Overview:

From the research conducted during this project it has been found that Geographic Information Systems (GIS) and Remote Sensing have a very critical and pertinent role not only in current conservation and management but of brook trout (*Salvelinus fontinalis*) but the future preservation of this native wild fish as well. There are many reasons for why these two technologies are such a valuable resources to combating the impending struggle this species faces and why managers and biologists must keep pushing the boundaries causing GIS and Remote Sensing to evolve.

The most prevalent way GIS and Remote Sensing are being used in the management and conservation of brook trout is monitoring the fish on a temporal scale. One of the most useful ways these technologies have helped in the protection of this species was the creation of the database that describes the historical range of habitat brook trout once occurred. This is significant because with the historical context known, now the current extent can be over laid and regions of extirpation can be displayed. This technique can also be used by managers to key in on specific reaches of river that may be most susceptible for brook trout extirpation so those sections of stream may become the areas of focused restoration efforts. Through doing this areas of concern may be identified and then risk assessments can be run to show the most vulnerable and rank them as well.

The temporal topic can also be paired with Remote Sensing band 6, the thermal infrared band, to monitor the extent the water temperature has been warming over the years. The warming water temperature can be observed and tracked to see what reaches of the rivers were suitable for brook trout and no longer currently. This technique can be used one step further in predicted where the water temperature will be increased in the future, so biologists and restoration efforts can focus on these areas to preserve the areas where brook trout are thriving. On an even finer temporal scale, water temperatures can also be tracked through-out the same year, at a fine of a resolution as 16 days, to getting an idea of how season changes affect the water temperature too.

The temporal theme of these technologies can be extended into the field of brook trout ecology as well. Migration is a very complex and not fully comprehended life event of brook trout that temporal implications of GIS and Remote Sensing can aid in learning more about. Monitoring migrations is a very important aspect of brook trout conservation because it directly shows the specific areas of river that must be conserved. The different habitats selected by the fish may vary based on dynamics of the stream and time of year but with these two technologies the specifics of each stream can be documented and understood. Using temporal aspects of these technologies can show what time of year the fish are spending in what sections of the stream and where the fish are in the stream. This is incredibly imperative to management efforts so the regions of the stream can be conserved during
certain times of the year. This understanding of knowledge can help managers settle the age old disputes of agriculturists and mangers battling over water rights in many areas of the country.

Another implication GIS and Remote Sensing can be used in conservation efforts, is in the predictions of where the fish may inhabit. This can be done by observing landscape features remotely and modeling how they would affect the riverine habitat. Such features include but are not limited to, forest buffer, riparian buffer, soil texture and minerology, slope, aspect, land use and impervious surface. All of these factors of the landscape are taken in account and modeled to show areas of the rivers that should be suitable for brook trout. The advancement of resolution has allowed for landscape measurements in areas that may be remote and complicated to get accurate measurements. This is important to management of this species because field sampling can be very time consuming and expensive to agencies. Using this technology is very useful because it can limit time spent in the field and it is possible to narrow down the areas that should be sampled. Using software instead of field work can make landscape calculations more accurate and easier to compute.

The landscape can now be measured in such detail now that scientists are now able to ask more complex environmental questions than ever before. With highly accurate landscape measurements thanks to precise Digital Elevation Models (DEM), the landscape can be managed like never before. The new DEM’s allow incredibly accurate calculations of slope. This seems like a simple insignificant measurement, but with that one parameter a world of possibilities become unearthed.

Once a precise slope calculation is derived it can be paired with calculations to find watershed size. When watershed sized is coupled with, roughness, land use, impervious surface and annual precipitation, flow can be discovered. Once flow is found, velocity can be considered then slow and open waters can be identified. Slow and open water lead to an increase in water temperature so the thermal bands in Remote Sensing can be used to find areas that are increasing water temperature. With temperature and velocity found, habitat can then be assessed by looking at soils and forest boundary data. Once the habitat is assessed carrying capacity and population density can be extrapolated then sooner or later in help with field surveys, to confirm accuracy, harvestable size fish distribution and catch per unit effort can be calculated as well. The more layers and the more parameters assessed and added into the model, the more accurate the models will be and they will be able to predict the suitable habitat almost to a T.

Basically with the current information available from both of these technologies, the entire brook trout ecosystem can be extrapolated. With this done, the managers can really focus in and rank the areas of highest concern and vulnerability by modeling. The models that can be used to find the predicted areas brook trout should be residing in are binary logistic regression, Bayesian and multiple linear regression models. According to numerous articles listed above these models are very important and very accurate when paired with in situ surveys in calculating potential pristine habitats.

Due to the new found accuracies of the recently discovered models, predictions of the habitat may also be made as well. Parameters can be identified and inferences can be made off of them. So if considerations such as flow, substrate size, water temperature and proper depth of water can be
identified, habitats such as spawning grounds, winter and summer habitat can all be predicted and managed for. This is so critical to manage for based on so management and restoration can be done on the stream.

These models are incredibly useful at identify the regions of the watershed that are causing the biggest threats to the biodiversity of the river too. These models have the capability of highlighting the good and in turn can also be prograemed to highlight the bad. This is very valuable to managers because specific features can be identified for restoration projects. This theory can also be put into use to find point source pollution areas based on all of the same factors listed above and with certain topology rules implied. These topology rules can be switched and changed to show the modeler what would happen to the river’s ecosystem if different scenarios are put into action. The models can pin point areas where habitat is being hindered and suggest ways to address the problems the watershed maybe facing.

Along with the complex, very scientific analyses GIS and Remote Sensing can complete they also have the capability of producing an image. This has been argued to be the most important and useful feature of these technologies. The phrase a picture speaks a thousand words says it all. GIS and Remote Sensing create a more user friendly final product for the public and for the people the managers are trying to get their points across to. Instead of having to read a long scientific paper with dense jargon in it, an image can be displayed showing all of the research and analyzations in an easy to comprehend graphic.

In conclusion, GIS and Remote Sensing are critical in brook trout ecology, management and conservation and will only become more useful in the future. Based on their ability to find answers to complex questions, analyze a labyrinth of data and produce and easy to comprehend final product, GIS and Remote Sensing is the most valuable tool brook trout researchers possess.
Annotated Bibliography:


This paper written by Clark et al. describes how GIS and an individual based model of both brook trout (*Salvelinus fontinalis*) and rainbow trout (*Oncorhynchus mykiss*) was used to predict the effects climate change have on trout populations in southern Appalachian streams. Individual of each species were tracked, through the model. Daily activity such as growth, feeding, mortality, spawning and movement were monitored. These activities were monitored for 30 years in streams that had features such as connected pools, runs and riffles in an area that was divided into 101 watershed elevation zones. Trout per meter was estimated by multiplying estimated trout densities by the total length of stream in each water elevation zone. Three scenarios were analyzed, 1, warmer stream temperatures, 2, warmer streams and 3, lower base flow/higher peak flow, warmer streams, changed flows and flow related scouring of redds. Scenario 1, increased the density of both trout species, 2, resulted in a mosaic of positive and negative changes in each zone with little abundance change, and 3, caused a net loss of rainbow trout. Predicted changes were weakly correlated to predicted changes in populations. It was suggested that coupling the models with GIS databases offers a promising methods to regional assessments of salmonids.


This article by Creque et al. exclaims how both site and landscape scale processes are crucial to river ecosystems and how an understanding of these influences on fish populations can lead management and research efforts. Various linear regression analyses of fish and habitat databases were used to determine the possibility of using GIS derived landscape-scale variables. This was done to explain spatial variations in the densities of the sport fish, Chinook salmon (*Oncorhynchus tshawytscha*), steelhead *O. mykiss*, brown trout *Salmo trutta*, brook trout *Salvelinus fontinalis* and white sucker *Catostomus commersonii* in Michigan’s Lower Peninsula. Models were compared with the ones that were developed using site-scale variables traditionally measured in the field. Landscape scale riverine habitat variables obtained through GIS analysis and modeling of watersheds characteristics accounted for the majority of variability of fish density. Mean July water temperature was negatively correlated with the density of brook trout, brown trout and chinook salmon. Watershed areas were negatively correlated with the density of steelhead and white suckers. Positively correlations were found with the exceeded flow yield and a higher density of Chinook salmon and steelhead. Habitat variables explained less than
60% of the variation of fish density then landscape variables. In the models depth was negatively related to all species densities and soft substrates positively correlated with white sucker density. It was also exclaimed that there was a lot of unexplained variation in density, but the models provided insight into key variables that influence fish density patterns on a larger regional scale.


In this paper written by Dauwalter et al. remote sensing in freshwater fisheries is discussed. It is reported that remote sensing is critical in understanding freshwater fisheries and the rapidly changing field of satellite and airborne applications are focused on and reviewed. Historically, the applications of remote sensing have emphasized variation spatially in the environment, especially in watershed land use and primary productivity in the in situ terms. Recent advances in image accessibility have enabled much better detection of temporal change. Due to the technology evolving, sensors have been able to progress and now images with higher spatial, temporal and spectral resolutions are now more possible than ever before. These advances have accelerated development of remote sensing products that have begun to characterize aquatic environments at a more highly accurate level. Some of the more important subjects that progressed were the now free access to previously sensed images, the computing of clouds, and ways to use images with clouds covering areas by piecing in images with no cloud cover in that region of the image. The largest advancement of remote sensing to fisheries professionals is the availability of products in the national hydrography databases. This development broke down barriers and allowed for a more free flow of information across interdisciplinary fields. Remote Sensing has now been able to advance and more complex questions have been able to be answered at a more detailed spatial resolution and across a larger landscape and even more comprehensive time frame. This has provided a broader scale perspective to freshwater fisheries in the fields of conservation and management.


Fransen et al. described in their paper that regulating and governing human activities in streams and riparian zones normally differ depending on whether or not a stream length supports fish or not. Presences and absence of fish in rivers is generally determined by sampling efforts or by assuming presence of fish due to certain characteristics of the stream. This paper declares that there are issues with both of the estimating efforts listed above. They include the facts that field sampling is often time consuming and expensive and the inference approach is often inaccurate. The authors of this article attempted to improve the accuracy and efficiency of fisheries predictions by developing GIS based model. A 10 meter digital elevation model incorporated field data on fish distributions from 517 streams in Washington State and GIS resulting of the physical characteristics of streams. Logistics regression
models coupled with stopping rules were used to predict the upstream extent of fish occurrences. Variables that were used for predictions were stream gradient, upstream watershed area, elevation and mean annual precipitation. When this model was compared to field surveys over 90% of the occupied habitat was correctly designated by the model. The small percentage of error occurred from marginal habitat, low topographic streams and streams that originated from head water ponds. Use of this type of model coupled with field surveys are more likely to reduce error and would improve efficiency and accuracy of the way current managers classify suitable habitat.


George et al. declare that water temperature is a vital part of aquatic ecosystems due to the fact that it plays a key role in determining the suitability of stream and river habitat to the majority of freshwater fish species. In this study continuous temperature loggers and airborne thermal infrared (TIR) were used to monitor temporal and spatial temperature patterns in New York Mountain streams. The objective of this paper were to characterize, 1, thermal conditions, 2, temporal and spatial variations in stressful water temperatures and 3, the availabilities of thermal refuges. In this research the in-stream temperature loggers recorded from October 2010 to October 2012 and displayed that summer water temperatures exceeded the 1 day and 7 day thermal tolerance limits for trout survival at five of the seven study sites during the summers. TIR information showed that there was minimal thermal refuge when the satellite flew over the region. The outcomes of this study show that summer temperatures in the majority of the study area are stressful for trout and most of the areas actually hinder growth and survival. It was stated that more studies are needed to confirm the conclusion that resident trout are in poor condition or non-existent in downstream portions of the study areas during summer months of warm water.


Hudy et al. studied and summarized previous knowledge in regards to the distribution and status of sustainable wild populations of brook trout (*Salvelinus fontinalis*) at the sub-watershed scale. This study was conducted across the native range of brook trout in the eastern United States of America, from Maine to Georgia. This paper exclaims that the region studied represents about 25% of the species entire original native range and 70% of the U.S. portion of the native range. This study resulted in an updated and more detailed range map, using GIS, to show the historical and current brook trout distribution. The authors used known and predicted brook trout status and each sub-watershed was classified due the percentage of historical brook trout habitat that is currently self-sustaining populations. This study deducted that 31% of the sub-watersheds contained over 50% of brook trout
habitat intact. 35% of watersheds had less than 50% of brook trout habitat intact, 28% of the watersheds brook trout were extirpated from and 5% of the watersheds brook trout were absent in with no known explanation. Classification and regression tree was created using five distinct metrics, total forest percentage, sulfate and nitrate deposition, percent mixed forest in the water corridor, percent agriculture and road density. These were used to predict brook trout distributions and statuses, to produce classification of habitat at a rate of 71%. The non-degraded watersheds had 94% if the forested areas intact, using over 68% of the land. The paper continues to describe that if rates of habitat loss persists from improper land use practices and the presence of naturalized exotic fish the remaining populations of brook trout will be threatened. The result of this paper is that the distribution of brook trout in the sub-watershed level paired with the related metrics listed above, can be used as a risk assessment to prioritize areas that are in need of the highest conservation efforts.


Kanno et al. analyzed the relationship between watershed scale and riparian scale factors in which brook trout (Salvelinus fontinalis) in headwater stream segments. A hierarchical Bayesian approach on GIS was used with a statewide stream survey dataset that encompassed brook trout detection probability that incorporated a statistical significance of environmental covariates that was based on credible intervals that were estimated. Forested land in the watershed level was the most important factor affecting brook trout occurrence. Heavily forested watersheds and in turn areas with low levels of development and minimal impervious surfaces were much more likely to be occupied by brook trout. Kanno et al. also determined that areas with course surficial geology, which is an indicator of groundwater potential, and stream slope, had a very significant and positive effect on brook trout presence. It was also found in this paper that herbaceous plant cover, wetlands and open water areas were considered to have significant negative effects on brook trout distribution. It was also found that watershed scale and riparian scale factors were highly correlated in most circumstances. The model used had high predictive ability and the fine spatial resolution of the study was able to identify patches of suitable riverine habitat for brook trout in Connecticut specifically in the northwestern region. The results of the paper showed a more hopeful status for brook trout in the study area that a more course spatial resolution studies that would have been done over a larger study area.


Kocovsky and Carline describe in their article that landscapes impact the ability of streams to produce trout due to the influence the landscape has on water chemistry and other factors in river reaches. Trout abundance oscillates on a temporal scale, due to this, to understand how spatial factors on the
landscape scale affect trout populations, monitoring changes in populations over time to offer framework for understanding the significance of spatial aspects. The data that was used for this study was from the Pennsylvania Fish and Boat Commission’s fisheries management database to look into spatial factors that affect the capacity of the river to support brook trout (Salvelinus fontinalis) to provide models for management practices. These authors assessed the importance of spatial and temporal variation; using GIS, this was done by calculating various mechanisms and comparing relative standard errors. To do this calculation, binary logistic regression was used to predict the presence of harvestable-length brook trout and multiple linear regressions was used to assess the links between landscape and trout populations to predict population density. Variation of trout density in rivers was equal to or higher than the temporal variation for several streams, depicting that differences among sites affecting populations. The logistic regression models used correctly predicted the absence of harvestable-length brook trout in 60% of the samples. Both the logistic and linear regression models that were run by the authors supported a buffering capacity against acidic incidences and an important feature the landscape contains and influences the trout populations. The results of the paper show that the models ran failed to predict trout densities precisely but the success was in linking landscape to the density of trout. The models also displayed the importance of spatial variation to understand factors affecting brook trout abundance. It was also claimed by the authors that these models and the facts they found will help managers and private consultants to protect and enhance populations of wild brook trout.


In this journal article written by Mollenhauer et al. describes that brook trout (Salvelinus fontinalis) populations face a complex web of threats throughout the native range of this species in the eastern United States. The comprehension of wild brook trout movement patterns and habitat preferences is crucial for conserving the populations that still currently exist and for habitat restoration efforts in regions with populations that are no longer self-sustaining. This study radio tracked 35 fish in headwater stream systems in central Pennsylvania during the fall and early winter of 2010-2011 to understand the uncertainties related to wild brook trout migrations and habitat selection. Multiple and various types of models were conducted to evaluate seasonal movement and habitat use. In these models there was variability among individual fish in movement patterns but generally the majority of the movements were associated with spawning season and correlated positively with the size of the fish and stream flow. There were some differences among fish in intermediate deep and deep pools but similar selection for shallow pools. Seasonal spawning is when fish opted for shallow pools followed by a selection for deeper pools once winter set in. The fish in this study showed a threshold for habitat selection with respect to pool attributes and selected for pools with larger pools up until 30 meters and any larger the pools were no longer selected for. The results of this paper showed two main points, 1, that linear models may not always provide an accurate representation of habitat use and migrations
causing problems for management and, 2, maintaining stream connectivity and habitat diversity are important for managing self-sustaining populations of brook trout.