisk denotes an extreme movement distance.

Table 2.3. Summary of Movement Statistics. Data set includes movements for 24 white suckers. See Chapter Two methods for definitions of terms below.

Fish	Absolute	Displacement	Range	Average Daily Movement
87	66	0	15	0.2
83	1014	-498	557	-0.2
73	1312	-1260	1273	-21.1
42	978	-56	978	2.8
43	1250	0	445	-4.8
38	13	-5	5	-0.1
76	734	698	716	11.3
39	1362	1300	1315	19.6
89	11	11	11	0.1
85	230	-94	105	0.3
84	563	-107	228	-3.7
44	217	-53	107	0.5
46	588	166	219	-0.9
86	106	0	25	0.4
90	346	-280	280	-3.2
92	398	-54	118	0.4
66	163	-37	40	-1.7
68	307	-307	307	-1.9
81	1008	-28	426	1.6
70	82	-10	18	0.2
37	20	20	20	0.3
93	128	28	32	0.0
48	177	123	136	0.3
78	111	51	51	0.6

PIT Tag

Passive PIT tag antennas recorded 213 individuals moving through one of the two antennas at least once. The 213 individuals accounted for 30% (213 / 703) of the white suckers tagged during initial fish sampling in June 2007. Many individual white suckers were recorded multiple times resulting in a total of 455 recordings. Of the 455 records, 92% (420 / 455) were between the hours of 7:00 pm and 7:00 am (Figure 2.2). Stream flow was monitored during the course of the study. Average daily flow was significantly positively correlated with the number of PIT tagged white suckers moving through an instream antenna (Pearson Correlation, $n = 199$, $p \leq 0.01$) (Figure 2.3).

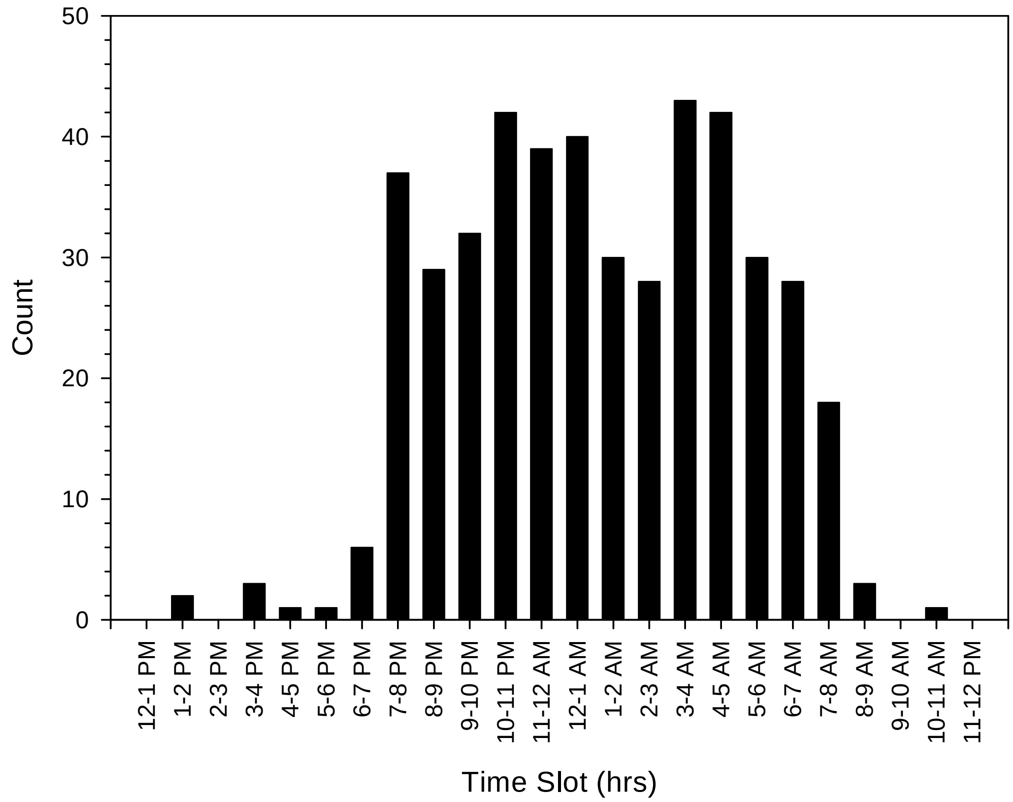


Figure 2.2. Time Frequency Histogram of White Sucker Movement by Hour. Data consists of all movements through two instream PIT tag antennas. Each record indicates the hour time slot that a white sucker passed through an antenna (n = 455).

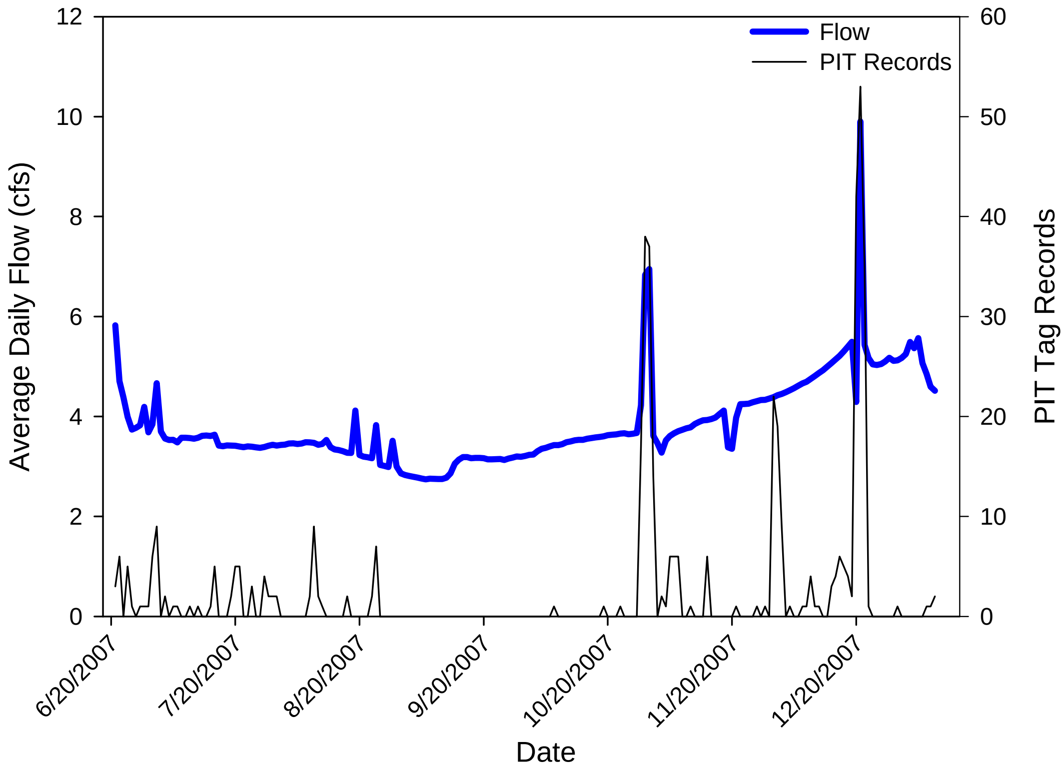


Figure 2.3 Correlation of Daily White Sucker Movement and Stream Flow. Graph illustrates average daily flow and number of PIT tagged white suckers moving through one of two instream antennas during the study period.

Discussion

My results suggest that white suckers are mostly sedentary and occupy relatively small linear home ranges for extended periods of time interspersed with infrequent long-distance migrations. I found that white suckers move more frequently at night and remain rather stationary during daylight hours similar to previous findings (Stewart 1926; Spoor and Schloemer 1938; Emery 1973). Night time movement is thought to be an anti-predation behavior. However, few white sucker predators are found in Smith Creek. White suckers are thought only be susceptible to avian predators such as the great blue heron (*Ardea herodias*) because aquatic top predators such as largemouth bass (*Micropterus salmoides*), smallmouth bass (*Micropterus dolomieu*), northern pike (*Esox* *lucius*), and muskellunge (*Esox masquinongy*) are not found in the study area. Therefore, an anti-predation tactic is probably not the sole motive for night time movements. A second explanation for night time movement may involve increased vulnerability of white sucker food items during hours of darkness. Likely, it is an adaptation evolved over time which accounts for multiple factors.

Long-distance movements were documented by telemetry relocations and by PIT tag antenna records, but the majority of relocations involved no movement or relatively small distances moved. Relatively short movements are not out of the ordinary given that the white suckers were not followed during spawning season. The results of this movement study correlate with a similar study on Potomac sculpin in the Smith Creek study area where most Potomac sculpin were found to be sedentary with a small percentage showing great dispersal capabilities (Hudy, unpublished data). Only a small proportion of individuals showing high rates of movement are necessary to colonize newly established habitat or recolonize disturbed habitat.

Some individual white suckers moved from the pool of initial tagging through both PIT tag antennas, which are roughly 500 meters apart. Using only active capture methods can underestimate movement, and many white sucker movements during this study would have been undetectable using only active recapture methods. Fidelity for certain habitats can also be misinterpreted by using only active capture techniques. PIT tag records showed white suckers retracing their path and ending up back in the same pool they were initially tagged in. These round trips took anywhere from days to sometimes weeks, yet some of these fish were never recaptured during electrofishing surveys. The PIT tag antennas allowed for the accumulation of a large amount of data with relatively little sampling effort. Data collected by PIT tag antennas corroborates the hypothesis from Chapter One that white suckers are moving freely through the study area and may have been in transit during recapture sampling. This partially explains the lower than expected recapture rates and the large influx of new fish.

Synthesis and Management Implications

White suckers displayed a preference for un-shaded pools in this experiment. Non-spawning movements were found to be relatively small with a few long-distance migrations interspersed for radio tagged white suckers. PIT tag records indicate transient behavior for non-radio tagged white suckers as well. Overall, the white sucker population in Smith Creek appears to be comprised mostly of sedentary individuals with a small percentage of fish moving freely and extensively throughout the study area. White sucker population dynamic changes associated with increasing riparian stream shade remain unclear. As restoration progresses stream fish assemblages, water temperature and quality measures, and terrestrial riparian community monitoring will remain critical to understanding the ecosystem processes and responses to disturbance and management of Smith Creek. The restoration process will introduce more shade to the Smith Creek study area resulting in potential changes to the current fish assemblage. The magnitude and direction of the foreseen changes is unknown. It is hoped that future changes will result in the reestablishment of native brook trout in Smith Creek. Connectivity of habitats between Smith Creek and a brook trout population located upstream on national forest property will hopefully increase the viability of this species in the subwatershed.

All trees planted as part of the restoration effort cannot be expected to live. Therefore, it is possible that gaps will emerge in the riparian canopy and a number of un-shaded pools will remain. If brook trout become established in the study area they could potentially compete with white suckers for food and space. However, the results of this study suggest white suckers may leave the study area in search of un-shaded habitats. If this happens, competition will not be an issue. Continued monitoring will be needed to document any interaction between these species.

White suckers are not a sought after sport fish and often times receive little attention other than a simple acknowledgement of their presence. They are easily encountered in the study area and represent a resilient, long-lived species to study. Future study of the white sucker population in Smith Creek should focus more on the dispersal capabilities and tendencies of the species. This will contribute general knowledge on riverine white sucker homing and pool fidelity tendencies, along with additional general movement data.

This research contributes knowledge of movement patterns and habitat preferences of the white sucker in the southern portion of the range and should help continuing investigations of the responses of stream fishes to restoration efforts.

Appendix

An archive of white sucker length frequency histograms for the ten study pools Before and After treatment. “Before” measurements were taken between 6 June and 12 June 2007. “After” measurements were taken between 23 July to 26 July 2007.

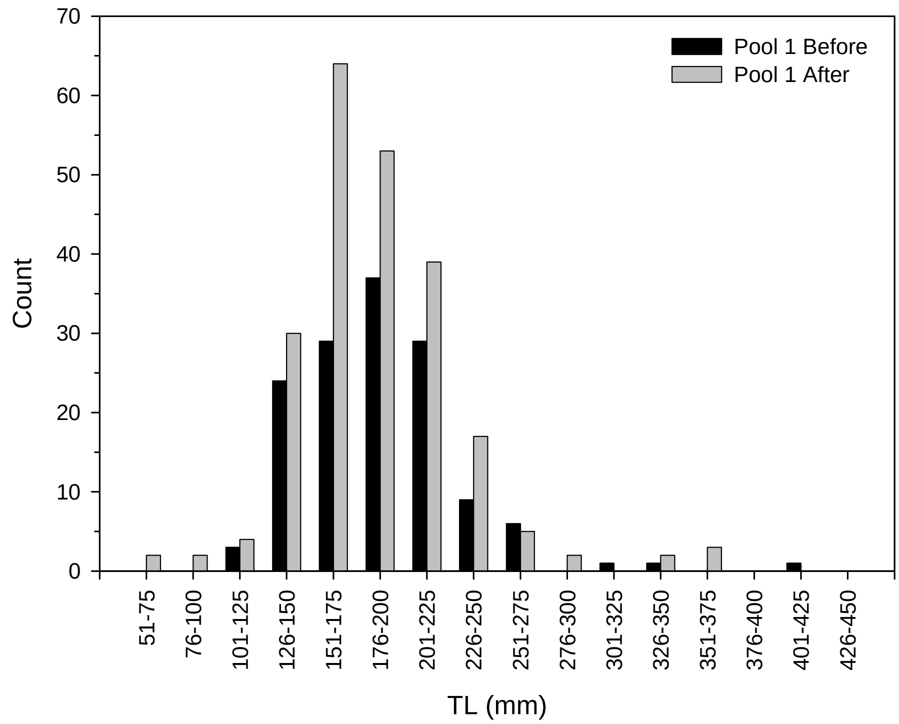


Figure A.1. Length Frequency Histogram of White Suckers Captured in Pool 1 (Before: n = 140, After: n = 223).

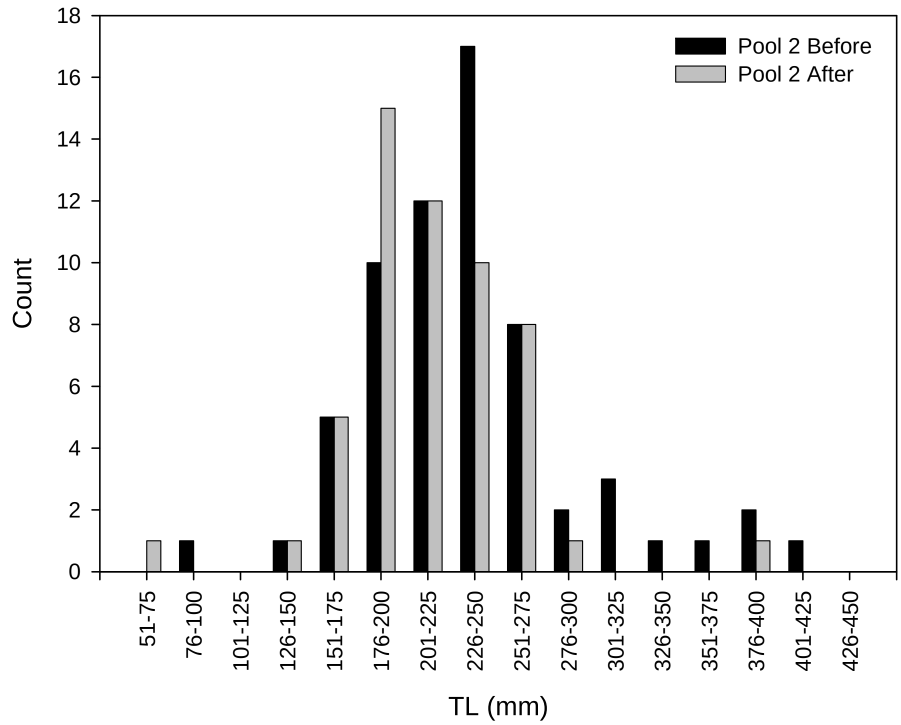


Figure A.2. Length Frequency Histogram of White Suckers Captured in Pool 2 (Before: n = 64, After: n = 54).

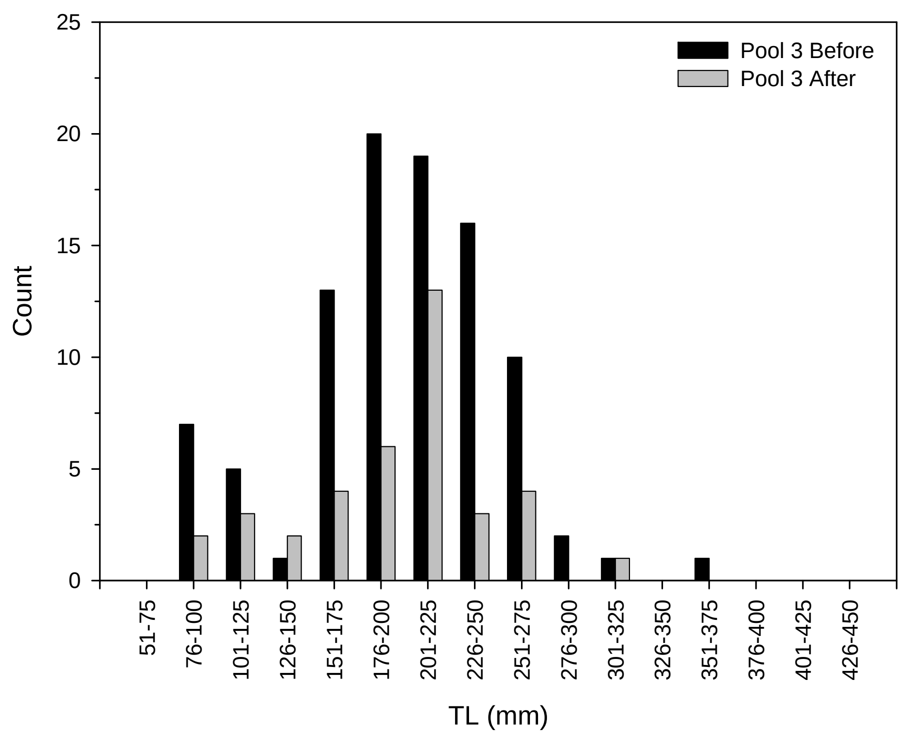


Figure A.3. Length Frequency Histogram of White Suckers Captured in Pool 3 (Before: n = 95, After: n = 38).

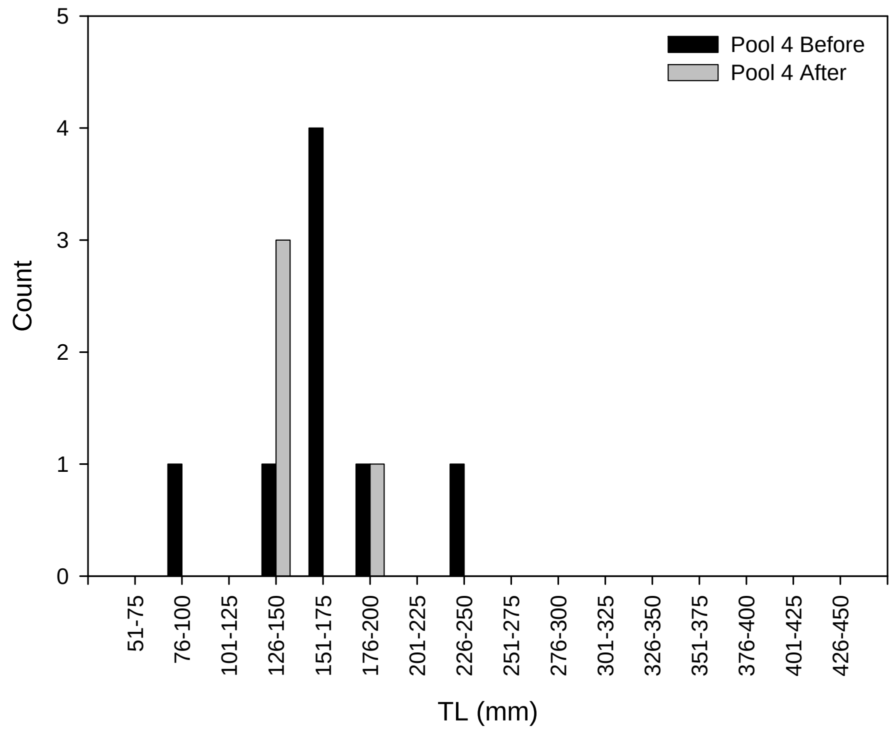


Figure A.4. Length Frequency Histogram of White Suckers Captured in Pool 4 (Before: n = 8, After: n = 4).

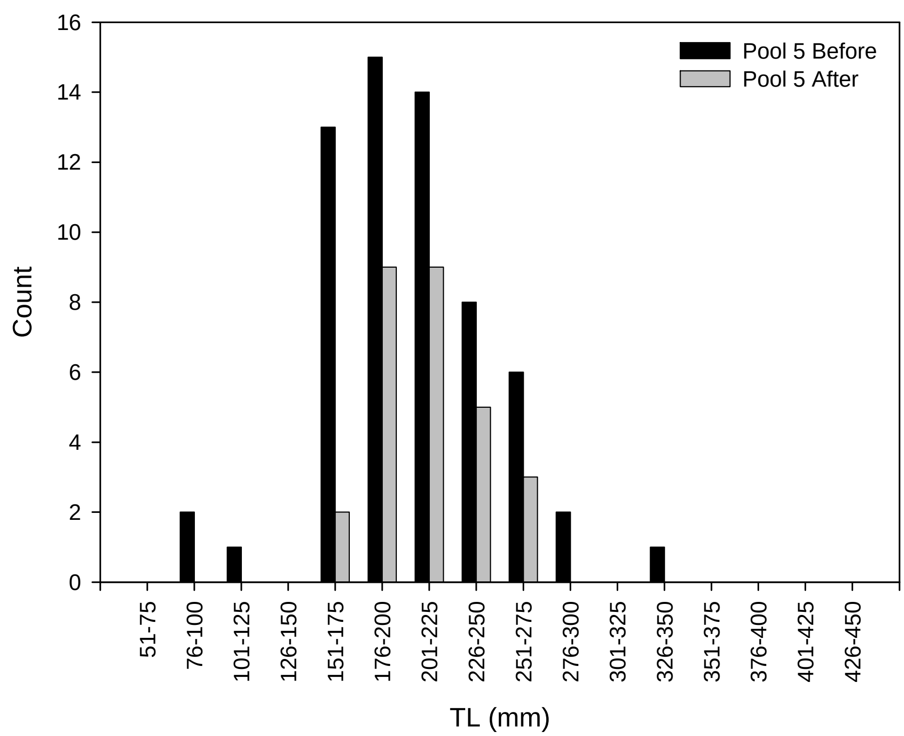


Figure A.5. Length Frequency Histogram of White Suckers Captured in Pool 5 (Before: n = 62, After: n = 28).

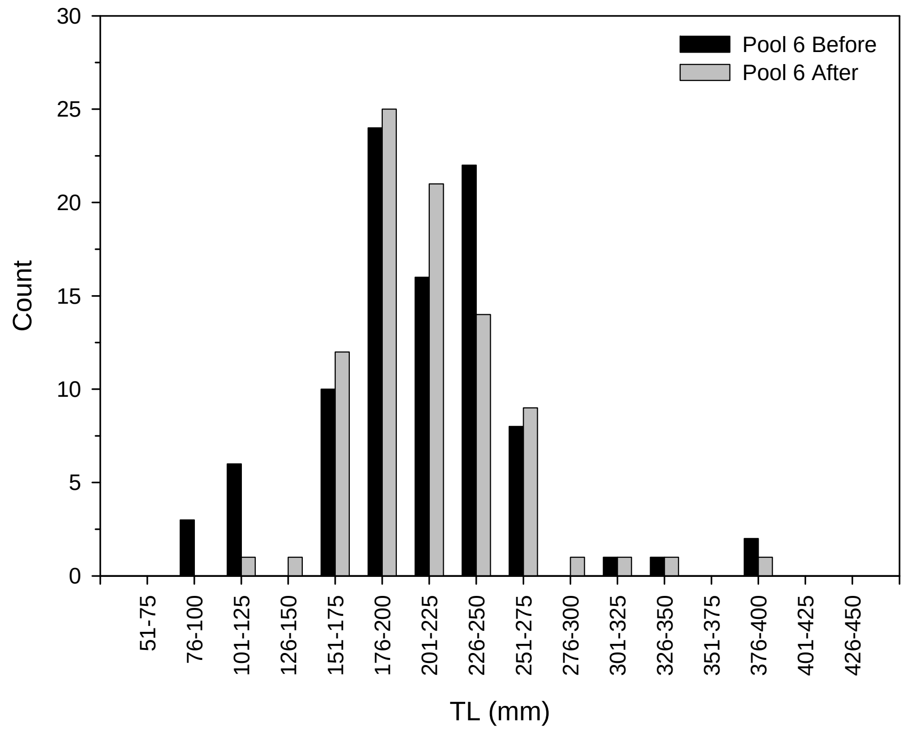


Figure A.6. Length Frequency Histogram of White Suckers Captured in Pool 6 (Before: n = 93, After: n = 87).

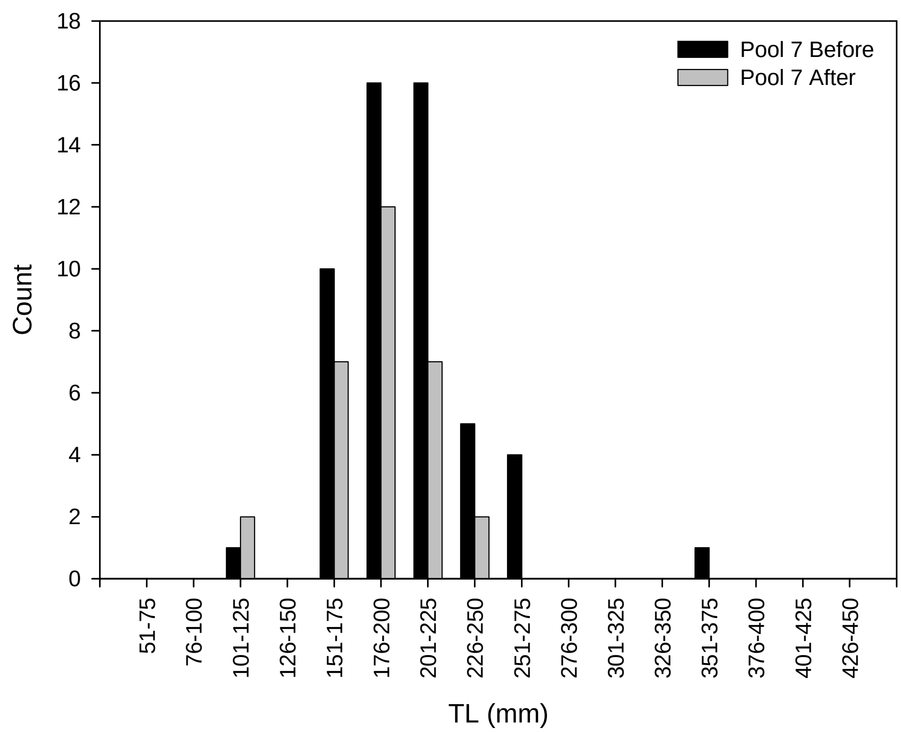


Figure A.7. Length Frequency Histogram of White Suckers Captured in Pool 7 (Before: n = 53, After: n = 30).

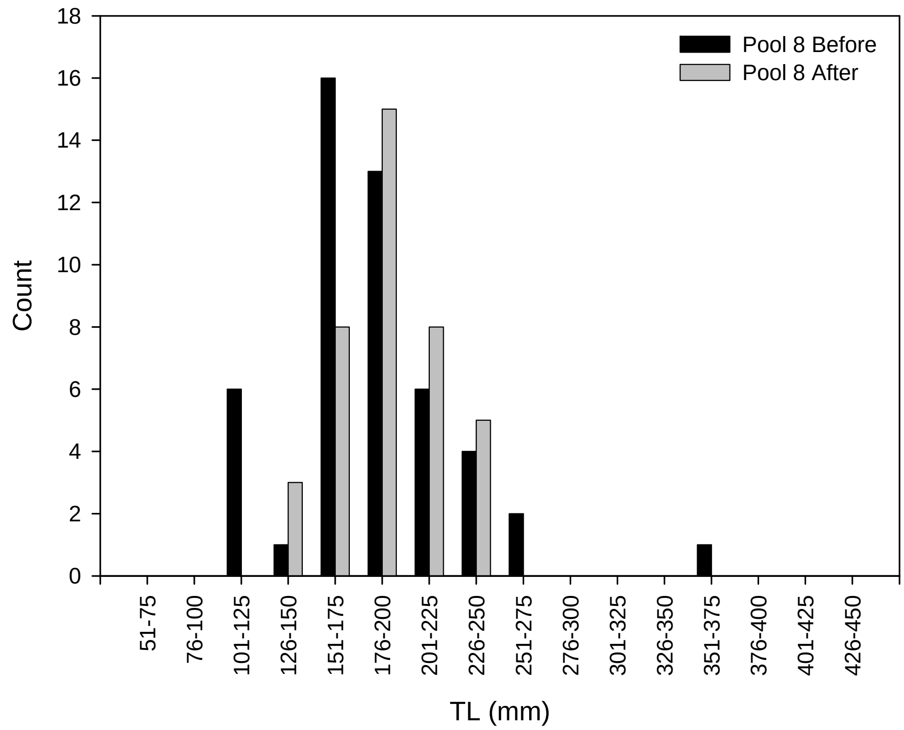


Figure A.8. Length Frequency Histogram of White Suckers Captured in Pool 8 (Before: n = 49, After: n = 39).

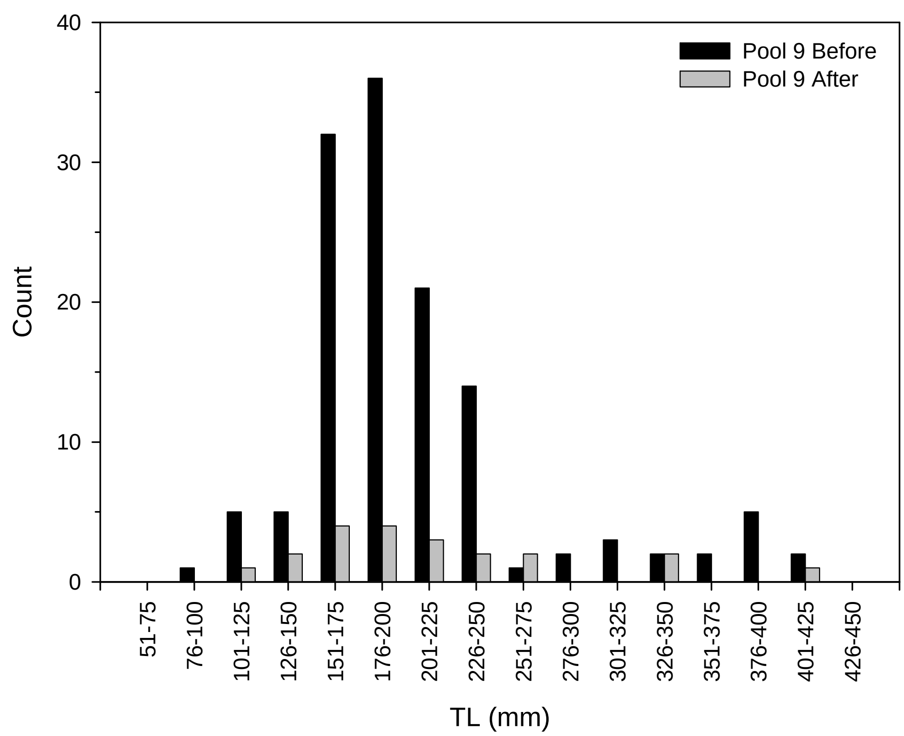


Figure A.9. Length Frequency Histogram of White Suckers Captured in Pool 9 (Before: n = 131, After: n = 21).

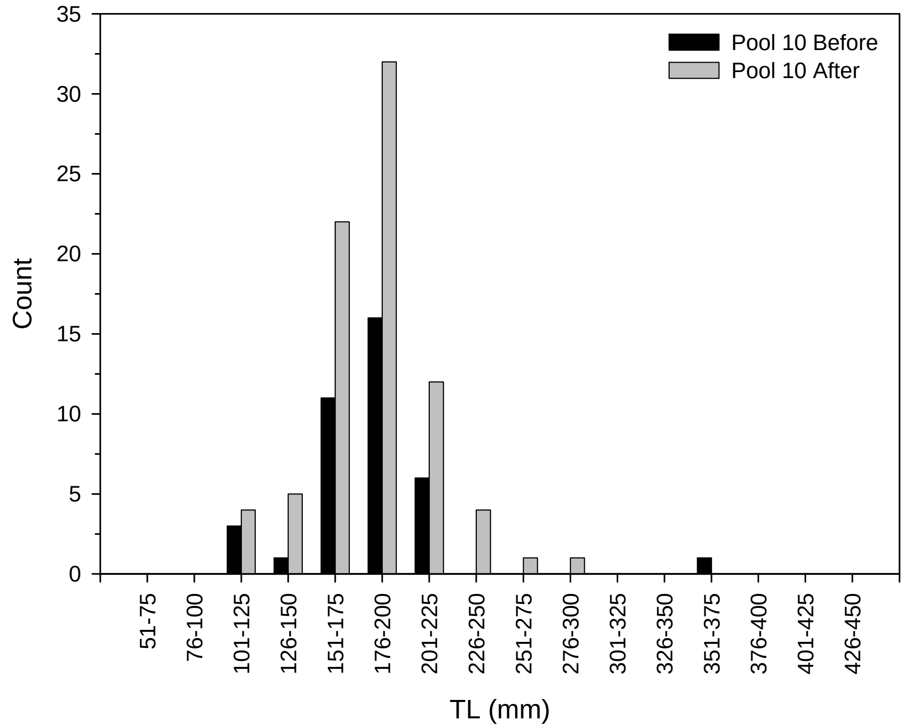


Figure A.10. Length Frequency Histogram of White Suckers Captured in Pool 10 (Before: n = 38, After: n = 81).

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