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An Assessment of New Jersey Trout Production Systems : a Movement Towards Sustainability

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AN ASSESSMENT OF NEW JERSEY
TROUT PRODUCTION SYSTEMS:
A MOVEMENT TOWARDS SUSTAINABILITY

A DISSERTATION

Submitted to the Faculty of
Montclair State University in partial fulfillment
of the requirements
for the degree of Doctor of Philosophy

by

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Upper Montclair, NJ

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MONTCLAIR STATE UNIVERSITY

THE GRADUATE SCHOOL

DISSERTATION APPROVAL

We hereby approve the Dissertation

AN ASSESSMENT OF NEW JERSEY TROUT PRODUCTION SYSTEMS:

A MOVEMENT TOWARDS SUSTAINABILITY

of

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ABSTRACT

AN ASSESSMENT OF NEW JERSEY TROUT PRODUCTION SYSTEMS: A MOVEMENT TOWARDS SUSTAINABILITY

by Luke J. Diglio

New Jersey supports reproducing populations of three lotic salmonids. Only Brook Trout (*Salvelinus fontinalis*) are native and until approximately 100 years ago, were found in abundance throughout the northern part of the state. Presently, native populations have been documented in 115 streams or stream sections and declines are thought to be in response to anthropogenically originated environmental stressors. To evaluate the deterioration extent and assess numbers of breeding non-native Brown Trout (*Salmo trutta*) and Rainbow Trout (*Oncorhynchus mykiss*), comparisons are made between sets of historical (1968-1977) and modern (2001-2010) young-of-the-year presence/absence and abundance data and several geologic and land use/land cover characteristics hypothesized to influence species' occurrence. The range of reproducing Brown Trout populations have expanded, while groups of Rainbow and Brook Trout, as well as the overall amount of non-trout water have all decreased slightly. Results show that land use and land cover catchment value thresholds exist at < 12% agriculture, < 22% barren and urban, > 64% wetland and forest, and < 4-6% impervious cover to allow for natural Brook Trout reproduction. Values for Brown Trout reproduction include < 14% agriculture, < 27% barren and urban, > 58% wetland and forest, and < 5-7% impervious cover. Additionally, a previously undocumented Brook Trout metapopulation has been discovered with abundance estimates suggesting that a flourishing, reproductive and viable population is being maintained. Also, observed movement between connected waters allows for gene flow and overall isolation may permit the existence of one of New Jersey's remaining relict Brook Trout groups. Conservation of the once endemic native species has become a regional priority and a review of current lotic salmonid management strategies has identified some practices that may undermine protection efforts. Suggestions to reverse declines and bolster unique populations include: 1) establishing a 'Wild Native' angling regulation, 2) creating stricter land use directives to support more natural flows, 3) curtailing or cessation of domestic salmonid stocking at larger catchment levels, 4) developing hatchery operation expansion to include indigenous origin fish, 5) removal of non-native fish from favorable standing within the State's Wildlife Action Plan, and 6) obtaining new or reallocating current funds to support more research.

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DEDICATION

To Mom and Dad, for introducing me to all of this in the first place,

To Mar and Adam, for sharing in adventures that allowed for it to all be appreciated,

To Lesley, for continued encouragement to be ever wiser,

To Jillian and Katelyn, for the two most important reasons to make sure special and wonderful things are still able to exist, be experienced, and be found…

if you just go look for them.

Table of Contents

Content **Page**

LIST OF FIGURES

LIST OF TABLES

Table **Page**

LIST OF SYMBOLS/ABBREVIATIONS

AG	Agriculture land use or land cover
BAR	Barren land use or land cover
BFF	Bureau of Freshwater Fisheries
BFI	Base-flow index
BKT	Brook Trout
BNT	Brown Trout
C	Total number of fish caught in the second sample of the Chapman-Peterson method
CFMP	Coldwater Fisheries Management Plan
DELT	Deformity, Erosion, Lesion, or Tumor irregularity
EPA	Environmental Protection Agency
FOR	Forest land use or land cover
H	Historical
IBI	Index of Biotic Integrity
k	thousand
km	kilometer
LU/LC	Land use or land cover
M/M	(context dependent) Modern or million
M	Number of fish caught, marked and released in the first sample of the Chapman-Peterson method
mm	millimeter

MSY	Maximum Sustainable Yield
N	Population estimate of the Chapman-Peterson method
NJAC	New Jersey Administration Code
NJDEP	New Jersey Department of Environmental Protection
NJDFW	New Jersey Division of Fish and Wildlife
NJFIBI	New Jersey Fish Index of Biotic Integrity
NT	Non-trout
OSY	Optimum sustainable Yield
P/A	Presence or absence
PIC	Percent Impervious Cover
R	Number of recaptures in the second sample (fish marked and released in the first sample) of the Chapman-Peterson method.
RBT	Rainbow Trout
SWAP	State Wildlife Action Plan
TOT	Total
TP	Trout Production
VIE	Visual Implant Elastomer
WAT	Open Water
WET	Wetland
WTS	Wild Trout Stream
YOY	Young of the Year

Chapter 1

Introduction

1.1 Background

Prior to European settlement, North America harbored the greatest diversity worldwide of temperate freshwater fishes (Warren and Burr, 1994). Currently about 20% of the aquatic species in the US are critically imperiled (Heinz Center, 2002), as are 40% of North America's freshwater fish species (Walsh et al., 2009). The endangered, threatened, or vulnerable status extends to 700 different taxa and has increased by 92% in the past 20 years (Jelks et al., 2008). Additionally, three genera, twenty-seven species, and thirteen subspecies of North American fish have gone extinct in the last century (Miller et al., 1989).

As a group of fish, salmonids serve as biological indicators, with their presence in an area pointing to waterbodies with high water quality (Behnke, 2000). However, it is also known that salmonid populations have declined worldwide as a result of numerous anthropogenic activities (Fausch et al., 2006). Brook Trout (*Salvelinus fontinalis*), Brown Trout (*Salmo trutta*), and Rainbow Trout (*Oncorhynchus mykiss*) are not threatened with extinction or extirpation in the region of this study, but because they are considered coldwater fish that require high levels of water quality and habitat to survive and reproduce, their breeding presence in a stream system is noteworthy. New Jersey contains naturally reproducing populations of all three species (Hamilton and Barno, 2005).

Brook Trout are indigenous to eastern North America and the only salmonid native to New Jersey. MacCrimmon and Campbell (1969) relate that about 100 years ago these fish were found in abundance throughout most of the northern part of New Jersey. However, Hudy et al. (2005) have identified this species as experiencing large losses in the US, with 21% extirpation and 27% greatly reduced numbers throughout all the subwatersheds of their entire original range. Moreover, New Jersey ranks in the top five US locations for percentage of total watersheds where Brook Trout have been extirpated (Hudy et al., 2005). Due to these changes, Brook Trout have become a species of conservation concern (DeWeber and Wagner, 2015) with many state, federal, academic, and other conservation minded stakeholders taking an interest in understanding and rectifying the related issues at hand.

Due to their demands for waters of a pristine nature and intolerance to disturbance (Steedman, 1988; Wehrly et al., 2003; Ficke et al., 2009), Brook Trout are seen as the most sensitive of New Jersey’s three stream salmonid species and extremely susceptible to environmental changes. Several specific reasons have been suggested for causing native population declines, including warming of rivers from urbanization and dam building activities, fragmentation of systems by roads and dams, and competition with introduced non-native fish species (Hamilton and Barno, 2005; Hudy et al., 2005). In spite of these anthropogenic alterations, Brook Trout are known to maintain naturally reproducing populations within 115 streams or stream sections at the most recent count (S. Collenburg, NJDFW Asst. Biologist, personal communication).

Brook Trout have been designated as a species of regional priority within New Jersey due to their declining numbers and native status (Niles et al., 2004). Brook Trout require habitat that contains water of exceptional quality and identification of reproducing populations is a strong indicator of excellent overall water characteristics and minimally impacted watersheds. Furthermore, their presence or absence in watersheds has taken on an even larger importance due to the recent demonstration by Hamilton (2007) that several of the state's lotic systems hold relict populations related to those fish that swam in the region's waters after the retreat of the Wisconsinan glaciation, approximately 20,000 years ago. The identification of Brook Trout possessing a genetic structure of heritage stock elevates the status of all naturally reproducing fish for these groups are irreplaceable components to the region's natural heritage and important components to biodiversity within the state.

Many different attitudes exist as to how natural resources should be managed within the state of New Jersey (Responsive Management, 2003; 2010). One prevailing approach involves end users obtaining as much as possible from natural systems when these places are open to exploitation. This is possible due to regulators bearing the responsibility for ensuring these natural places are replenished with the goods and services being sought. Nielsen (1999) explains that such a philosophy adheres to the maximum sustainable yield (MSY) concept. As it relates to freshwater fisheries, this philosophy was most popular in the US between 1900 and 1950 and had wildlife managers stock and poison fish, build and modify water bodies, and regulate fish harvest "with the single aim of providing the greatest sustained quantity of fish" (Nielsen, 1999) to meet the needs of recreational angling and replenish declining fish numbers. Stocked fish were considered desirable as they fulfilled a need and their presence solved the perceived problem of not having ample supply of a resource. Resource managers very ably, successfully, and efficiently met their goals.

However, a newer approach has been formulated that is important to natural resource use and the systems from where they are found. Since the mid-1970's the concept of optimum sustainable yield (OSY) as a natural resource management strategy was identified. Consideration was given to the reality that fisheries are multifaceted and include biological, ecological, sociological, and economic resource aspects (Nielsen, 1999). No longer was a fisheries managers' single aim to maximize the physical fish yield. Resource management was to proceed in a way that realized a unique management goal exists for each situation and each fishery. In the US, fisheries are public resources held in trust by state and federal governments for the general use by all citizens and fishery management has been defined as, "the manipulation of aquatic organisms, aquatic environments, and their human users to produce sustained and ever increasing benefits for people" (Nielsen, 1999).

It may be true that a MSY goal can be simpler to reach compared to OSY, especially concerning stocking a water body with catchable sized fish, but an OSY approach is much more practical for it considers the fact that aquatic ecosystems are diverse and the human needs related to them are equally as diverse (Nielsen, 1999). Currently, part of fishery management focuses on the possible return of self-sustaining populations. Reliance on MSY goals for such sustainability is impossible, as even the best efforts fail to include all parts of the equation. Goals governed by OSY may be more difficult to reach, but they more rationally allow for attaining sustainability, as every aspect of the involved system is taken into account.

Salmonids have been described as one of the most important natural resources in North America (Jones et al., 1996). Dudgeon et al. (2006) relate that use of natural resources will undoubtedly involve compromise to meet the needs of all involved stakeholders. Species preservation is difficult within the larger context of a regulated activity such as fishery management so goals that are grounded in conservation are more likely to be supported and attainable. Nowhere is this more important than conserving the naturally reproducing Brook Trout populations of the New Jersey. Searching for ways to assist in maintaining or even expanding these groups is paramount, because every self-sustaining population is potentially a relict and possesses irreplaceable fragments of the genetic structure of the species. Through this research I seek to bring more clarity to the reasons for population strength and weakness and ultimately make advancements towards sustainability related to the management of freshwater fisheries within the state of New Jersey.

1.2 Research objectives

The first objective of this study was to evaluate several abiotic factors that were hypothesized to influence the presence, absence, and abundance of naturally reproducing lotic salmonids within the state of New Jersey. Through looking at historical and modern sets of data, comparisons could be made to ascertain which land use or land cover or other characteristics may be driving the types, numbers, and range of wild salmonids found within stream segments.

The second objective of this study was to ascertain the structure and movement of a previously unknown and potential relict Brook Trout group. The discovery of undocumented assemblages of fish is evidence that there is still much to learn regarding how to manage resources appropriately, especially within the modern context of multiple stakeholders interested in resources for different purposes. Furthermore, due to the noted decline in native salmonid populations in New Jersey, locating new native groups that are essentially cut off from the rest of the larger system and within the general vicinity of identified heritage fish could be useful for transplants or broodstock in future repopulation efforts.

The third objective of this research was to assess the management of salmonids within New Jersey with an emphasis on the only native species: Brook Trout. Much has been done recently to assist in strengthening or expanding naturally reproducing native groups, but continuing conservation needs still exist. Through a solid foundation based within related literature, practices that support, and those that may be undermining the process of wise management are investigated and suggestions are provided for a more sustainable pathway forward.

The fourth objective seeks to guide freshwater fishery coldwater salmonid management to include a movement toward sustainability. Conclusions from personally conducted research are cast within the larger purpose of moving some currently employed freshwater salmonids management strategies that are more MSY aligned to more of an OSY approach. Freshwater fishery management has changed a great deal since its first inception and there is room to improve management strategies. I believe this to be especially true with the added responsibility that has been incurred upon the revelation of irreplaceable components of our natural heritage still being amongst us today.

1.3 Organization of thesis

All chapters are briefly introduced as follows:

Chapter 2, *New Jersey's Land Use and Land Cover Change; Effects on Trout Production Waters,* evaluates the deterioration of naturally reproducing native salmonids, as well as the extent of wild groups of other lotic coldwater salmonid species. Additionally, reasons for observed changes are hypothesized with land use/land cover and other influential abiotic characteristics statistically correlated to salmonid species presence/absence and abundance between historical and modern data sets.

Chapter 3, *Headwaters case study: Raritan River-South Branch, Mt. Olive, New Jersey*, assesses the potential for a previously unknown isolated group of naturally reproducing Brook Trout to be able to serve as a source of wild broodstock. This research was conducted with mark and recapture methodology to assess population size and movement. The generation of population length-frequency histograms outlines the overall structure and movement of the individuals within the study area as well. The hypothesis of the existence of a thriving metapopulation is also investigated. Such an isolated group remains as an important discovery for there is a high likelihood that it remains uncompromised and contains a new large collection of heritage genes.

Chapter 4, *A Review of New Jersey's Management of Brook Trout Production Waters*, assesses the current management practices concerning New Jersey's freshwater fisheries as related to lotic salmonids. Due to New Jersey's status of having some of the worst population declines within the natural range of native Brook Trout, a qualitative assessment evaluates current and past management practices to assist in elucidating some reasons for the present level of the natural resource. Suggestions for additional approaches to help with bolstering native Brook Trout populations are offered with reasons for the incorporation of each outlined.

Chapter 5, *A Movement Toward Sustainability*, acknowledges the current status and efforts of freshwater fisheries management as it related to salmonids in New Jersey. The chapter also synthesizes what has been learned throughout this research and makes suggestions for a pathway forward to include a more sustainable component into freshwater fishery management within the state. Like any philosophical change, progress may take time for a newer paradigm to gain in practice or popularity. My attempt here is to create another opportunity for the concept of OSY to find a more successful place within a regulatory framework that is required to meet the needs of many different end users.

Chapter 2

New Jersey's Land Use and Land Cover Change; Effects on Trout Production Waters

Abstract

Despite having only one native trout species, New Jersey provides valuable lotic waters supporting three wild salmonids: Brook Trout (*Salvelinus fontinalis*), Brown Trout (*Salmo trutta*), and Rainbow Trout (*Oncorhynchus mykiss*). Found mainly in the northern part of this highly urbanized state, naturally reproducing populations of these coldwater fish are considered precious natural resources. However, it is commonly believed that Brook Trout numbers have declined in response to numerous environmental stressors over the last one hundred and fifty years. To more clearly evaluate the deterioration extent and assess numbers of breeding Brown and Rainbow Trout groups, this work makes comparisons between sets of historical (1968-1977) and modern (2001-2010) young-of-the-year presence/absence and abundance data and several land use, land cover, and other geologic characteristics hypothesized to influence species' occurrence. Investigations determine if relationships exist between factors at survey locations within each time frame. This research suggests that the ranges of reproducing Brown Trout populations are expanding, while similar groups of Rainbow and Brook Trout, as well as the overall amount of non-trout water, have all decreased slightly. Results showed that land use and land cover catchment value thresholds exist at < 12% agriculture, < 22% barren and urban, > 64% wetland and forest, and < 4-6% impervious cover to allow for natural Brook Trout reproduction. Similarly, values uncovered for Brown Trout

reproduction include < 14% agriculture, < 27% barren and urban, > 58% wetland and forest, and < 5-7% impervious cover.

2.1 Introduction

New Jersey's lotic trout supporting waters are currently located primarily in the northwestern portion (Figure 2-1) (Hamilton and Minervini, 1981; Hamilton and Barno, 2005) of this highly urbanized state (Brown et al., 2005). For the aesthetic, recreational, and other natural services provided, watersheds that maintain reproducing groups of these coldwater fish are extremely valuable and remain as important resources and popular destinations for the residents of this state (Responsive Management, 2003; 2010). Hamilton and Barno (2005) relate that streams and rivers in the Piedmont, Highlands, and Ridge and Valley physiographic provinces are known to hold natural groups of three trout and char species: Brook Trout, (*Salvelinus fontinalis)*, Brown Trout (*Salmo trutta*), and Rainbow Trout (*Oncorhynchus mykiss*). All belong to the subfamily Salmoninae of the Salmonidae family and, along with their specific names, collectively will also be referenced as salmonids throughout this writing.

Brook Trout are the only native salmonid to the state, but continued stocking for recreational angling purposes from as far back as the late 1800s and early 1900s has resulted in self-sustaining or naturalized populations of Rainbow and Brown Trout (Hamilton and Barno, 2005), as well as possibly domestic lineage Brook Trout strains. Hamilton and Barno (2005) also relate that 175 streams or stream sections have been identified as holding wild fish, which equates to about 5% of all of the streams of the state and composes over 1,000 miles (about 1,600 km) of water. Soldwedel (1979) tabulated the earliest number of streams or stream sections holding wild fish at 95. However, additional waters continue to be identified and added to this list during periodic re-inventory survey activities or as additional finer scale investigations discover previously unknown populations (Hamilton and Barno, 2005; Diglio and Bologna, 2012).

It has long been recognized that the existence of trout in an area strongly correlates with excellent water quality (Steedman, 1988; Hamilton and Barno, 2005; Ficke et al., 2009). Hamilton and Barno (2005) report that identification and classification of New Jersey's waters specifically for the presence of trout did not earnestly begin for Fish and Wildlife managers until 1968 and continued until 1972. During that time, ninety-five sampling sites provided data that were then used to establish a standard that could categorize the ability of a stream to support coldwater trout species. Managers used the data from this original five year effort to group waters into those that contain naturally reproducing salmonids, as well as the presence or absence of trout and/or trout associated species.

Soldwedel (1979) presents a list of the sampled waters and their subsequent classifications which in 1981 were officially recognized within the Department of Environmental Protection's Division of Water Resources under the State's Surface Water Quality Standards. These criteria essentially state that the more likely a waterway is to support trout, the greater its level of categorization and the more protection it receives (NJDEP, 2011). These standards still remain today as surveyed waters are placed into the following three classifications; 1) trout production, used by trout for spawning or nursery purposes during their first summer of life, 2) trout maintenance, used for the support of trout throughout the year, 3) non-trout, not used by trout for production or maintenance purposes. The New Jersey Surface Water Quality Standards are listed under N.J.A.C. 7:9B (NJDEP, 2011).

Trout production waters receive more strict regulatory land use restrictions. Streams earn such status when sampling identifies young-of-the-year (YOY) of any coldwater salmonid species during the summer months. Finding this age class of fish is extremely important because if found, it is likely they came from parents that spawned towards the end of the previous calendar year, making these offspring less than one year old upon summer capture. It is well known that trout require exceptional water quality and habitat to reproduce naturally and the existence of wild individuals points to unspoiled water conditions (Raleigh, 1982; Raleigh et al., 1984; Raleigh et al., 1986; Lyons et al., 1996). In the northern tier of New Jersey self-sustaining groups of these fish serve as biological indicators of the overall health of not only the waters in which they inhabit, but for the surrounding lands as well. Their breeding presence is an excellent indicator of high overall water quality, habitat, and minimally impacted watersheds. An observed absence of a previously noted existing wild group can be a cause for concern, as can a drop in overall population numbers or particular age class, especially the reduction or loss of YOY (Fausch, 1988; Schueler, 1994; Karr and Chu, 2000; Fausch, 2007; Steen et al., 2008).

Despite the land use regulatory protections designed to assist in preventing potential fish losses, Hamilton and Barno (2005) and Hudy et al. (2005) suggest that over the last century the most important factors influencing native trout populations in the state are due to increases in anthropogenic land use practices and have led to a decline in overall numbers and total watersheds inhabited. Specific problems seen in New Jersey are warming of rivers from urbanization and dam building activities, fragmentation of systems by roads and dams, and competition with introduced non-native fish species. MacCrimmon and Campbell (1969) relate that about 100 years ago Brook Trout were found in abundance throughout most of the northern part of the state and Hudy et al. (2005) has ranked the New Jersey in the top five US locations for percentage of total watersheds where these fish have been extirpated.

It is known that Brown and Rainbow Trout have the ability to competitively exclude Brook Trout through displacement due to more aggressive behavior (Fausch and White, 1981; Moore et al., 1983; Waters, 1983; Larson and Moore, 1985; Dewald and Wilzbach, 1992; Lohr and West, 1992), direct predation (Alexander, 1977), higher growth rate (Waters, 1983; Lyons et al., 1996; McKenna et al., 2013), greater fecundity (Clark and Rose, 1997), and taking advantage of erratic flow regime disturbance and related year class disruptions or failures (Waters, 1983; Clark and Rose, 1997; Fausch, 2008). It can be assumed that reproducing populations of all three species are going to interact with each other in New Jersey streams. Additionally, since Brown and Rainbow Trout are known to be tolerant of higher water temperatures (Magoulick and Wilzbach, 1998; Watson, 1999; Zorn et al., 2002; Baird and Krueger, 2003; Wehrly et al., 2003;

McKenna et al., 2013), related loss of forested land cover and altered surface and groundwater flows that follow increases in urbanization necessarily leads to warming of streams, lower overall water quality, and creates a circumstance for native Brook Trout numbers to decline and succumb to population replacement.

As native Brook Trout populations have dwindled to relicts of their former prominence in New Jersey, concern for their return to sustainable levels has called for ameliorative action to increase the following for this species: individual abundance levels, numbers of overall populations and related metapopulations, and direct connectivity of as many groups as possible. The best ways to achieve these ambitions still remain unknown. Recognized in Hamilton and Barno (2005), the need exists to manage the State's coldwater lotic systems in such a way that allows wild populations of all three trout species an opportunity to thrive. To assist with meeting that goal, previously sampled locations continue to be revisited by New Jersey Division of Fish and Wildlife (NJDFW) officials and undergo re-inventory surveys. Any trout production streams having historical data continue to be re-sampled to obtain current information, with the original waters from Soldwedel (1979) being re-sampled first in this effort. All data have been entered into NJDFW database *Fish Track*, which allows for comparisons between historical and modern examinations.

Determination of biological changes that have taken place over the decades within identified fluvial locations is important. Karr and Dudley (1981) define the biological integrity of aquatic ecosystems as "the capability of supporting and maintaining a balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of natural habitat of the region." Fish community assemblages are excellent indicators of the relative health of the aquatic ecosystem in which they are found and both are also known to be reflections of the surrounding watershed conditions (Fausch et al., 1990). Other than natural environmental fluctuations and stochastic events, Fausch et al. (1990) state that the main agents of stress in communities of fish are human induced disturbances. Such actions often lead to environmental decline. Impairment levels or information related to important deterioration thresholds can go unnoticed unless some measureable way of observing them exists.

Fish are used as indicators of environmental change because they hold a high level of economic and aesthetic value (Responsive Management, 2003; 2010) and the public generally understands when declines occur and support corrective actions that address deterioration (Karr, 1981) brought about by anthropogenic activities. Compared to other organisms used for biological monitoring, fish are extremely helpful in this regard because they can be affected by many direct and indirect stressors and since they are generally long-lived, their populations reflect a lengthy and cumulative record of environmental impacts (Karr et al., 1986; Fausch et al., 1990). The Index of Biotic Integrity, or IBI, was designed as a tool used to assess the quality of running waters based upon the types and amounts of fish found in different regions of the US (Karr, 1981; Karr et al., 1986). Kurtenbach (1994) created the IBI for fish in northern New Jersey (NJFIBI) that was later refined and adjusted (Vile, 2008) to better meet the specific attributes found in the region. When employing this method, researchers collect fish using standard electrofishing protocols (Barbour et al., 1999) within a 150 m length and all individuals are identified to the species level and enumerated. Vile (2008) reports that subsequent data sets are organized by ten specific metrics and each category earns a score of one, three, or five (Table 2-1). All scores are summed and waters attain a final tabulation from 10-50 that ultimately rank locations as poor (10-28), fair (29-36), good (37-44), and excellent (45-50) (Vile, 2008).

Within the NJFIBI, two metrics specifically focus on trout; metric three looks at the number of total trout in the survey and metric eight calculates the proportion of all individuals in a sample as trout. Trout are viewed as important indicators of overall stream health because of their sensitivity and need for excellent water quality. However, the mere presence of trout in a body of water does not always indicate areas are of high condition. If averaged, over the last four years NJDFW annually stocks over 596,000 Brook, Brown, and Rainbow Trout (NJDFW, 2015), so finding a coldwater salmonid may only mean a fish was released in that locale or moved there from a nearby stocking point. A better gauge of a stream's well-being concerns finding trout that were born in a particular waterbody. Locating YOY salmonids during the summer months when stream conditions are severe due to waters typically being at base-flow and temperatures are elevated, suggests it was born within the system. Finding coldwater fish under such stressful conditions suggests exceptional water quality exists throughout the year affording trout the opportunity to survive. All three species of New Jersey's lotic trout spawn in the fall or early winter and it is known that this occurrence takes place naturally for Brook and Brown Trout. Recent observations in a study previously being conducted under the guidance of NJDFW have identified Rainbow Trout redds in the autumn as well (B. Neilan, pers. comm.).

Many researchers have relied on trout presence or absence (P/A) data to ascertain stream water quality (Barton, et al., 1985; Steedman, 1988; Wang et al., 2003b; Vondracek et al., 2005; Stanfield et al., 2006; Steen et al., 2006; Steen et al., 2008; Stranko et al., 2008; Smith and Sklarew, 2012), while others have focused on trout abundance or fish density per sample length (Steedman, 1988; Wang et al., 2003b; McKenna and Johnson, 2011; Smith and Sklarew, 2012) to gain an understanding of the characteristics of the waters from where the fish were sampled. Both total biomass and P/A numbers are influenced by landscapes and land use surrounding flowing waters in numerous ways, including temperature fluctuations, changes in flow rates, and associated sedimentation rates (Wang et al., 1997; Diana et al., 2006). Such biological metrics are extremely useful in providing information on fish stock health in sample reaches (McKenna and Johnson, 2011) and present helpful insights into what is occurring in the watershed and waterbody from where they drain. Relationships of this nature are true for the members of the Salmonidae family, with impacts readily affecting all of the trout, salmon, and char of the subfamily Salmoninae. Such connections are most easily observable related to New Jersey’s least tolerant species, the Brook Trout (Lyons et al., 1996; Stranko, et al. 2008).

Wang et al. (2003b) explain that P/A shows how frequent fish are found, while abundance numbers relate the success level of a species. Smith and Sklarew (2012) suggest that abundance numbers are a more nuanced description of the relationship between trout and another metric because fish quantity more strongly correlated to land characteristics than simple P/A. Both quantitative strategies are included in this current research. The purpose of this chapter is to tie specific survey location YOY trout species P/A or abundance numbers to particular LU/LC characteristics measured between two time periods. Understanding connections of this nature are essential to managing fish populations and may uncover answers as to why some populations have remained stable and why changes have occurred in others. Observed threshold levels may help to explain fish assemblage changes and can assist in directing conservation, restoration, and other future fishery resource management actions.

2.2 Methods

Paper copies of the sample locations identified in the Solwedel (1979) original five year endeavor (1968-1972) were obtained from the data housed at the NJDFW Bureau of Freshwater Fisheries (BFF) Lebanon, NJ Field Office. All original data sheets were assessed to verify information accuracy and extensive efforts were taken to validate all sample locations. It was discovered that some information in the original report was inaccurate and some records remained unconfirmed. In several instances data sheets clearly identified YOY trout in surveys, but waters were listed as trout maintenance, or even non-trout. Additionally, several reasons for excluding specific surveys or survey data include lost, incorrect, or indiscernible information contained on the data sheets; mistaken follow-up survey locations; locations that contained no water upon the follow up effort; or sites that had any portion of their upstream catchment contained in another state. The survey locations with portions of their watershed outside New Jersey were eliminated because I was unable to obtain land use and land cover information for these catchments. In light of the inability to validate certain records and the discovery that a more expansive pool of data existed, the dates of the earliest work were expanded to include surveys up until the year 1977. Modern comparison data were then expanded from the original 2001-2005 time frame to include surveys up to and including 2010.

Through the combination of original data sheet hard copies, a *Fish Track* catalog data pull, and ArcGIS (version 9; Environmental Systems Research Institute (ESRI), Redlands, CA) geographic information system mapping software, I confirmed eighty survey pairs (one hundred sixty sample events) that met the criteria of occurring within the delineated time frame, in the proper stream location, and containing YOY in one of the two surveys. While modern surveys include latitude and longitude coordinates that were plottable on GIS mapping software, equivalent information for the beginning time frame does not exist as GPS was not yet commercially available. In these instances, corresponding site positions were ascertained from included survey location descriptions and checked against appropriate GIS layers. Examples of descriptors that aided in this process include noted road and bridge crossings, village names, and other listed natural and man-made landmarks. Sites were also indicated on paper United States Geologic Survey 1:24,000 topographic quadrangle maps housed at the BFF and compared for reference. For a variety of reasons, some of the intended analogous positions did not exactly match up, but such situations were still considered a valid match as long as the sample points were within 0.25 miles (about 400 m) of each other.

The total upstream land area draining to each plotted point can be defined as a catchment (Brenden et al., 2006; Johnson et al., 2009). I used digitized United States Geologic Survey topographic maps, the contour lines and they contain, and ArcGIS to digitally hand draw the lower boundary of each drainage area, as other researchers have done (Steedman, 1988; Wang et al., 2000; Stranko et al., 2008). To ascertain the total upstream land area of combined catchments that would affect each survey point, the drawn edge was then incorporated into the available USGS National Hydrography Dataset Plus (NHDPlus, 2006) elevation-derived catchment drainage area GIS layer. Watershed catchment shape files for each location were then placed over GIS vector or raster layers of abiotic characteristics that were hypothesized to be influential in trout YOY P/A and overall abundance. Shapefiles were clipped out for each characteristic (converting raster data to vectors when needed) and adjusted attribute tables allowed for each factor's total acre or percentage calculation.

From the accompanying listed GIS layers, I determined watershed catchment information for the following characteristics: bedrock geology (NJDEP/NJGS, 1999), 1972 land cover (CRSSA, 2000), and 2007 land use/land cover (NJDEP, 2010). Due to the relative influence bedrock can have on salmonid populations (Weiss and Schmutz, 1999), I further divided the bedrock geology information into two categories: rocks that are composed of carbonates (limestone or dolomite) and rocks that are considered non-carbonates (all others). Average yearly base-flow (BFI) (Wolock, 2003) was also included. Base-flow is the component of streamflow that is attributable to ground-water discharge in streams and the BFI is a ratio of base-flow to total flow volume expressed as a percentage for a given year. While not as precise as other analysis, the approach is consistent, indicative of base-flow levels, and relies on a grid that was interpolated from point value estimates for USGS stream gages (Wolock, 2003). Additionally, based on Anderson et al. (1976), the 1972 and 2007 land use/land cover data were organized into the following six different groupings: agriculture (AG), barren (BAR), developed/urban (DEV), forest (FOR), open water (WAT), and wetland (WET). Lastly, the 2007 data included impervious surface acreage. It was included within the attribute information and converted into percentage of the catchment area. These are henceforth referenced as impervious cover.

As with the current approach, electrofishing was the main method used to sample streams in the late 1960s and early to mid-1970s. During the modern era, stream sampling procedures follow those outlined in Hamilton and Barno (2005) and mirror the specifics presented in Environmental Protection Agency's (EPA) 'Rapid Bioassessment Protocols for Use In Wadeable Streams and Rivers' (Barbour et al., 1999). With block nets situated to signal the ending point, a single up-stream pass is made through a 150 m section of water. Depending on the size of the waterbody (Dunham et al., 2009), single or multiple backpack units, a streamside generator or one positioned on a floatable barge employ one to four amps of pulsed direct electric current to sample the waterbody. Upon completion of the measured distance, individual fish were enumerated by species and total length measurements in millimeters taken on all salmonids. The previous generation of field work relied on an alternating current generator with about 2 amps of current flow to sample six-hundred feet of stream, or the equivalent of just less than 183 m. To coincide with factors that are known to limit the range and survivability of coldwater salmonids, surveys occurred in the summer months from June through mid-September in both the current and historical sampling cases. During these months, stream base-flow conditions exist and potentially the warmest water temperatures of the year are expected.

Currently, any trout found to be less than 100 mm in total length at this time of year is considered to be a YOY individual (Hamilton and Barno, 2005). While the surveys of the late 1960s and early 1970s did not always take specific fish length measurements, the biologists' professional judgment categorized individuals into two age class distinctions, YOY and all others (sub-adults as well as adults). I believe these youngest individuals were around the significant 100 mm YOY size limit of today's standards.

Hypothesized abiotic factors related to YOY abundance of the three New Jersey resident salmonid species were compared using Pearson correlation coefficient (*r*) analysis (SAS®(PROC CORR), Cary, NC). Others have looked for data trends in a similar way (Diana et al., 2006; Wang et al., 2000; Rashleigh et al., 2005; Wang et al., 2000). More specifically, abiotic values were set against the YOY number of each species in each time frame, the total combined YOY value of all species per survey (either 183 m or 150 m, depending on whether the data were historical or modern respectively), and the number of each species YOY per meter. Where each variable was evaluated against each other variable, as well as throughout all statistical analyses in this research, findings were considered significant if $p < 0.05$.

Additionally, UseableStats (Measuring Usability LLC, Denver, CO) statistical software was employed to compare YOY presence or absence of all three trout species individually to percentage and total overall land use or land cover acreage variables. The six LU/LC categories previously used were modified to create four data groups (sensu Diana et al., 2006). The agriculture and open water metrics remained the same, but I combined the numbers for barren and developed LU/LC to reflect a how these places are in a more disturbed state, and wetlands and forests were joined to echo their more natural condition. Other similar studies have used different types of *t*-tests to understand their data (Wang et al., 1997; Wang et al., 2000). My efforts relied on the use of a two sample *t*-test of independent means by way of the Welch-Satterthwaite procedure to determine the relationship and discover the means of different land uses on particular species YOY P/A percentage and total acres LU/LC between the two time frames. Statistically significant values (α=0.05) reflect differences in land use between where YOY were collected (present) versus where YOY were not gathered (absent). Due to the heteroscedacity of the gathered land use data for each particular category, as seen in Steen et al. (2006), mathematical transformations were performed to homogenize the variance for each group through the use of arcsin for the percentage values and square root for the total acre information.

Moreover, *t*-tests were conducted to make comparisons of YOY presence in each time period to overall total subwatershed acreage size. Further use of *t*-tests involved the

NJFIBI. Since this metric is only able to assess the health of lotic systems in those places that have catchments of at least 5 miles squared (about 8.1 square kilometers), I created a spreadsheet template in Microsoft Excel (Microsoft Office 10, Redman, WA) and following Vile (2008), generated an IBI score at twenty-four locations of my 80 paired historical and modern sample sites and compared calculated means. Finally, *t*-tests were again used with percentage and total acreage LU/LC and YOY species P/A data to make comparisons between the characteristics of catchment values when shifts (losses or gains) of each species took place. In the same way, I also investigated LU/LC changes for waters classified as trout production, regardless of the species, and those known to be of a non-trout quality.

2.3 Results

Eighty individual sample locations from seventy-six different streams and rivers were used in this study and account for one hundred sixty total surveys. Between the catchments in the survey locations and the two studied time frames, the mean value of farmed, forested, and wetland LU/LC in New Jersey has dropped, while the amount of barren and developed land and amount of open water has increased. Significant changes in LU/LC occurred in barren areas ($t = 2.7$, $p = 0.007$), developed places ($t = 10.6$, $p < 0.001$), and forested lands ($t = -5.25$, $p < 0.001$). During this same time period the overall mean IBI score for the 24 catchment locations that were large enough to be included within in this research has increased significantly ($t = 3.19$, $p = 0.003$) (Table 2-2). On average the earlier time frame had a score of 34 and rose to a value of 40. In terms of the IBI rank scale, the scores moved positively from fair to good.

With the exception of one species, the general breakdown of the presence or absence of young-of-the-year by stream during the two time frames of this study remained generally stable (Table 2-3). From the 1968-1977 (historical) data set, Brook Trout YOY were present in 41 streams and absent in 39, Brown Trout YOY were present in 32 streams and absent in 48, and Rainbow Trout YOY were present in 9 streams and absent in 71. A total of 11 streams were of non-trout classification in the historical time frame, but were later able to be classified as trout production. In the 2001-2010 (modern) data set, Brook Trout YOY were present in 42 streams and absent in 38, while Brown Trout YOY were present in 46 streams and absent in 34, Rainbow Trout were present in 8 water bodies and absent in 72 stream. Additionally, seven streams that were trout production on the earlier data set were found to contain no trout in the latter time frame.

Specific changes include ten streams that did not find Brook Trout in the second survey, while eleven water bodies showed new Brook Trout presence (Table 2-4, A and B). Brown Trout were not located again in seven places, but were gained in twenty-one cases (Table 2-4, C). Rainbow Trout were not gathered again from five waters, but subsequently found in four surveys. In seven instances trout production waters turned into non-trout areas, and conversely, in eleven situations non-trout waters we able to be reclassified as trout production after the second survey (Table 2-4, D and E).

Many changes have taken place in the presence and absence of the three species of coldwater salmonids’ young-of-the-year in New Jersey’s lotic ecosystems (Appendix

A). By way of locating the presence of YOY, reproducing populations of Brook Trout were found in 52 of the 160 surveys at one time or another and they were present in both time frames at 31 of the 80 locations. There were ten instances where these fish were found in the first time frame (Table 2-4, A), with Brown Trout replacing the Brooks in three instances. In three other reclassification losses, Brook Trout were found living with Brown Trout in the first time frame, but after the second survey only Brown Trout were sampled. In one other instance, sampled waters were first known to contain Brook Trout with Rainbow Trout, but later only Brown and Rainbow Trout were found. In the remaining three locations that originally contained Brook Trout, no young-of-the-year trout of any trout species were encountered in the second sampling. In eleven other locations, Brook Trout were collected in the second survey after not being seen in the historical sampling (Table 2-4, B). Two of the gains had non-trout waters turn into Brook Trout production areas, and in another original non-trout area had the survey location later hold both Brook and Brown Trout. Two other surveys had Brook Trout replace Brown Trout, and one had Brook Trout replace Rainbow Trout. In four instances Brown Trout waters gave way to Brook and Brown Trout living together, and one case had Brown Trout now sharing space with Brook and Rainbow Trout when historically waters were purely Brown Trout.

Study results concerning Brown Trout show that YOY were located at 53 of the 160 surveys at some point during either time frame and Brown Trout were found upon both inspections 25 times. Brown Trout were not collected from the recent surveys in seven instances. In three cases Brown Trout waters turned into non-trout areas, in two cases reproducing populations consisting solely of Brown Trout were replaced by Brook Trout, and in two other instances waters where Brook and Brown Trout were historically found together have turned into Brook Trout only waters. Conversely, Brown Trout were collected in the second survey in 21 streams where they had not been previously found (Table 2-4, C). Specifically, in ten cases only Brown Trout were found most recently with three occasions of allopatric Brook Trout waters changing to allopatric Brown Trout locations and seven non-trout areas becoming allopatric Brown Trout. Seven other times had historical Brook Trout waters give way to Brook Trout sharing space with Brown Trout. In one case solely Rainbow Trout waters changed to a Rainbow and Brown Trout location. Finally, in one instance Brook and Rainbow Trout YOY found originally in sympatry were replaced by sympatric Brown and Rainbow Trout groups, and in another case, sympatric Brook and Rainbow Trout changed to a sympatric Brook and Brown stream section in the modern work.

Lastly, Rainbow Trout YOY were present in both surveys only 4 of the 80 sample times, but were sampled in 13 locations out of the 160 at one time or another. Generally, from the historical to modern surveys, reproducing populations were not identified in five streams and four streams gained wild groups of Rainbow Trout. Specifically, one stream would be reclassified as non-trout, one changed from Brook and Rainbow Trout to Brook and Brown Trout, and another went from Brook and Rainbow Trout to Brook Trout only. Finally, Rainbows were replaced by Brooks once, and Rainbows living with Browns changed to allopatric Brown Trout waters one time also. On the other hand, four locations saw waters gain young-of-the-year Rainbow Trout. One went from non-trout to trout production, two went from Brown Trout only to Brown and Rainbow Trout, and a sole location changed from only Brown Trout to Brown, Brook, and Rainbow Trout waters.

It is also noteworthy that in seven instances waters originally classified as trout production were later found to be non-trout (Table 2-4, D) and in eleven other cases non-trout locations were reclassified as trout production (Table 2-4, E). Losses include three waters that initially contained Brook Trout, three that contained Brown Trout, and one known to hold Rainbow Trout. Newly classified trout production streams occurred three times to include Brook Trout, twice as the only species present and once in sympatry with Brown Trout. Seven streams were reclassified from non-trout waters to Brown Trout production and one was reclassified from non-trout to Rainbow Trout production. Figure 2-2 illustrates the relative presence of breakdown YOY occurring in stream segments of all salmonid species for the two survey periods. Comparatively, of the waters included in the survey, non-trout areas have decreased from 14% to 9%. Additionally, my findings suggest that the overall range of the reproducing Brook Trout and Rainbow Trout has shrunk but, the areas where wild Brown Trout are found is expanding. Allopatric Brook Trout waters have decreased in from 36% to 30% and sympatry with Browns has gone up from 11% to 21%. Brook Trout sympatry with Rainbow Trout has decreased to zero (from 4%) and although minor, total percentages of times Brook Trout were involved in surveys rose from 51% to 52%.

Brown Trout locations have increased from 40% to 57%, with 30% as allopatric, 21% as sympatric with Brooks, and 6% with Rainbows or Rainbows and Brooks.

Percentage of Rainbow Trout waters has decreased from the historical work to the modern surveys from 6% to 4%. Overall, total percentage of waters where YOY Rainbow Trout were found in any capacity have dropped slightly from 11% to 10%, with no modern groups seen living with Brook Trout when historically 4% did. An increase of sympatry between Rainbows and Brown Trout occurred as numbers have gone from 1% to 5%. In the modern work, one instance (1%) was found where Rainbow Trout YOY were sampled alongside Brown and Brook Trout YOY. In conclusion, numbers of waters holding Rainbow and Brook Trout YOY have given way to either allopatric Brown Trout waters or waters with Brooks and Browns or Rainbows and Browns living in sympatry. Loss of allopatric Brook Trout YOY in the second time frame is also higher than either allopatric Brown or Rainbow Trout losses.

Brook Trout YOY abundance and number per meter correlation results were weakly negative surrounding the total acreage data from the 1972 time frame related to agriculture (AG) (r = -0.229, p = 0.0406), developed (DEV) (r = -0.21859, p = 0.0514) and forest (FOR) (r= -0.22516, p = 0.0446) LU/LC. The number of total acres (TOT) from the 1972 time frame also displayed a weakly negative correlation (r = -0.2429, p = 0.0299) (Table 2-5). I did not see similar relationships with any other variables in this specific scenario, in the acre category devoted to land uses of the 2007 data, or with percentage land uses for either time frame.

Significance of the other non LU/LC data occurred for YOY from the 2007 timeframe (Table 2-6). Specifically, a positive relationship occurred between percent impervious cover (IC) and amount of developed acres (r = 0.24267, p = 0.0301), the percent of catchments in developed LU/LC (r = 0.88657, $p < 0.001$) and a strong negative relationship took place between IC and percentage forest LU/LC (r = 0.55855, $p < 0.0001$). Significant results occurred involving the average base-flow (BFI) characteristic and percentages of LU/LC devoted to developed and forested areas, as well as percent land covered with impervious surfaces. I found a strong positive correlation between average base-flow and impervious cover (r = 0.44855, $p < 0.0001$), and there was a strong positive relationship between BFI and percentage developed land (r = 0.42859, $p < 0.0001$), and a strong negative relationship between BFI and percentage forest (r = -0.40724, p = 0.0002). No other significant results occurred in the correlations.

Additionally relationships between P/A and LU/LC parameters, when traits were grouped in a way that linked similarities of how the land was modified as percent agriculture (AG), barren and developed (BAR+DEV) (altered), wetlands and forest (WET+FOR) (natural), and open water (WAT) a few cases of significance were seen (Table 2-7). No clear trends in the percentage LU/LC data emerged between both time frames. However, significance occurred in the historical association of Brook Trout related to the BAR+DEV parameter. Natives were present in surveys when catchments were on average 3% covered with this altered LU/LC type and absent when altered lands reached 7% (t = 2.890, p = 0.0051). Open water significantly affected Brook Trout presence also, but this took place in the modern surveys. The threshold at which Brook Trout were no longer occurring in samples was seen for open water at 1.5% (t = 2.248, p = 0.0290). Also from the modern surveys Brown Trout were influenced significantly by the natural LU/LC (WET+ FOR) in that they were present in catchments that contained on average 58% natural cover, but were no longer recorded when watershed averaged 67% (t = 2.205, *p* = 0.0312). Also in the modern surveys set Rainbow Trout were more often found in areas of low agriculture land use and in general, when agriculture exceeded 13%, this species did not occur (t = 4.888, *p* < 0.0001). Finally, waters that became non-trout in the modern surveys showed increases in disturbed habitats (BAR+DEV) than trout production waters, with 14% and 26% seen respectively (t = 2.353, *p* = 0.0508), as well as for open waters at 2.5% and 1.2% (t = 2.306, *p* = 0.0415). No other statistical significance was found in the data as related to percentage LU/LC and P/A.

Total acreage of each LU/LC parameter had a more significant role with trout YOY presence and absence in survey locations than overall percentage data (Table 2-8). Not surprisingly, but most noteworthy, is the fact that Brook Trout were significantly and consistently (occurring in both time frames) present in catchments that averaged smaller total acreage than where they were absent. Historically these fish were located in catchments averaging 1,783 acres and absent when areas averaged 6,108 acres (t = 3.858, *p* = 0.0003). In the modern data set, Brook Trout were present when catchments averaged 2, 119 acres and absent when places averaged 5,850 acres (t = 3.129, *p* = 0.0030). I did also discover significance in both the historical and modern time frames concerning Brook Trout and sensitivity to total acreage for all LU/LC characteristics. Again, they were always found where agriculture (AG) (t = 2.859, *p* = 0.0188 and t = 2.5145, *p* = 0.0309), disturbed areas (BAR+DEV) (t = 4.819, *p* = 0.0018 and t = 3.637, *p*

= 0.0163), and open water (WAT) acres (t = 2.577, *p* = 0.0133 and t = 2.824, *p* = 0.070) were lowest. However, these fish were also always found were natural areas (WET+FOR) (t = 3.569, *p* = 0.0168 and t = 2.638, *p* = 0.0683) were lowest, a result which is counterintuitive to high quality habitat which yields good water quality. Interestingly, the significant *t* - test results from the historical time frame have connections to the correlations from that time as well. Agriculture, developed, and forested lands all have negative relationships to Brook Trout abundance and number per meter.

Furthermore, from the modern surveys, I found that Brown Trout YOY were on average more likely to be located where agriculture (AG) (t = -2.228, *p* = 0.0288) and disturbed (BAR+DEV) (t = -2.750, *p* = 0.0074) was higher and were absent where these land uses were lower on average. Rainbow Trout were again associated with lower total amount of agriculture (AG) (t = 2.052, *p* = 0.0002). Finally, the historical surveys showed that non-trout waters were much more associated with disturbed (BAR+DEV) (t = 2.5561, *p* = 0.0286) land cover than trout production waters.

Looking specifically at P/A species shifts between the two time frames did produce some significant results (Table 2-9). As might be expected, catchments that experienced the loss of Brook Trout YOY saw significant increases of both percentage and total acres of the disturbed (BAR+DEV) LU/LC characteristic (t = 2.868, *p* = 0.016 and t = 3.458, *p* = 0.007). However, in the catchments where Brook Trout YOY presence increased, percentage of barren and developed land areas went up (t = -4.290, *p* = 0.001), as did wetland and forest areas (t = 2.213, *p* = 0.017). Similarly to Brook Trout, where new Brown Trout presence was observed in catchments, the percentage and total acreage devoted to disturbed (BAR+DEV) LU/LC increased (t = -6.790, $p = 0.001$ and t = -2.399, $p = 0.022$), and the percentage natural (WET+FOR) LU/LC decreased (t= 3.554, $p = 0.001$). Finally, in the locations that went from non-trout in the historical surveys to trout production in the modern samples, on average, disturbed (BAR+DEV) lands increased (t = -7.035, $p < 0.001$) and natural (WET+FOR) areas decreased (t = 5.029, $p < 0.001$).

2.4 Discussion

Increased species distribution comprehension and general knowledge regarding shifts in populations leads to better fish assemblage management. Such information is especially important since North America once harbored the greatest diversity worldwide of temperate freshwater fishes (Warren and Burr, 1994). However, it is known that about 20% of the aquatic species in the US are critically imperiled (Heinz Center, 2002), as are 40% of North America’s freshwater fish species (Walsh et al., 2009). The endangered, threatened, or vulnerable status extends to 700 different taxa and frighteningly has increased by 92% in the past 20 years (Jelks et al., 2008). Additionally, three genera, twenty-seven species, and thirteen subspecies of North American fish have gone extinct in the last century (Miller et al., 1989). Brook, Brown, and Rainbow Trout are not threatened with extinction in the region of this study, but because they are considered coldwater fish that require quality habitat to survive and reproduce, their breeding presence designates high value environments. However, of the three species, Brook

Trout require habitat that contains water of the highest quality, so the presence of any of these YOY is significant and indicates that lands surrounding a sampled stream reach have been impacted minimally.

Due to their intolerance of disturbance (Steedman, 1988; Wehrly et al., 2003; Ficke et al., 2009), Brook Trout are the most sensitive of New Jersey's three natural reproducing stream salmonids species. As a result, Brook Trout are extremely susceptibility to environmental changes and Hudy et al. (2005) have identified these fish as experiencing large losses in the US with 21% extirpation and 27% greatly reduced numbers throughout all the subwatersheds of their entire original range. Additionally, since this species is the only salmonid indigenous to New Jersey, and this state ranks in the top five US locations for percentage of total watersheds where they have been extirpated (Hudy et al., 2005), identifying streams containing Brook Trout YOY and protecting both is paramount. Finally, Brook Trout presence or absence in the New Jersey has taken on an even larger importance due to the recent demonstration by Hamilton (2007) that several flowing waterbodies there hold relict populations that may be direct descendants of those that swam in our waters upon the retreat of the last glaciation.

The overall decrease in percentage of non-trout waters in this present study suggests that water quality in New Jersey streams has improved. Such a result makes sense since the survey periods bracket the implementation of the Clean Water Act, producing an overall increase in water quality within the United States. The NJFIBI investigation also supports the general water quality recovery observation and might possibly reflect a larger regional occurrence. However, it should be noted that the NJFIBI has only been in use for approximately two decades. Differences between the survey time frames' fish assemblages may be an artifact of sampling effort that seeks to gather all individuals and species in the modern work when compared to historical efforts that primarily were searching for trout. Additionally, sampling gear may not have been as effective in the past when compared to modern equipment that is designed to be specifically adjusted to meet the criteria of each stream's characteristics. Lastly, overall fish diversity in the modern samples may be skewed higher as a result of the greater number of non-native species that were not seen historically, but are now expanding their ranges.

In spite of these caveats, it seems that New Jersey is experiencing a positive trend, especially since this has all taken place while the State's land use/land cover has been modified so much. The drop in farming may be seen as a positive change for trout habitat improvement. However, this may be offset by the increase in other human related LU/LC disturbances of barren, developed, and open water areas. Coupling these changes with a decrease in natural forest and wetland land cover, it is understandable why native salmonids, fish that require clean and cold water to live, thrive, and reproduce, are struggling to survive in New Jersey (Hudy et al., 2005; 2008). However, there are various other factors involved in this process besides those included in this research that may have an equal or greater influence on trout numbers, especially in the waters that have gone from, or changed to, non-trout classification.

Upon closer inspection, care must be taken in understanding the observed changes since reproducing exotic Brown Trout have been able to expand their range. In most instances, New Jersey waters that went from being devoid of coldwater salmonids to containing reproducing populations (i.e., YOY) involved non-native Brown Trout. The 17% gain in steam assemblages that include Brown Trout is remarkable since total percentages of Rainbow and Brook Trout have respectively either decreased or risen negligibly over the same time period. It is plausible that in the cases involving Brown Trout production, water quality improved to the point that they were able to survive in new areas, but due the Brook Trout's need for cold water (MacCrimmon and Campbell, 1969; McCormick et al., 1972; Wehrly et al., 2003; Kratzer and Warren, 2013) and systems that remain relatively undisturbed (Wang et al., 2006; Stanfield et al., 2006; Hudy et al., 2008), water quality and habitat improvement were insufficient to allow these stream segments to support Brook Trout.

However, the most recent surveys have indicated that Brook Trout populations have been identified in several stream segments which previously were not classified to hold them. Consequently, it is probable that water quality has improved to the point that Brook Trout might be able to survive and reproduce in New Jersey's newly available areas as this species has been shown to recolonize previously disturbed areas (Phinney, 1975; Roghair and Dolloff, 2005). Despite this fact, their expansion may be limited by stream fragmentation from man-made impoundments, natural physical barriers, or other stream obstacles. More likely it is that populations may not have any direct route to expand into open or improving habitats. Lastly, it is possible that Brook Trout did manage to locate these new places, but upon arrival they were out competed by naturalized non-native salmonids or even domesticated stocked fish (McKenna and Johnson, 2011). Regardless, Brown Trout are advancing into new waterways, while evidence suggests Brook Trout are in decline.

The abundance and richness of aquatic organisms found in riverine systems are limited by the quality of water in stream segments (Pegg and Chick, 2010). This is especially true for fish (Dauwalter et al., 2010) and even more so for more sensitive species like coldwater salmonids (Kocovsky and Carline, 2006; Rieman et al., 2001; Hunter, 1991; Wiley et al., 1997). I searched for potential reasons for observed changes because watersheds readily act to influence the characteristics of the lotic systems into which they drain (Steedman, 1988; Allan, 2004; Vondracek et al., 2005; Diana et al., 2006; Galster, 2008; Hudy et al., 2008). To better comprehend observed changes within this region of study, I explored the linkage between presence or absence of YOY coldwater fish species and the management of lands surrounding sample reaches. Related to the biological make-up of any ecosystem, Levin (1992) stated that “different processes are likely to be important on different scales”, but Steen et al. (2008) note that local aspects of systems can be influenced by landscape scale alterations. As others have done (sensu Steedman, 1988; Vondracek et al., 2005; Hudy et al., 2008), I addressed the question from the larger landscape perspective to uncover findings that point to reasons for the existence of stable, growing, or shrinking groups of reproducing salmonids in New Jersey’s lotic waterways.

My findings suggest that overall land use within the watersheds of study does play a role, but may have less to do with any overall species change. While it is true that Brook Trout always fared better where there was less agriculture (AG), disturbed (BAR+DEV), and open water (WAT) acreage, they also thrived were there was less natural (WET+FOR) LU/LC. I believe that this finding is really just a result of the fact that Brook Trout YOY were located in smaller catchments on average, so necessarily there will be smaller amounts of all total LU/LC categories. Despite Brook Trout being such a sensitive fish species, the earlier data illustrated a significant average threshold of 3% disturbed (BAR+DEV) land use when present and 7% when absent, but this type of relationship did not hold true for the latter data set. Within the modern surveys Brook Trout were both present and absent on average when disturbed (BAR+DEV) land use was over 20%. Other factors must be having a greater influence in explaining the observed variation. Steedman (1988) had about 25% urban LU/LC as the threshold for the presence of Brook Trout, but in his work this was linked to forest cover of about 75%, something that is no longer found in the catchments of my study. While lower acreage of open water came up as a factor in the modern data set, it did not come out as significant in the earlier data. This is most likely due to the 63% increase of open water observed in the modern survey impacting the overall trout production waters of the state.

Significant factors concerning the location of Brown Trout were identified in LU/LC total acreage and percent situations, but only in the modern portion of the study. While not seen in the initial time frame, when compared to Brook Trout data, Brown Trout seem to fare better where natural landscapes were less common and where human disturbance was more evident. Brown Trout presence was noted in catchments with higher average agriculture acreage and their absence occurred in locales with higher percentages of non-developed habitats, despite the fact that both these types of LU/LC are decreasing in the state. Further supporting this concept is that Brown Trout are flourishing in more disturbed areas. This species was present in catchments that averaged over two times as much total acres devoted to development compared to the average amount when they were absent. Interestingly, the expansion of the locations where these fish are now able to reproduce has outpaced the other species considered and may be connected to their ability to tolerate and even thrive among a certain level of human disturbance (Schueler, 1994; Stanfield et al., 2006; McKenna et al., 2013; Wagner et al., 2013). This was not noted for the other species.

However, watershed and stream influence are complex and different aspects of systems can act to control fish assemblages at various scales. For example, Wang et al. (2006) illustrated how Midwestern fish assemblages were largely controlled by local factors and natural gradients when catchments were less disturbed, but as urbanization and agriculture increased, so did the weight these land uses had in shaping the make-up of the fish found in each area. This assertion is not supported by the findings in my study. While it is true Brook Trout were lost as a result of an increase in barren and developed LU/LC for some stream segments, their presence also increased in catchments were percentage of this category increased, as well as where wetland and forest percent decreased. It seems some other factors are at work here to explain the observed variability of this study’s most sensitive trout species. By looking at Brown Trout expansion, their range was extended into places were barren and development also increased, and where wetland and forested lands decreased. This land use trend of increasing development and loss of natural systems is symptomatic at the local, regional, and national scales (Brown et al., 2005). Similarly, this LU/LC change has also transpired where non-trout waters have given way to those that are trout production. This would be expected since most of the catchments once barren of salmonids in the 1960-70's are now host to Brown Trout that are more tolerant of lower water quality, but most likely held wild Brook Trout 150 years ago.

Determining the factors associated with stream and river fish, their spatial patterns, and how each change over time is a very challenging task (Stevens et al., 2007). It has been suggested that riparian buffers (Barton et al., 1985, Wesche et al., 1987, Wang et al., (2003a), instream habitat (Wang et al., 2006), spatial arrangement of instream habitat patches (Schlosser, 1995; Fausch et al., 2002) and biological interactions (Korsu et al., 2007; Ficke et al., 2009) may be potentially more influential on species presence or absence than landscape scale land use. Part of this difficulty stems from lotic species', such as the coldwater salmonids, naturally high rate of variability concerning the yearly population abundance fluctuation (Platts and Nelson, 1988; Milner et al., 2003; Zorn and Nuhfer, 2007; Ham and Pearsons, 2000; Moyle and Vondracek, 1985; Karr and Chu, 1999; Moscrip and Montgomery, 1997). Fish population numbers do adjust annually, but groups of healthy individuals will tend to settle around an equilibrium biomass value (Allen and Hightower, 2010). To limit erroneous estimations, Ham and Pearsons (2000) suggest that salmonid abundance numbers can only truly be detected after five or more years of annual surveys and Wiley et al. (1997) relate that this can only be determined after 15 to 20 years of sampling. Rarely are stream inventories collected by State or Federal agencies carried out for this length of time on an annual basis, since broad spatial coverage is often of greater importance given fiscal concerns and the labor intensive nature of surveys. The 30 year data set analyzed here however provides insight into long-term temporal changes in land use and fish utilization of streams.

Different landscapes have different potential for supporting trout and management plans and regulations that acknowledge this will provide more realistic and achievable objectives than those that do not (Kocovsky and Carline, 2006). Because of their importance as indicators of stream and overall watershed health, looking at the streams used in this study as a subset of the New Jersey as a whole, my data suggest that New Jersey's waters are improving for habitat requirements related to Brown Trout, but the opposite seems to be taking place for Brook Trout. However, this may be misleading for various other factors may be involved that provide an advantage for Brown Trout. Potentially, all of the following could play a role in Brown Trout expansion and Brook Trout contraction: increased rates of domestic trout stocking, more hearty trout stains being stocked, adaptation of stocked fish to more successfully deal with local conditions, recent dam removals, or simply the passage of time and subsequent opportunity for non-native spreading to new territories.

Furthermore, climate change also plays a role in observed changes. Ficke et al. (2007) explain that freshwater systems will encounter changes in the next century due to a predicted 1-7°C increase in mean global air temperature. Alterations that may affect fish habitat quality include increased water temperatures, decreased dissolved oxygen levels, hydrologic regime changes and increased groundwater temperatures. Clarke et al. (2001) describe that the warming of streams may actually increase Brook Trout abundance in certain situations, but stream flow modifications lead to bed scour, the washing away of eggs and fry and an overall decrease in fish numbers. Others have noted habitat loss for all trout due to rising temperatures beyond species' physiological requirements, as well as specifically up to a 77% loss for Brook Trout when increased warmth is coupled with higher flooding rates (Wenger et al., 2011). Scenarios including such extremes are predicted to ultimately extirpate natives from the southern portion of their range (Meisner, 1990; Clark et al., 2001; Flebbe et al., 2006). Since New Jersey is adjacent to the margin area it seems likely salmonid populations there are beginning to experience the negative effects already.

In spite of these predictions, Trumbo et al. (2014) describe how the previously assumed linearly related climate change model of a 1°C air temperature increase equating to a 0.8°C water temperature increase may be erroneous. Less than half of the predicted water temperature rise was found to occur in that study and groundwater influences were hypothesized to have mitigated much of the negative outcomes expected to occur. If this study represents a larger scale occurrence, it is probable that more Brook Trout habitat may persist under a warming climate than previously thought (Trumbo et al., 2014). However, Jensen et al. (2008) describe how salmonid genetic plasticity allows for local adaptations to arise that afford an advantage to some populations. Specifically, it was discovered that warming temperatures negatively affected some populations, but other groups of Brown Trout took advantage of the habitat changes with their locally adapted characteristics that were well suited to similar conditions. From the observed expansion rate of New Jersey's Brown Trout, potential populations are also exploiting similar phenotypic adaptations.

Focusing on land use and land cover specifics, Steedman (1988) suggested that the 10-100 km² directly upstream of survey sites were most influential on the quality of the fish community. More specifically, he stated that catchments that were composed of greater than 75% forest, something not seen in the catchments of this study, and less than 25% urban cover contained waters of excellent quality. Presumably, places of this nature would lend themselves to Brook Trout habitat. Nevertheless, Steedman (1988) continues that good quality water was able to exist as long as urban areas remained below 50% and total forest was in the 25% to 75% range. Such values were observed in this research and are able to support salmonids, such as the Brown Trout that have been increasing in abundance.

Hudy et al. (2005) illustrated that the two biggest factors for declining numbers of Brook Trout in their original range are agriculture and urban land use changes. In New Jersey, rising water temperatures and other stream quality degradation resulting from land use changes, specifically urbanization, has been suggested as the cause for the decline. Others have looked to land use percentages and other related metrics to understand trout species presence and absence (Table 2-10). Hudy et al. (2008) looked further at this problem across the entire eastern US range of these fish and proposed that in order to maintain intact populations of Brook Trout, catchments need to contain at least 68%

forest and less than 12% agriculture land use. New Jersey's agriculture LU/LC in the catchments of study has fallen to the suggested threshold level, but forest cover has not been at the necessary advisement point since 1972. In addition to agriculture land uses, Blann (2004) includes percentage of wooded land cover in her explanation for presence of Brown Trout. Such fish were known to occur in systems when forests made up at least 24% of the catchment and agriculture was no higher than 59%. Brown Trout were notably absent when wooded lands comprised 9% of the catchment and farming reached 69%. My findings fell well within the range of these reported thresholds. Siitari et al. (2011) found intact Brook Trout populations with forest and agriculture land use percentages that differed from Hudy et al. (2008), as their surveys containing these fish averaged about 24% agriculture lands, 45% forest (55% natural land use if the 10% wetland characteristic is included), and 7% developed land. My current findings fare better in these categories, with the exception of average development. Remarkably, my results were also very similar to those found in Maryland by Stranko et al. (2008) after a data adjustment offset a hypothesized groundwater flow anomaly. Utz et al. (2010) observed loss of Brook Tout from systems upon LU/LC independently reaching about 13% urban and about 35% agriculture.

Coincidently, Siitari et al. (2011) suggest that high amounts of groundwater flowing in survey areas can offset any negative influences from other LU/LC factors. That study contained streams that averaged an annual base-flow numbers of 63%, well higher than the suggested ≥55% required for the achievement of excellent (Raleigh, 1982) and ≥50% for good (Raleigh et al., 1986) water quality. In my case, the base-flow ranged from 43-59% and had a mean of 52%. Moreover, only 28 of the 80 areas averaged greater than or equal to the suggested 55%. Stanfield et al. (2006) also spoke of the importance of high levels of base-flow to support populations of salmonids, with >51% noted for Brown Trout presence, but that report pointed to catchment percent impervious cover (PIC) as the most influential factor on coldwater fish.

That study also related that total absence of Rainbow Trout occurring when PIC reached 8.9%, while Brown Trout were lost at 6.9%, and Brook Trout were eliminated at 6.6%. In this current research, only 29% of the cases fell into the mentioned areas for concern, as overall they averaged 4.9%, and ranged from 0.06-17%. Of the 80 study sites, 59 had less than a 6.6% value, 60 had less than 6.9%, and 68 had less than 8.9%. Interestingly, the mean PIC for non-trout sites was 2.3%, while Brook Trout presence was found to be 4.3%, Brown Trout was 5.2%. Others have recommended that PIC is the main controlling agent in lotic system water quality, with between 4%-14% as the threshold for streams to begin to become impaired (Klein, 1979; Moscript and Montgomery, 1997; Wang et al., 2000; Stranko et al., 2008).

Furthermore, Schueler et al. (1994) suggested a loss of Brown Trout at 13% PIC and Wang et al. (2003b) noted that greater than 10% of this land cover results in poor coldwater fish assemblages. Again, with the range and average PIC found in this current study things seem to be at the lower end (around 4-5% PIC as opposed to 11-14%) of the previously suggested levels for impairment. However, in Maryland, Stranko et al. (2008) noted that Brook Trout were rarely found when PIC was above 4% and averaged 5% and Boward et al. (1999) did not find these species when this land cover was as low as only

2%. Moreover, the key findings of Wang et al. (2003b) suggest that PIC is such a negative factor to coldwater fish populations because urbanization acts to raise water temperatures, lower base-flow through infiltration to groundwater reduction and increased runoff, and ultimately a lowering of an area's water table and alteration of a stream's flow characteristics. It is further purported that urbanization influence is so strong it actually swamps out any positive results from a catchments' forest LU/LC or other vegetation.

Others have also found that base-flow is reduced upon urbanization (Simmons and Reynolds, 1982), but my research is at odds with this concept. High base-flow is extremely important to cold water fish species because groundwater is ultimately connected to in-stream habitat and it can offer temperature moderation (Power et al., 1999), flow stability (Wiley and Seelbach, 1997), thermal refuge from summer and winter extremes (Waco and Taylor, 2010), and even allow populations to persist in locations that are otherwise too warm (Trumbo et al., 2014). As such, base-flow and its related relative lower temperature, is seen by many as the single most important factor to limiting the existence of Brook Trout (McCormick et al., 1972; Siitari et al., 2011; Kratzer and Warren, 2013). Lowering a catchment's base-flow is believed to take away from the traits that are necessary for salmonids to survive and as such, urbanization leads to their decline.

Despite these facts, my calculated correlations illustrate a strong positive relationship between the average base-flow characteristics and percent impervious cover. Initially this result seemed counterintuitive, but several studies have shown that urbanization does not always lower a catchment's base-flow (Barringer et al., 1994; Evett et al., 1994; Brandes et al., 2005; Meyer, 2005). In fact, septic systems, leaking water mains, sanitation sewers, storm drains, and the use of detention basins within developed areas have been found to actually raise the ground water base-flows of built up locations (Lerner, 1986; Barringer et al., 1994; Meyer, 2005; Schueler et al., 2009). In another situation, I found a strong negative relationship between average base-flow and percent FOR LU/LC. Again, this seems counterintuitive to me, but perhaps what I have discovered relates more to the underlying geology or topography of the studied watersheds or the overall size of the basin being evaluated, as has been suggested by Barringer et al. (1994). In other New Jersey areas, the climate (Barringer et al., 1994; Lins and Slack, 1999) or even alterations to the process of evapotranspiration upon removal of vegetation (Meyer, 2005; Zang and Schilling, 2006) has also been suggested as playing a large role in base-flow calculations. Potentially, it could also simply be related to the location and arrangement of the developed areas being placed at lower elevations which happen to be near waterways.

Others have also included correlations between land uses, water quality, and fish assemblages in their research. Wang et al. (1997) noticed positive relationships between these factors when catchments contained forest cover greater than 80%, something rare on average in this current study. They also illustrated that negative correlation associations occurred with catchment forest cover less than 15%, agriculture greater than 50%, and urbanization greater than 20%. My research contained average LU/LC above the lower forest threshold level, well under the agriculture cut-off, and greater than the urbanization amount noted. Finally, Zorn et al. (2002) focused on trout abundance and found Brook Trout were most common in catchments that were smaller than 30 km² and Brown Trout were highest in areas that were smaller than 65 km² in total size. Stanfield et al. (2006) also proposed comparable catchment areas supporting both species in that they came across Brown Trout in areas < 75 km² and Brook Trout were in places < 33 km². My research reflects similar outcomes, in the sense of the overall watershed size related to the species present, but on a much smaller scale. I found Brook Trout on average present in catchments between 7-9 km^2, Brown Trout consistently were present in places of 19 km^2 and for comparison purposes, Rainbow Trout were located in areas between 9-27 km^2. Potentially, however, my catchment size numbers could be a result of the original data set used in that the streams studied had to be of a certain size to fall into the rapid bioassessment protocols for wadeable waters and larger systems were omitted from inclusion here.

Landscape scale factors have an influence on the presence, absence, and abundance of lotic salmonids in New Jersey. Although not the main focus of this study, groundwater flows, the spatial arrangement and connectivity of habitat patches, as well as local scale stream characteristics undoubtedly play a role in the existence of coldwater fish species in watersheds too. From my work it is clear that Brook Trout are more sensitive than Brown Trout to disturbances that replace natural land cover with anthropogenically altered land cover. This research suggests that in order to support reproducing Brook Trout populations, catchments in New Jersey should contain an average of the following land use or land cover characteristics: 12% agriculture, < 22%

urban, > 64% forest and wetlands, and 4 - 6% impervious cover. Catchments with waters expected to hold reproducing Brown Trout groups should on average be composed of the following land use or land cover traits: < 14% agriculture, < 27% urban, > 58% forest and wetlands, and < 5-7% impervious cover. While there was a range for each land use variable, on average the means reported here represent a good target threshold for managers and other interested stakeholders to aim toward in conservation efforts related to Brook Trout and coldwater fisheries in general.

2.5 Conclusions

For the 80 northern New Jersey waters included in this study that were of trout production classification at one point in the last 40 plus years, the land use and land cover of the watershed catchments changed from the late 1960s and early 1970s to about 2010. Specifically, land devoted to agriculture and more natural cover decreased, while those that resulted in human induced disturbances increased. Based upon the NJFIBI for the 24 of the 80 locations that contained enough associated watershed land area to complete the proper calculation, this current study finds that despite these land alterations, condition of the lotic water bodies has improved overall. If these two data sets are seen as a subsample of what has taken place in New Jersey as a whole over this period of time, the findings suggest that improvements have taken place to the state’s aquatic ecosystems. Support for this assertion comes in the form that during the studied time frame an expansion of one coldwater fish species has outpaced all other types as well. The non-native, but naturalized Brown Trout is responsible for most of the new habitat occupied by salmonid species.

Despite these findings, care must be taken when viewing this information within the larger framework of lotic waterbodies found in New Jersey. Extrapolation of my results to the rest of the State's systems is challenging since the 80 included sites were not selected at random from all of those available to sample. I only worked with sites that were trout production quality within the historic and modern data sets and I did not address the other larger percentage of lotic waters that are contained in the State. Furthermore, NJFIBI scores may be misleading for there are fish used in the modern calculation that were not as common in the State's waters historically (i.e., smallmouth bass, largemouth bass, green sunfish, and others) that when incorporated may improve the overall total score in that they increase the total number of fish species present. However, when IBI scores increased between the two time periods, in each metric in which the noted species were included, other species that fulfilled the category requirement were also sampled. Additionally, in some cases, final IBI scores remained the same when these noted species were surveyed in the modern work and other times scores improved when they were not sampled. Either way, the presence of salmonids during surveys points to excellent water quality for sample locations, as is stated in the NJFIBI.

Regardless of the cause, unfortunately, the spatial expansion of the Brown Trout is often at the expense of the native Brook Trout, a species much more sensitive overall and less tolerant of lower water quality. Such observations suggest that anthropogenic changes to land use and land cover may have made it more difficult for Brook Trout to thrive and as a consequence, this important piece of natural heritage is becoming more rare. Bradshaw (1984) stated that, “we cannot hope to know how to put the pieces together again unless we understand how the system works” as well as, “when proper ecological understanding is combined with appropriate technology, … effective and self-maintaining end products are produced.” While his topic of study was a bit different than this current work, the basic premise is the same. My research has taken steps to further the recognition of biodiversity associated with pristine watersheds as well as the resultant changes that can occur upon land use alterations. Correlations and *t* - tests confirm the sensitivity of native fish to land use and land cover changes and point to the success of non-native trout species being related to observed human disturbances. Several threshold levels for land use characteristics have been offered that can be strived for and thus allow for increased Brook Trout sustainability.

Figure 2-1. New Jersey's current lotic trout production waters.

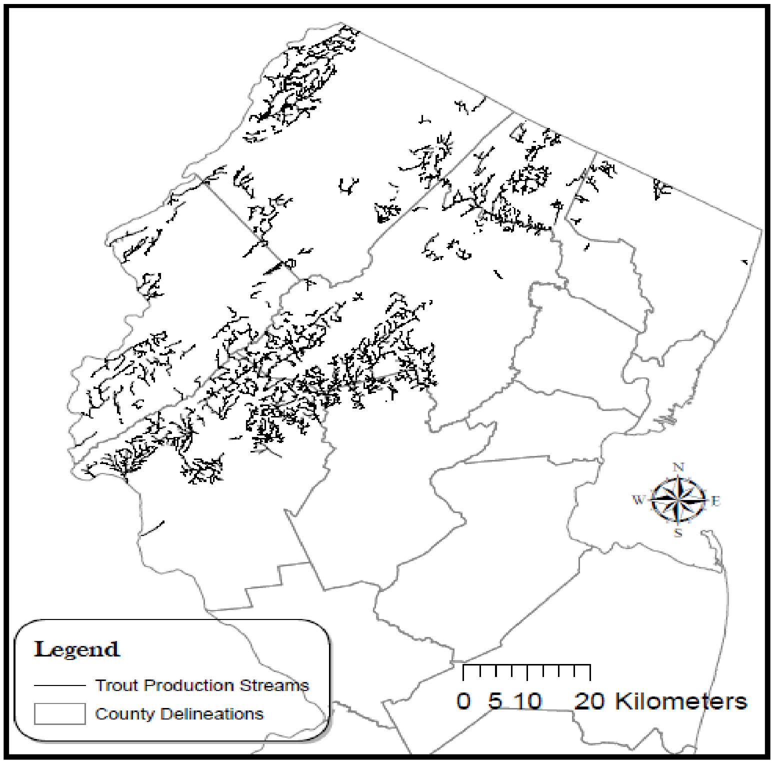


Figure 2-2. Comparisons of reproducing trout species. From 80 historical (1968-1977) and modern (2001-2010) trout production (TP) classified stream survey locations.

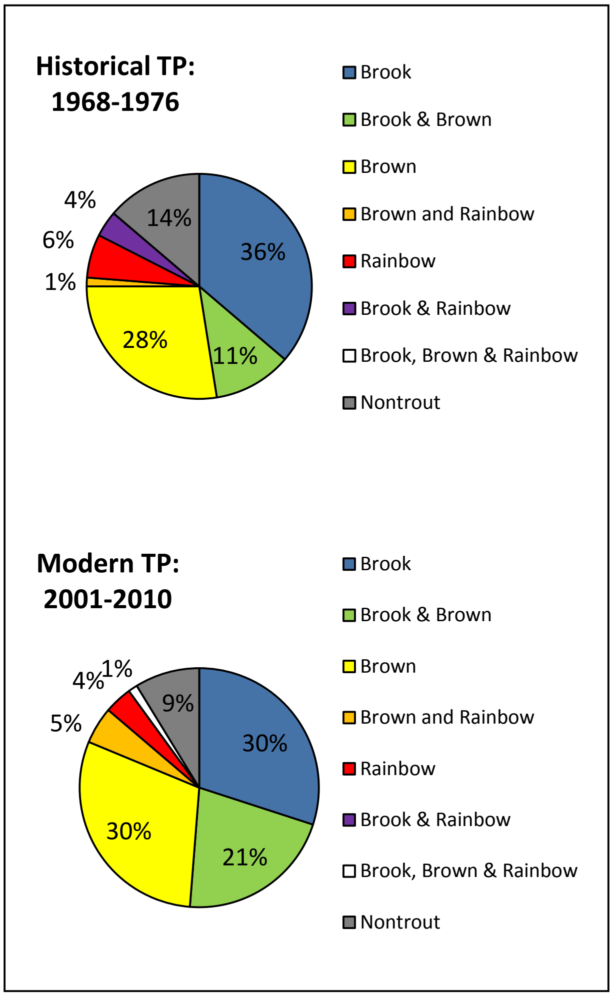


Table 2-1. Metrics and scoring criteria for Northern New Jersey Index of Biotic Integrity for Fish. Presented by Vile (2008).

Metric Category	**Scoring Criteria**		
SPECIES RICHNESS AND COMPOSITION:	**5**	**3**	**1**
1)Total Number of Fish	VARIES WITH STREAM SIZE		
2)Number and Identity of benthic insectivores spp.	VARIES WITH STREAM SIZE		
3)Number and identity of trout &/or sunfish spp.	VARIES WITH STREAM SIZE		
4)Number and identity of intolerant spp.	VARIES WITH STREAM SIZE		
5)Proportion of tolerant individuals	<20%	20-45%	>45%
TROPHIC COMPISITION:			
6)Proportion of individuals as generalists	<20%	20-45%	>45%
7)Proportion of individuals as insectivorous cyprinids	>45%	20-45%	<20%
8)Proportion of individuals as trout or (whichever is a higher score)	>10%	3-10%	<3%
Proportion of individuals as piscivores (exc. Am. eel)	>5%	1-5%	<1%
FISH ABUNDANCE AND CONDITION:			
9) Number of individuals in the sample	>250	75-250	<75
10) Proportion of individuals with disease and anomalies (exc. blackspot disease)	<2%	2-5%	>5%

Condition Categories

45-50 Excellent	Comparable to the best situations with minimal human disturbance: all regionally expected species for the habitat and stream size, most intolerant forms are present and there is a balanced trophic structure.
37-44 Good	Species richness somewhat below expectation, especially due to the loss of some intolerant species; some species present with less than optimal abundances or size distributions; trophic structure shows some signs of stress (increasing freq. of generalists and tolerant spp.).
29-36 Fair	Signs of additional deterioration include fewer species, loss of most intolerant species, highly skewed trophic structure (high frequency of generalists and tolerant species); older age classes of trout and/or top carnivores may be rare.
10-28 Poor	Low species richness, dominated by generalists and tolerant species, few (if any) trout or top carnivores, individuals may show signs of disease/parasites and site may have overall low abundance of fish.

Table 2-2. Mean percent value of each land use/land cover characteristic. Information from catchments above 80 sample sites and mean calculated numeric score and ranking value for 24 catchments able to be included in Index of Biotic Integrity for Fish (FIBI) (larger than 5 km^2) per time frame. Abbreviation of H represents historical data (1968-1977) and M corresponds to modern data (2001-2010). As a result of *t* – tests (α=0.05), statistically significant changes noted in bold and indicated with an asterisk.

Time Frame	**Agriculture**	**Barren**	**Developed**	**Wetland**	**Forest**	**Open Water**	**NJFIBI**
H	16	**0.2***	**5***	10	**68***	0.8	**34*** (FAIR)
M	12	**0.7***	**24***	9	**53***	1.3	**40*** (GOOD)

Table 2-3. Number of streams included for each data set. Information from the historical 1968-1976 and modern 2001-2010 timeframe (P-present, A-absent, BKT-Brook Trout, BNT-Brown Trout, and RBT-Rainbow Trout, NT-non-trout).

	Historical		**Modern**	
Species	**P**	**A**	**P**	**A**
BKT	41	39	42	38
BNT	32	48	46	34
RBT	9	71	7	73
NT	11	69	7	73

Table 2-4. Notable Changes to New Jersey's Trout Production Waters: 1968-1977 to 2001-1010. BKT= Brook Trout, BNT = Brown Trout, RBT= Rainbow Trout, NT= non-trout.

Stream Name	Trout Species Present 1968-1977	Trout Species Present 2001-2011
Black Brook	BKT	BNT
Dawson's Brook	BKT	BNT
Flanders Brook	BKT & RBT	BNT & RBT
Herzog Brook	BKT & BNT	BNT
Parker Brook	BKT	NT
Pohatcong Creek	BKT & BNT	BNT
Rinehart Brook	BKT & BNT	BNT
Shawanni Creek	BKT	NT
Trout Brook- Middleville	BKT	BNT
Trout Brook- Tranquility	BKT	NT

A) Sites where young-of-the-year Brook Trout were lost from 1968-1977 to 2001-2010.

Stream Name	Trout Species Present 1968-1977	Trout Species Present 2001-2011
Green Brook (Passaic)	BNT	BKT
Hewitt Brook	BNT	BKT
Hickory Run	RBT	BKT
Hollow Brook	BNT	BKT & BNT
India Brook (A)	BNT	BKT & BNT
Lamington (Black) River	NT	BKT
Ledgewood Brook	BNT	BKT & BNT
Little Brook	NT	BKT & BNT
Mine Brook (A)	NT	BKT
Van Campens Brook	BNT	BKT, BNT, & RBT
West Portal Brook	BNT	BKT & BNT

B) Sites where young-of-the-year Brook Trout were gained from 1968-1977 to 2001-2010.

Stream Name	Trout Species Present 1968-1977	Trout Species Present 2001-2011
Beatty’s Brook	BKT	BNT & BKT
Black Brook	BKT	BNT
Dawsons Brook	BKT	BNT
Flanders Brook	BKT & RBT	BNT & RBT
India Brook (A)	BKT	BNT & BKT
Little Brook	NT	BNT & BKT
Macopin River	NT	BNT
Mulhockaway Creek (A)	NT	BNT
Musconetcong River (trib) Changewater	BKT	BNT & BKT
Musconetcong River (trib) Franklin	BKT	BNT & BKT
Musconetcong River (trib) Port Murray	BKT	BNT & BKT
Norton Brook	BKT & RBT	BNT & BKT
Pophandusing Creek	NT	BNT
Raritan River North Branch	NT	BNT
Raritan River South Branch	NT	BNT
Stonehouse Brook	NT	BNT
Trout Brook (Middleville)	BKT	BNT
Whippany River (trib) Brookside	RBT	BNT & RBT
Whippany River (B)	NT	BNT
White Brook	BKT	BNT & BKT
Wilhoughby Brook	BKT	BNT & BKT

C) Sites where young-of-the-year Brown Trout were gained from 1968-1977 to 2001-2010.

Stream Name	Trout Species Present 1968-1977	Trout Species Present 2001-2011
Buckhorn Creek	BNT	NT
Parker Brook	BKT	NT
Paulinskill River East Branch	RBT	NT
Paulinskill River (trib.) Emmons Sta.	BNT	NT
Shawanni Creek	BKT	NT
Shimers Brook	BNT	NT
Trout Brook- Tranquility	BKT	NT

D) Sites where young-of-the-year trout of all species were lost from 1968-1977 to 2001-2010.

Stream Name	Trout Species Present 1968-1977	Trout Species Present 2001-2011
Indian Grove Brook	NT	RBT
Lamington (Black) River (A)	NT	BKT
Little Brook	NT	BKT & BNT
Macopin Brook	NT	BNT
Mine Brook (A)	NT	BKT
Mulhockaway Creek (A)	NT	BNT
Pophandusing Creek	NT	BNT
Raritan River N/Br	NT	BNT
Raritan River S/Br	NT	BNT
Stonehouse Brook	NT	BNT
Whippany River (B)	NT	BNT

E) Sites where young-of-the-year trout were seen in the second time frame after waters were initially classified as non-trout.

Table 2-5. Significant results for (*r*) Pearson correlation coefficient tests. Value related to $p < 0.05$ in the historical time frame for Brook Trout YOY abundance and number per meter in each survey versus total acres in each catchment devoted to agriculture (AG), developed land (DEV), forest (FOR), and overall size (TOT).

Trait	AG72	DEV72	FOR72	TOT72
BKTYOY72	-0.2295 0.0406	-0.21859 0.0514	-0.22516 0.0446	-0.2429 0.0299
BKTM72	-0.2295 0.0406	-0.21859 0.0514	-0.22516 0.0446	-0.2429 0.0299

Table 2-6. Statistically significant results for (*r*) Pearson correlation coefficient tests. Value for $p < 0.05$ in the modern time frame for catchment land use/land cover characteristics of total acres devoted to developed (DEV) and forested (FOR) land versus percentage of land impervious cover and the average base-flow of groundwater as a percentage of total water flow.

Trait	IC07P	AVBFI07P
DEV07	0.24267 0.0301	NA
DEV07P	0.88657 <0.001	0.42859 <0.0001
FOR07P	-0.58781 <0.0001	-0.40724 0.0002
AVBFI07P	0.44855 <0.0001	1.0000

Table 2-7. Mean percent catchment land use and land cover per presence (P) and absence (A) of trout production classified waters by species. (BKT-Brook Trout, BNT- Brown Trout, RBT-Rainbow Trout, and NT-non-trout) of 80 locations in historical (H) 1968-1977, and modern (M) 2001-2010 surveys of northern New Jersey. Statistical significance of difference between the two time frames as determined by two-sample *t*-test results indicted with asterisk (*) and bold font, with *p* <0.05.

	Agriculture		**Barren & Developed**		**Wetlands & Forest**		**Open Water**	
	P	**A**	**P**	**A**	**P**	**A**	**P**	**A**
BKT H	17	16	**3***	**7***	79	76	0.6	1
BKT M	12	12	22	27	64	59	**0.8***	**1.5***
BNT H	16	16	5	5	77	77	1	1
BNT M	14	10	27	22	**58***	**67***	1.5	1.5
RBT H	12	17	7	5	80	77	1	1
RBT M	**2.8***	**13***	32	24	63	62	1.5	1.3
NT H	13	17	9	5	76	78	2	1
NT M	11	12	**14***	**26***	72	61	**2.5***	**1.2***

Table 2-8. Trout production classified waters mean total acres land use and land cover per presence (P) and absence (A) by species. (BKT-Brook Trout, BNT- Brown Trout, RBT-Rainbow Trout, and NT-non-trout) of 80 historical (H) 1968-1977, and modern (M) 2001-2010 northern New Jersey survey catchments. Total catchment acres and approximate km^2 area also included. Statistical significance of difference between the two time frames determined by two-sample *t*-test results indicted with asterisk (*) and bold font, with p <0.05.

	Agriculture		**Barren & Developed**		**Wetlands & Forest**		**Water**		**Total Acres**		**Approximate area/km^2**	
	P	A	P	A	P	A	P	A	P	A	P	A
BKT H	**291***	**874***	**40***	**495***	**1,439***	**4,631***	**13***	**108***	**1,783***	**6,108***	**7***	**25***
BKT M	**217***	**624***	**440***	**1,500***	**1,437***	**3,571***	**26***	**154***	**2,119***	**5,850***	**9***	**24***
BNT H	684	503	256	265	3,611	2,585	87	40	4,638	3,394	19	14
BNT M	**539***	**236***	**1,260***	**515***	2,946	1,780	116	48	4,861	2,579	19	10
RBT H	370	602	338	252	5,758	2,645	249	35	6,711	3,534	27	14
RBT M	**47***	**451***	575	985	1,523	2,534	40	92	2,185	4,081	9	17
NT H	1,044	596	**940***	**154***	6,063	2,506	120	49	8,166	3,216	33	13
NT M	461	405	699	967	2,312	2,464	98	86	3,571	3,922	15	16

Table 2-9. Shifts of species presence and absence of surveyed waters between historical (1968-1977) and modern (2001-2010) time frames per land use/land cover (LU/LC) characteristics. Barren and developed land (B+D) are considered disturbed and wetland and forested (W+F) land are seen as natural areas. Statistical significance values shown of difference between the two time frames determined by two-sample *t*-test results, with $p < 0.05$. NS = non-significant values.

	LU/LC	***p* – value**	**Historical % LU/LC**	**Modern % LU/LC**	***p* – value**	**Historical total acres LU/LC**	**Modern total acres LU/LC**
BKT							
loss	B+D	0.016	3	20	0.003	52	274
gain	B+D	< 0.001	5	25	NS	278	887
gain	W+F	0.041	83	65	NS	2,357	1,861
BNT							
gain	B+D	< 0.001	7	28	0.022	414	1,394
gain	W+F	0.001	73	56	NS	3,194	2,377
NT-TP							
gain	B+D	< 0.001	9	32	NS	870	2,608
gain	W+F	< 0.001	76	55	NS	5,634	4,067

Table 2-10. Mean percentage values per characteristic related to Brook Trout (BKT) and Brown Trout (BNT) presence/absence in study catchments providing favorable habitat for populations. Unless noted, percentages of land use / land cover related to trout of all age classes.

Species	**% Agriculture**	**% Barren & Urban**	**% Wetland & Forest**	**PIC**	**% BFI**	**Citation**
BKT	NA	NA	NA	NA	≥55	Raleigh (1982)
BKT	NA	NA	NA	<2	NA	Boward et al. (1999)
BKT	NA	NA	NA	<6.6	NA	Stanfield et al. (2006)
BKT	12	NA	NA & 68	NA	NA	*Hudy et al. (2008)
BKT	12 (9)	NA & 23 (39)	NA & 66 (51)	5 (17)	NA	**Stranko et al. (2008)
BKT	35	NA & 13	NA	NA	NA	Utz et al. (2010)
BKT	24	NA & 7	10 & 45	NA	63	Siitari et al. (2011)
BKT	12	22	64	4.3	52	***This study
BNT	NA	NA	NA	NA	≥50	Raleigh et al. (1986)
BNT	NA	NA	NA	13	NA	Schueler et al. (1994)
BNT	59	NA & 3	24	NA	NA	Blann (2004)
BNT	NA	NA	NA	<6.9	>51	Stanfield et al. (2006)
BNT	14	27	58	5.2	52	***This study

*Subwatershed scale
** Small study with one highly urbanized case (with skewed results in parentheses)
*** YOY P/ A use only

Chapter 3

Headwaters Case Study: Raritan River-South Branch, Mt. Olive, New Jersey

Abstract

To ascertain the structure and movement of an eastern Brook Trout (*Salvelinus fontinalis*) population, I conducted surveys and marked fish in the headwaters of New Jersey's South Branch of the Raritan River. In 2010, four hundred twenty-five trout were tagged above an on stream barrier, and recapture efforts occurred in early 2011. Based upon recapture success, it is approximated that the surveyed subwatershed sections hold approximately 3,008 trout, with most contributed from three tributaries. Fish size ranged from 50-254 mm (total length) and five individuals traveled to locations other than where they were initially marked. A second mark and recapture survey at the same locations tagged three hundred thirty-six trout and yielded a population estimate of 2,618 Brook Trout. During the second marking episode, fish ranged in size from 48-316 mm (total length) and the largest numbers of fish came from the same streams as the original work. Recapture efforts discovered six individuals that had moved from the waterbodies where they were marked. To gain an understanding of how fish use these connected waters, additional recapture assessments were conducted at these sites during the April that followed each marking survey, as well as in the summer of 2012. My research suggests that I have discovered a Brook Trout metapopulation in this catchment, as the observed movement between the mainstem and connected tributaries would allow for potential

gene flow to occur among the fish of the area. Perhaps most importantly, this population may represent one of the few remaining relict Brook Trout groups in New Jersey.

3.1 Introduction

Without a basic comprehension of a species' location or an understanding of related population shifts, fish assemblages can be lost due to lack of proper management. Such information is especially important since it is known that that about 20% of the aquatic species in the US (Heinz Center, 2002) and 40% of North America's freshwater fish species (Walsh et al., 2009) are critically imperiled. This endangered, threatened, or vulnerable status extends to 700 different taxa and has frighteningly increased by 92% in the past 20 years (Jelks et al., 2008). Moreover, three genera, twenty-seven species, and thirteen subspecies of North American fish have gone extinct in the last century (Miller et al., 1989). Brook Trout (*Salvelinus fontinalis*), Brown Trout (*Salmo trutta*), and Rainbow Trout (*Oncorhynchus mykiss*) are not threatened with extirpation in the region of this study, but because they are considered coldwater fish that require high quality habitat to survive and reproduce, their breeding presence in a stream system is noteworthy. Brook Trout require habitat that contains water of exceptional quality, and since it is also known that native salmonid populations have declined worldwide as a result of numerous human effects (Fausch et al., 2006), these fish serve as biological indicators. Identification of reproducing populations is a strong indicator of excellent overall water characteristics and minimally impacted watersheds. The presence of any young-of-the-year (YOY) of this species is not only significant, but relates valuable information concerning the catchment surrounding areas of interest.

Due to their intolerance to disturbance and increased demands for waters of a pristine nature (Steedman, 1988; Wehrly et al., 2003; Ficke et al., 2009), native Brook Trout are seen as the most sensitive of New Jersey's three wild stream salmonid species. As a result, Brook Trout are extremely susceptible to environmental changes and Hudy et al. (2005) have identified these fish as experiencing large losses in the US with 21% extirpation and 27% greatly reduced numbers throughout all the subwatersheds of the entire original range of the species. Additionally, since New Jersey ranks in the top five US locations for percentage of total watersheds where Brook Trout have been extirpated (Hudy et al., 2005) and this is the only indigenous salmonid to the area, a greater meaning surrounds the discovery of any YOY here. Finally, Brook Trout presence or absence in the watersheds of the Garden State has taken on an even larger importance due to the recent demonstration by Hamilton (2007) that several lotic systems hold relict populations of these fish that are direct descendants of those that swam in the region's waters upon the retreat of the Wisconsinan glaciation that began about 20,000 years ago.

Continued stocking for recreational angling purposes from as far back as the late 1800s and early 1900s, until the present, has resulted in naturalized groups of Rainbow and Brown Trout as well in the lotic waters of the New Jersey (Hamilton and Barno, 2005). Despite this, MacCrimmon and Campbell (1969) relate that about 100 years ago Brook Trout were found in abundance throughout the northern part of New Jersey. However, populations of these fish have dwindled to fractions of their former prominence

(Hudy et al., 2005). Hamilton and Barno (2005) also relate that at the most recent count, 175 streams or stream sections have been identified as holding wild salmonids of any kind, which equates to about 5% of all of the streams of the state and composes over 1,000 miles (about 1,600 km) of water. Soldwedel (1979) relates the earliest documentation of streams or stream sections holding wild trout at 95. Additional waters are often discovered annually during fisheries surveys (Hamilton and Barno, 2005; Diglio and Bologna, 2012).

As evidenced in a recent report by New Jersey Division of Fish and Wildlife's Bureau of Freshwater Fisheries (NJDFW-BFF), the amount of allopatric Brook Trout water in the New Jersey is shrinking while the amount of allopatric Brown Trout and sympatric Brook and Brown Trout waters are on the rise (Diglio, 2014 NJDEP unpublished report). The extent of such population shifts are not totally known, but expansion of invasive species at the cost of native ones is a troubling situation that may point to larger issues within watersheds. Hamilton and Barno (2005) and Hudy et al. (2005) suggest that over the last century the most important factors influencing indigenous trout populations in the state are land use changes. Specifically, the warming of rivers from urbanization and dam building activities, fragmentation of systems by roads and dams, as well as competition with introduced domestically cultured and non-native fish species have led to a decline in overall Brook Trout abundance, as well as the total number of watersheds inhabited.

The alteration of many flowing waterbodies first occurred as the region's streams were dammed to harness their mechanical energy and run the numerous small mills that operated in the past (Walter and Merritts, 2008). Over the last 150 years the use of these structures has largely been discontinued, but many dams still remain intact. Finally, as the state continued to urbanize, dams were constructed to meet flood control, water supply, and recreational demands. Similar to the mill structures, many of these obstructions have been abandoned, but still remain in place, and are now known to contribute to water quality degradation, serve as impassable obstacles to lotic organisms, and isolate fish populations found in stream segments. As the current status of Brook Trout in New Jersey has become recognized, ameliorative action to strengthen population numbers has become urgent.

Dam removal has the potential to reconnect isolated populations and improve water quality by restoring stream flow to the major stems of lotic system (Freeman and Bowerman, 2002; Tsuboi et al., 2010). Stream obstruction razing events are currently seen as important components in watershed restoration because of these positive contributions (Pohl, 2002), but further urbanization, habitat destruction, and introduced species create ever increasing challenges to species conservation. For the only native salmonid in New Jersey, these changes in the environment have substantial consequences. Stocking of streams with Brown and Rainbow Trout have led to competitive interactions (Ficke et al., 2009; Hudy et al., 2008) and it is now understood that dams may actually play a role in protecting small, relict populations (Thompson and Rahel, 1998; Morita and Yamamoto, 2002; Diglio and Bologna, 2012). Despite a growing body of literature regarding positive impacts resulting from dam eliminations (e.g., Pohl, 2002), structure removal, without prior investigation of the involved stream segments to determine potential consequences, could lead to actions that might allow for non-native species to colonize and occupy new areas.

In cooperation with New Jersey State Freshwater Fisheries Managers, I have uncovered a previously unidentified Brook Trout population which may be a heritage strain. Moreover, the group exists free from invasion and competitive interactions of non-native Brown Trout and Rainbow Trout existing below a dam structure that separates the upper most part of this catchment. In 2009, previously undocumented Brook Trout populations were found in four individual tributary streams and the mainstem of the Raritan River's South Branch, just upstream of an on-stream impoundment. Originally built in 1926 to fulfill recreational needs of a summer camp (Hilbert, 2001), at the time of this writing the dam had been cited by NJDEP Dam Safety Unit as in need of attention, with either removal or rehabilitation as options. Just prior to this research a notch was cut in the dam to lower the level of impounded water and while still a formidable obstacle, questions existed whether this local Brook Trout population would remain free of any competitive interactions with invasive trout species (wild or domestic) that are established in the system below the barrier. Rehabilitation of the dam took place after my in-field research was completed.

It remains unclear whether razing activities would increase the potential for Brook Trout to be lost from these waters through competitive exclusion by Brown and Rainbow Trout or if dam removal would improve connectivity, gene flow, and strengthen the population as a whole. It also is unknown how long the above dam Brook Trout can remain as a viable and intact group, due to their isolation and relatively small overall population size. This research aims to address the following objectives prior to dam removal or repair activities: A) Assess Brook Trout population size for six previously unknown sections of water; B) assess population size structure and determine if these segments are trout production waters; and C) assess trout movement potential among tributaries.

3.2 Methods

Nielsen (1992) states that the use of marking as a technique for fisheries research and management is essential. Many different approaches to fulfilling this need exist, including fin clipping, application of external tags, branding, as well as the insertion of internal marks. According to McFarlane et al. (1990) marking fish with an internal tag originated in the 1920s and increased in popularity during the 1960s and 1970s. The visual implant elastomer (VIE) and its subsequent marking process have been devised by Northwest Marine Technology Inc. (NWMT) (Shaw Island, WA). The VIE tags are meant to be implanted internally beneath transparent or translucent tissues in many types of animals, from finfish to reptiles, but still remain externally visible. VIE is a medical-grade, two part silicone based polymer material that is mixed immediately before use and then injected as a liquid that cures into a pliable, biocompatible solid (NWMT, 2008). To my knowledge, no research involving freshwater salmonids in New Jersey has relied on elastomers as a marking strategy.

Multiple studies have shown this method to be extremely successful for several reasons. Ficke and Myrick (2009), Adams et al. (2000), and Close (2000) all were able to complete studies where they used VIE on fathead minnows, creek chubs, and Brook and Rainbow Trout as small as 50 mm (total length). Other studies have marked much larger fish, including bull trout up to 400 mm (total length) (Bonneau et al., 1995). Additionally, it has also been established that even in field studies, if inserted properly, tag retention approaches 100% for up to a year for Rainbow Trout (Walsh and Winkelman, 2004). Baily et al. (1998) was able to recapture Coho salmon that retained marks for up to two years and FitzGerald et al. (2004) had 17 month retention in over 90% of the Atlantic salmon in her net-pen study. Josephson et al. (2008) had a 100% retention rate in Brook Trout after 2.66 years in both a hatchery setting as well as for those fish that were placed into three separate lakes. Overall fish health and growth rates do not seem to be affected by the insertion of the elastomers either. Evidence for this was shown with Brook Trout (Zerrenner et al., 1997; Josephson et al., 2008; Bryan and Ney, 1994), Brown Trout (Olsen and Vollestad, 2001), Chinook salmon (Garcia et al., 2004), and Atlantic Salmon (FitzGerald et al., 2004).

Despite the successful field and hatchery use of VIE, the literature does contain some writings where researchers did have lower tag retention or detection rates. Examples include Close and Jones (2002) with a study using marked yearling Rainbow Trout and by Bryan and Ney (1994) using wild Brook Trout. It should be noted that there seems to be a general consensus by many authors that the longer the study the greater the chance of loss or inability to relocate the inserted mark (Zerrenner et al., 1997; Hale and

Gray, 1998; Fitzgerald et al., 2004). Some situations had some tags lost within a few hours of being implanted, while others saw tag loss at a later time, but still before the fish were released (Zerrenner et al., 1997; Bailey et al., 1998; Adams et al., 2000). Finally, some fish lost their marks while in the study environment. It is also a fair assumption that the more a fish is handled the greater the likelihood for tag loss or mortality.

I felt it necessary to take a look at my ability to mark fish since several authors mentioned that marking retention rates are closely related to tag insertion quality and that a more experienced tagger is more likely to be a more skilled tagger. I was interested to see how well we could tag small fish due to the knowledge that many of the fish in the larger project location are less than 100 mm (total length) in size. We were also interested to see if any tags were lost over the course of the study, and to see how fish reacted to different levels of stress from being handled.

To determine the efficacy of the use of VIE as an option for my infield research, a pilot batch study was conducted at the Charles O. Hayford State Fish Hatchery in Hackettstown, New Jersey. The study ran from April 7 to May 2, 2010. Surplus domestic Rainbow Trout were obtained from the Pequest State Hatchery and used in this research. Two large raceways were separated with a metal screen for a total of four sections. All sections had a continuous flow of 12° C water and all fish were fed typical hatchery food from automatic feeders in amounts previously determined for this size and species of animal. Tanks were cleaned daily of any uneaten food and any dead fish were removed at that time.

Two hundred fish were randomly sampled from two other raceways filled with similar sized fish and ultimately ranged in size from 54 mm to 115 mm. Before being used in the study fish were inspected for DELT (deformities, erosion of fins, lesions, and tumors) anomalies. The first group consisted of 50 fish which were simply placed into the first raceway section. Group two also contained fifty fish but, before being placed in the water, was exposed to two seconds of pulsed, direct current electricity from a Smith-Root backpack electroshocker. The settings on the pack were similar to those used in any field sampling procedure and produced between one and a half and two and a half amperes of electric current. The third group was also exposed to the same electricity as the second, but they additionally experienced a dose of the fish anesthesia tricaine methanesulfonate, or MS-222. One half of a teaspoon of the powdered substance was placed into two and a half gallons of water to achieve the desired concentration of the solution of 100mg/l (Tricane-S, Western Chemical, Ferndale, WA). At this sedation level the animal totally loses its equilibrium, relaxes, and turns over after the passing of about a minute. The final group experienced the electricity and tricane, but additionally they received the VIE. With great care taken to handle fish with wet hands and as little as possible, a two to three mm fluorescent green VIE mark was placed just beneath the adipose tissue behind the left eye of each fish. All fish from all groups were up off the bottom and swimming upright by the end of the first day.

Results of the pilot batch study had no control fish die. On April 21 one of the electroshocked only fish from group two died, but this group saw no other mortality during the experiment. On April 27 one of the fish from the electroshock and tricane group three died. Like group two, no other death occurred again. Despite being handled the most, group four saw no mortality throughout the entire study as all fish were accounted for after the allotted time had passed. At the conclusion of the study, all fish were removed from the tanks, again checked for DELT anomalies and released to an outside pond on the hatchery property. With the exception of two fish, one from group two and one from group three that had a pronounced bend in their backs that affected their ability to swim, all fish looked healthy. Without individually measuring each fish they generally noticeably grew quite a bit, and were noted to be behaving much like the fish from the group where they were originally randomly selected.

All of the fish from group four were inspected more closely upon the conclusion of the study. As previously mentioned, all fish survived the study and 100% of the fish retained the VIE tags. Most fish marks were visible in the ambient light, but when any questions regarding retention arose an ultraviolet light source provided by Northwest Marine was directed toward the marked location. During these situations the tags were very easily and clearly seen. All fish looked healthy and no sores or infections were seen on or near the VIE injection sites. Based upon the results that out of 200 handled fish the mortality rate was 1%, the 100% retention rate of VIE by tagged fish, as well as the fact that the elastomer was able to clearly be seen in white or ultraviolet light we were encourage by this marking product and process. In conclusion, visual implant elastomers can be successfully implemented in a larger field study.

In conjunction with NJDFW-BFF, a mark and recapture field study was conducted in the headwaters of the South Branch of the Raritan River below Budd Lake, Mt. Olive, New Jersey at approximately 40° 50’34.77” N and 74° 45’14.61” W. The specific stream segments sampled included the mainstem of the South Branch of the Raritan River (MS) and the following six tributaries: South West of Budd Lake (SW), North of Drakestown (NDT), Drakestown (DT), Small Ditch (DD), Sun Valley Brook (SV), and Warmwater (WW) (Figure 3-1). All stream segments sampled populations above a 5.5 m high structure known as the ‘YMCA Dam’. Employing a single upstream pass and following the procedures and strategies determined by NJDEP-BFF (Barbour et al., 1999; Hamilton and Barno, 2005) and approved by the Montclair State University IACUC (protocol #2010-10), Smith-Root electrofishing backpacks with 1-3 amps of pulsed DC electricity were used to survey 150 m sections within each tributary and the mainstem river.

In August and September of 2010, a target collection of 100 individual Brook Trout was gathered for each waterbody, but where I was unable to reach this number in the first stretch of water the sampling team continued up stream until we met our goal or covered an additional 150 m. An expanded effort was employed on the Raritan River mainstem that included a continued upstream single pass covering the entire above dam waterbody area until we reached the section known to be too warm to possess lotic salmonids (> about 22° C). Actual acquisition numbers ranged from zero on the Warmwater tributary, six in Sun Valley Brook, thirty-five from the Small Ditch, and eighty-four from the Mainstem. We were able to achieve our 100 fish goal from the remaining streams. Individuals were measured to the nearest mm (total length), anesthetized with MS-222, injected with a VIE unique to each stream reach, revived, observed, and finally released. All other gathered fish species were identified by species, enumerated, inspected for anomalies, and released. In January 2011, the stream segments were again visited, but the recapture surveys were expanded to check for fish movement (sensu Moore et al., 1985) and included a total stream length of 400 m. At this time captured fish were measured, simply examined for previous VIE tags, and released. As in the previous marking situation, the entire mainstem of the Raritan River was sampled again. During this time, no other fish species were gathered or identified. All recaptured fish were noted by GPS coordinates to determine if they had moved from where they were originally tagged and later Terrain Navigator mapping software (Maptech, Billings MT) was used to plot the locations of the moved fish.

With the same previously mentioned procedures in place, except employing a different set of VIE colors, the entire marking and survey process was repeated a second time in the summer months of August and September, 2011. Coinciding with this second marking episode, recapture efforts took place in the winter that followed, specifically during December, 2011 and January, 2012. Specific VIE colors used on each stream, numbers of fish marked, numbers of captured individuals upon the follow up efforts, as well as the specifics surrounding recapture rates can be located in Table 3-2.

In both marking and capture/recapture events, to approximate Brook Trout numbers overall and in individual stream sections we used a modified version of the Lincoln-Peterson population estimation approach, originally presented in Ricker (1975) and summarized in Lockwood and Schneider (2000), known as the Chapman-Peterson method, as listed below.

$$N = \frac{(M+1)(C+1)}{R+1}$$

$$Variance\ of\ N = \frac{(M+1)^2(C+1)(C-R)}{(R+1)^2(R+2)}$$

where,

C = total number of fish caught in the second sample (including recaptures),
M = number of fish caught, marked and released in the first sample,
N = population estimate,
R = number of recaptures in the second sample (fish marked and released in the first sample).

All estimates are also presented with 95% confidence intervals.

Lockwood and Schneider (2000) suggest using the Chapman-Peterson strategy in a study of this nature for this model produces population estimation results that are statistically unbiased in that calculations account for an upper and lower range of confidence limits, and allows for variability to be more accurately measured. Despite a longer than typical amount of time used to attain capture/recapture information in this research (Beard and Carline, 1991; R. Carline, personal communication), Ricker (1975) explains that it is acceptable for follow up samples to occur over long periods. Additionally, because the portions of the waters looked at in the study are essentially closed (due to the warm water conditions and a large dam at the fringes of the research location) I believe there is negligible immigration and emigration overall into and out of the general area. Furthermore, birth events in the system had not yet occurred from any late fall and early winter spawning activities, and stream conditions at this time of the year in the inhabited areas are ideal (cool temperatures, high oxygenation levels, and low flows) to limit the general rate of death. Moreover, due to the close consideration of tagging and sampling methods and procedures, marked and unmarked fish were considered to have no differences in the following experiences: rates of mortality, vulnerability to capture, and overall random mixing. Finally, as demonstrated in the previously mentioned highly controlled batch study and close inspection with ambient and ultraviolet light sources upon recapture surveys, all marks were recognized and retained. As such, the assumptions of the overall method have been met and this work can provide acceptable population estimates for the area of study. Difference between, and averages among the two estimate time frames were also determined.

3.3 Results

Based upon our results from the first year of the mark-recapture study, I approximate the population size of Brook Trout in this above dam study area as 3,008 individuals (±788), with the majority contributed from three tributary streams of the South Branch of the Raritan River's mainstem (Table 3-1 and Table 3-2). The Drakestown, South West of Budd Lake, and North of Drakestown tributaries contributed 1,111 (±530), 716 (±383), and 494 (±279) individuals respectively. Brook Trout were not recorded in the Warmwater tributary and marked fish were not recaptured in Sun Valley, while the Mainstem is estimated to hold 349 (±183). These headwater fish ranged in overall size from 50-254 mm ($\bar{x}$ (mean) = 103 mm and s (standard deviation) = 45.3) during the marking period. All tributaries where fish were collected contained

YOY individuals, generally recognized for this species in New Jersey at less than 100 mm in total length (Hamilton and Barno, 2005), but verified through the age-class cohorts observed from length-frequency assessment histogram graphs (Petty et al., 2005) (Appendix B). Others have also placed similar sized trout into the YOY category in their studies (Moore et al., 1985; Moyle and Vondracek, 1985). The largest individuals were found in the Sun Valley Brook tributary (254 mm) and the Mainstem (249 mm), with these stream sections containing the largest average fish sizes also ($\bar{x}$ =158 mm and 129 mm respectively).

During our second mark-recapture study, I approximated the Brook Trout population in the study area at 2,618 individuals (±647). During this marking period these headwater fish ranged in overall size from 48 to 306 mm ($\bar{x}$ =96 mm and s = 36.0) and again, the Sun Valley Brook tributary held the largest individual (306 mm). All other water segments contained YOY fish. Again, the majority of fish were found to be in the same watercourses as previously discovered in the initial marking event. In this case, specifically the Drakestown tributary was estimated to hold 941 (±371) Brook Trout, the South West of Budd Lake water had 815 (±394) Brook Trout, and the North of Drakestown tributary was estimated at 384 (±165) individuals. While overall total abundance numbers were less for all waters when combined compared to the first marking (2,618 (±647) versus 3,008 (±788)), two locations did see an increase in numbers of fish (Table 3-2). The South West of Budd Lake and Small Ditch tributaries saw an estimate increase by 99 and 56 fish in the second survey, while all others had a decrease in total abundance.

Averaged together, the total study area has an estimated population of 2,813 Brook Trout, with a decrease in abundance in the second time frame compared to the first estimation. Despite having the largest total coverage area, over the two survey years the South Branch of the Raritan River mainstem averaged among the smallest total number of Brook Trout. Only the Sun Valley Brook and Small Ditch tributary averaged smaller population estimates, but the Small Ditch water did see a year over year rise in abundance. Despite a decrease between the two population estimates, the Drakestown tributary averaged the largest population estimate each year as well as, in its overall average abundance calculation with 1,026 Brook Trout. Additionally, in the year over year comparison, the South West of Budd Lake tributary saw an increase in overall abundance of individuals and averaged the second highest in its population estimation. The North of Drakestown tributary had a decrease in Brook Trout abundance. No recaptures of marked fish were found in Sun Valley Brook or the Warmwater tributary.

As others have done, Brook Trout that were identified to have moved from their stream of marking were considered as a percentage of total marked individuals (Corbett et al., 2008). However, many other researchers report fish movement percentages as they relate to the total number of recaptured individuals (Moore et al., 1985; Carlson and Letcher, 2003; Wilson et al., 2004; Pepino et al., 2012; Ecret and Mihue, 2013; Kanno et al., 2014). Over the course of this study, twenty-three of the seven hundred sixty-one marked and one hundred ninety three recaptured fish were recaptured in stream segments other than where they were marked (Figure 3-2, Table 3-2). Respectively this calculates to 3% and 11.9% of the total for each. During the first recapture effort (winter 2010-

2011) five fish moved overall, for a value of 1.2% of all those marked. Three fish that were marked in the mainstem were found to have traveled into two different tributaries; two into Drakestown and one into the Small Ditch. Additionally, one marked fish moved from the Drakestown tributary into the mainstem, while another marked individual moved from the Small Ditch into the mainstem. Furthermore, the size of the fish that were found to have moved ranged from 96 mm to 165 mm and had a mean of 120 mm and median of 116 mm, while those fish that were recaptured in their home-waterbodies ranged in size from 50 mm to 249 mm and averaged 99 mm in total length (Table 3-3). However, when fish movement was viewed compared to total recaptures, 9.4% of the group had traveled. No marked and moved fish were recaptured during the spring or summer 2011 surveys.

However, during the spring work the average of all captured fish was found to be 110 mm, with a range of 24 mm to 236 mm and in the summer fish ranged from 48-306 mm and averaged 96 mm overall. After the second marking, the winter (2011-2012) recapture gathered six marked fish that were from another stream than where they were sampled, or 1.8%. As a percentage of the recaptured Brook Trout, 10% of the fish were seen to have moved. Interestingly, all moved fish were gathered in the mainstem of the Raritan River. One came from the South West of Budd tributary, one from Sun Valley Brook tributary, two from the Drakestown tributary, and two moved from the North of Drakestown tributary. Again, the moved fish averaged larger than the overall captured fish average at 157 mm (median 143 mm) compared to 111 mm, while a comparison of the ranges had 58 mm to 316 mm versus 114 to 233 mm.

The spring 2012 capture sampling discovered the most moved fish of any recapture endeavor, with ten of the marked fish identified as migrants, or 3%. When looked at as a percentage of total recaptures, 29% of the Brook Trout were seen to have moved. Again, the fish that traveled were on average larger (181 mm with a median of 176 mm) than the rest of those taken during the surveys (mean and median of 120 mm). The migrants ranged from 126 to 245 mm, while the other captures ran from 29 to 318 mm. Specifically, during this spring all the marked and relocated fish were again found in the mainstem and originated from the following tributaries; one from Sun Valley Brook, two from Drakestown, three from the Small Ditch, and four from North of Drakestown tributaries. Finally, in the summer 2012 recapture survey two migrants were noted, at 0.6%, or 11.8% of the total recaptures. One found in the mainstem from the Small Ditch and another located in the Drakestown tributary when they were tagged in the North of Drakestown waters. As noted in other seasons, the migrants averaged larger (181 mm and a median of 181 mm) compared to all others (104 mm) and ranged from 165 to 196 mm while the other captures ranged from 50 mm to 299 mm.

Despite identifying only native Brook Trout in the above dam area in the pre-study preliminary work and initial marking surveys, I did ultimately uncover thirteen nonnative Brown Trout in five of the six subsequent follow-up field events. In the first winter work the survey team surprisingly uncovered one Brown Trout (262 mm in total length) and we encountered another one the following spring (239 mm) (Table 3-3). In the second summer effort we sampled four Brown Trout (ranging 156 to 258 mm) and the following winter we surveyed a total of six Brown (ranging from 215 to 334 mm).

We gathered one final Brown Trout (321 mm) in our last survey in the summer of our work. All exotics were gathered in the lower reaches of the mainstem of the South Branch of the Raritan River.

Finally, other than Brook and Brown Trout, eighteen other species of fish were gathered in my work (Table 3-4). While I conducted seven total infield survey events, identification and enumeration of non-salmonid species was only conducted during the summer sample surveys. At these times official NJDFW-BFF sample strategies were employed.

3.4 Discussion

Trout naturally move throughout their environment as they seek food, refuge, and/or a chance to breed, as well as to realize other life history needs (Northcote, 1997; Fausch et al., 2006). If presented with the opportunity, Brook, Brown, and Rainbow Trout can and will move great distances to fulfill these requirements (Clapp et al., 1990; Meyers et al., 1992; Riley et al., 1992; Gowan et al., 1994; Gowan and Fausch, 1996). Dams and other water restrictions impede these migrations and generally create a situation where populations become isolated (Rieman et al., 1993; Young, 1995b). Such segregation has the potential for creating genetic bottlenecks, genetic drift, and ultimately sub-population loss through reduction of individuals below a minimum viability threshold (Wofford et al., 2005; Morita et al., 2009). However, impediments also have been identified as playing a positive role in regions where introduced species may outcompete native ones, leading to a substantial reduction or total loss of the indigenous organisms (Thompson and Rahel, 1998; Young, 1995a). Identifying populations and understanding related species shifts is necessary to ensure the health of fish as a natural resource.

After confidently conducting two marking and recapture procedures, as well as three additional simple recapture undertakings on all six waterbodies located above the YMCA dam, my observations demonstrate evidence of trout movement among the stream segments. On average, approximately 1% of the marked or 10% of the recaptured fish did migrate. However, of the six recapture opportunities to observe fish traveling from streams where originally tagged, I noticed this type of movement only four times. Interestingly over the course of this study, migrating fish averaged six per infield event, and the majority were found to have traveled from the outer tributaries into the mainstem. I believe the Brook Trout in this headwater section of the South Branch of the Raritan River are not isolated to individual streams and are using the mainstem in some capacity as a corridor for movement. While fish from South West of Budd Lake tributary entered the main river one time, this did not occur again. However, Brook Trout from other waters moved quite often, as demonstrated by two seasons of movement to the mainstem from the North of Drakestown tributary, and Sun Valley Brook, as well as three seasons of travel for the Drakestown and Small Ditch tributaries.

In the two years of this study, the North of Drakestown water did supply seven marked fish in total to the mainstem (two in one recapture, four in another, and one in the last), the largest contributor of any the tributaries. Next in abundance of marked and moved fish was the Small Ditch, with five Brook Trout in total (three in one season, and two others with one). In one other season I did discover fish marked in the mainstem that moved into a tributary. In my first winter recapture, two Brook Trout were sampled in the Drakestown tributary and one was discovered in the Small Ditch water. I never did see this type of travel again. Finally, on one occasion I found fish moving from one tributary into another nearby tributary. Specifically, a Brook Trout that was marked in North of Drakestown water was recaptured in the Drakestown tributary, waters that are just south of the marking location. During both mark and recapture events the North of Drakestown waters ranked directly in the middle for overall abundance estimates, but ended up associated with the largest amount of migratory fish, with seven in total. Also of interest, is the fact that my recapture effort picked up a fish originally marked in the Sun Valley Brook tributary in the mainstem on two occasions from only three total tagged fish! While it is true that I may have gathered the same fish in the Spring 2012 re-sampling and again in the Summer 2012 work, it is also plausible that in each time frame a separate individual was sampled.

Fish traveled into and out of these study waters from the tributaries, but this was not common. Of the six chances to detect movement it was noticed four times and was composed of 1.2%, 1.8%, 3%, and 0.6% of the total tagged group or 9.4%, 10%, 29%, and 11.8% of the recaptured group when it was found. This averaged 1.7% of the total tagged or 15.1% of the total recaptured individuals in the four times when movement did occur. However, looking at the mean of all six field events, movement between the mainstem and tributaries was lower, at 1.1% overall for marked and 10% for recaptured fish. Movement percentages such as these are generally in line with what has been described in other cases involving Brook Trout. Ecret and Mihue (2013) and Kanno et al. (2014) noted between 8% and 18% and 6% and 19% for longer range trout movement of recaptured individuals. Moore et al. (1985), Carlson and Letcher (2003), Wilson et al. (2004) and Pepino et al. (2012) saw larger range Brook Trout movement of recaptured fish no higher than 5%, while Corbett et al. (2008) had about 9% of the marked fish move. In my study, movement among the tributaries was more rare than tributary to mainstem or mainstem to tributary travel as it was observed on only one occasion. Others have also seen low rates of this specific type of movement in studies conducted on similar tributary/mainstem type systems (Moore et al., 1985). All of the described movements imply that the potential for gene flow among the various sections of this system exists.

As noted earlier, the generated length-frequency graphs (Appendix B) identify at least two and up to three or more age class groups when the data are all pooled together. This was also the case in most of the individual stream sections for the headwaters of this system. Young-of-the-year for Brook Trout are generally known to be around 100 mm or less, and for my purposes, any fish larger were considered sub-adults and adults. Since male Brook Trout can reach sexual maturity and reproduce when as small as 89 mm (Raleigh, 1982) and in the first (Watson, 1999) or second (Scott and Crossman, 1973) year of life, and females reach this capability a year later (Ficke et al., 2009), all of the waters surveyed above the dam support breeding fish groups.

Hallmarks of a metapopulation includes local populations that are at least partially isolated in tributaries (Rieman and McIntyre, 1993), contain YOY, are not too isolated to prevent recolonization, have an increased risk of going extinct (Hanski, 1997), and are linked by relatively low rates of migration (Levins, 1969; Hanski and Simberloff, 1997). My findings suggest that fish in this headwater section can be considered to be part of this type of population structure (Levins, 1969; Rieman, et al., 1993; Hanski and Simberloff, 1997; Fausch et al., 2006). This ‘population of populations’ (Levins, 1969) concept can be noticed here through individuals originating from tributaries and interacting with each other within the mainstem river with a small amount of movement from this mixing location.

Furthermore, to allow for the maintenance of a flourishing, reproductive, and viable total population, Soule (1987) describes the need for a breeding population of between 50 and 500 individuals for vertebrates in general, while Kruse et al. (2001) and Rieman and Allendorf (2001) respectively suggest that between 500 and 1,000 members are needed to make up an area’s effective population related to salmonids. My averaged findings of 2,813 ± 718 suggests there are sufficient numbers of Brook Trout in the headwater study area that have the potential to breed and enable persistence of the total group. Additionally, applying to this study the recommendations put forth by Rieman and McIntyre (1993) related to bull trout (*Salvelinus confluentus*), a species that also shares many of the same habitat requirements and pristine water quality needs as Brook Trout, by my estimation these headwaters surpass the necessary 1,000-2,000 total members to not substantially increase the extinction risk of this local isolated group.

Results from my study also indicate that the down-stream dam which separates these headwaters may in fact be providing some form of refugia necessary for Brook Trout to continue to remain in the area and not succumb to the competitive pressures that often follow when introduced species come in contact with native ones (Fausch and White, 1981; Korsu et al., 2007). While over the course of this work I did encounter thirteen total Brown Trout in five of the seven field events, exotics were not surveyed every time out. I believe that the existence of the dam held down the number of invaders and substantial movement rates only occurred after an atypical amount of rain fall (Table 3-5) during the summer of 2011 resulted in extreme water flows that created an opportunity for upstream travel. Adams (1999) relates that others have experienced Brook Trout ascending a four foot vertical drop when high spring flows allowed for the possibility of this feat to occur.

By looking at data taken from the three closest recording locations to the study site, the late summer of 2011 produced rates of precipitation on the order of two to three times greater than the previous or following summers' rainfall amounts. In 2011 the most intense rainfall took place in the months of August and September and that summer averaged 8.2 inches (20.8 cm) overall, when the previous and following summers averaged 3.0 inches (7.6 cm) and 2.4 inches (6.1 cm) respectively (NOAA, 2014). I believe that this increase in the amount of water in the mainstem offered the chance for Brown Trout to navigate up and over the recently notched dam and is a plausible explanation as to maybe why I found four individuals in these waters in the summer 2011 and six more in the following 2011-2012 winter surveys. When flows were lower in the previous and following years, at best I only ever located one exotic salmonid.

Other researchers have observed trout movement occurring upon higher stream flows (Heggenes, 1988; Gowan and Fausch, 1996; Mollenhauer et al., 2013). Additionally, Ney and Bryan (1992), Petty et al. (2005), and Mollenhauer et al. (2013) all found the salmonids that moved away to be larger individuals, something also noted in this study (Table 3-3 and Appendix C). As used by Ney and Bryan (1992), this current study relies on a two sample *t*- test (Usable Stats, 2004-2014) to confirm the statistical significance of the difference in mean sizes between the Brook Trout captured in their home streams verses those that were known to have immigrated into an area (109 mm versus 160 mm, $p = 0.040$). My findings related that the largest individuals are not always the most mobile. Riley et al. (1992) had similar findings and suggest that strayers may not be big enough to select prime habitat locations that are already being held by the largest fish. Movers are forced to search elsewhere downstream for suitable locations that can better meet the needs of their larger size.

Hanski and Gilpin (1991) and Hanski and Simberloff (1997) believe that the conservation of a species can begin to take place only after an understanding of the dynamics of the specific situation has been learned. Protecting the isolated populations in this area of study is important because in this highly urbanized state (Brown et al., 2005) these animals serve as sentinel species that warn of environmental degradation. Additionally, until genetic testing can allow for confirmation, conservation of the metapopulation here is essential for there is a high likelihood that these are a heritage group of fish, thought to be uncommon in the state. Understanding this area's Brook Trout is also imperative for these fish may be able to serve as a source population necessary for maintenance and expansion on a range-wide level, whether that is a natural process or something initiated by freshwater fisheries resource managers.

As Moore et al. (1985) explain is possible, I did notice important metapopulation dynamics in action through the course of this study with the potential refounding of a local Brook Trout population. Within the Warmwater tributary, a waterbody that by my measure was completely lacking native salmonids until the seventh and final field sampling event, two larger Brook Trout were encountered. Rieman and McIntyre (1993) advocate that in metapopulations, some local populations are more stable than others and nearby groups will likely support each other through migratory movements. The discovery of two strayers during my research in a stream that until that time was devoid of any trout, helps to demonstrate the short-term resilience of this overall above-dam Brook Trout assemblage.

The movement of fish also is believed to support long-term persistence by potentially strengthening of imperiled gene pools by the migration of natives in an otherwise isolated area (Fausch et al., 2006). Though occurring on a limited basis in this study, when fish movement occurred and they vacate their home streams, their travel did cover long distances. Dunham et al. (2002) propose that migrant fish are often bigger than those that remain close to the location of their birth and, by virtue of their size, are more fecund. Such a combination of factors is significant for these fish can potentially successfully breed in the locations of emigration and in the process allow for the entrance of new genes. Those authors continued to explain that such a situation is vital for the metapopulation as unit for such actions can offer demographic support and general resistance to environmental stochasticity, two factors that are believed to have negative effects on local groups from a population genetics standpoint.

Large adults are more mobile and do move to meet their own needs, but tributaries can also allow for persistence of group by acting as sources for spawning to occur (Petty et al., 2005). Additionally, resident life histories may be selected for over migratory ones when systems occur that do have barriers in place (Neville et al., 2006b). Northcote (1992) and Neville et al. (2006a) explain that there is a disadvantage for headwater fish to move away in that fish that possess the resident genes remain in an area and can make genetic contributions to the next generation. Migratory life-forms take their contributions away with them upon leaving the local section of their birth, thus ensuring the residency characteristics are well developed among the members of those that remain. Letcher et al. (2007) also note that naturally isolated subpopulations of Brook Trout differ genetically from those in a more connected larger population.

While it has been noted that movement of fish is important in persistence of groups, local populations do exist that are totally free of immigration support. Specifically, Letcher et al. (2007) relate that local adaptations were thought to allow for population persistence through a phenotypic response to environmental conditions in that members were skewed toward smaller and younger individuals that reproduce sooner compared to those in a more open system. Such higher early survival and sexual maturation rates have been suggested as a means to increase resilience to stochastic extinction (Winemiller, 2005). Koskinen et al. (2002) also show how positive natural selection can occur relatively rapidly and lead to noticeable changes in salmonids existing in small populations.

While obstructions can protect the fish living in headwaters from invasion, isolating qualities also have the potential to lead to extirpation of above barrier groups (Soule and Mills, 1998; Frankham, 2005). It is believed that losses occur due to a decrease in genetic diversity, overall random genetic drift, and subsequent inbreeding depression that follows (Rieman and Allendorf, 2001; Neville et al., 2006b). Caughley (1994) uses the term “small population phenomena” to describe the vulnerability of extinction of groups due to the coupling of a lack of genetic variability and demographic and environmental stochasticity that can act to negatively influence populations. Ultimately, isolation can lead to the removal of resiliency that larger more connected groups possess in the form of genetic heterogeneity and the existence of additionally life histories that have emerged by chance. Finally, small populations are vulnerable to extirpation with no potential for recolonization when local extinctions occur.

Morita and Yamamoto (2002) relate that in less than a century almost 60% of the White Spotted Char populations (*Salvelinus leucomaenis*) situated above erosion control dams were predicted to be, or had already been, extirpated in 50 years. These authors also suggest that a minimum of 2.3 km^2 to 9 km^2 of watershed area is necessary to allow populations a 50 to 90% chance to sustain themselves. Additionally, Letcher et al. (2007) found that the existence of barriers would result in local population extinction in two to six generations, and this would increase the likelihood of system-wide extinction as tributaries no longer have the ability to act as sources of fish. Harig and Fausch (2002) also suggest that larger catchments are ideal for persistence of isolated populations of salmonids, and Neville et al. (2006b) states that if the population above the dam is large enough, genetic drift may be reduced.

Despite these findings, Reinman and McIntyre (1993) purport that metapopulations are more likely to go extinct from environmental reasons than genetic ones. Hayes (1995) relates that processes that act to control the strength of a year class in salmonids usually operates in the early life stages, like the eggs and alevins in the redd or in the first year of the free swimming stage (Alonso-Gonzalez et al., 2004). It has been reported that high flows and related floods can scour out and destroy redds and the eggs and alevins (Seegrist and Gard, 1972; Cattaneo et al., 2002) and fry (Heggenes and Traaen, 1988; Jensen and Johnsen, 1999; Zorn and Nuhfer, 2007) contained there. Additionally, high flows can displace or eliminate YOY (Hoopes, 1975) and ultimately cause weak or failures of year classes for Brook (Elwood and Waters, 1969; Waters, 1983; Spina, 2001; Carline and McCullough, 2003), Brown (Hayes, 1995), and Rainbow (Strange et al., 1992) trout. However, as the size of salmonids increase, the direct effect of floods on trout is lowered as the chance of getting washed away decreases for Brook (Elwood and Waters, 1969), Brown Trout (Heggenes, 1988; Hayes, 1995; Lobon-Cervia, 1996; Cattaneo et al., 2002) and Rainbow (Simpkins et al., 2000) trout. Interestingly, Heggenes and Traaen (1988) demonstrated that when salmon and trout reach lengths of around 40 to 50 mm they were able to better tolerate higher water velocities and thus lower the chance of being washed out and displaced by high flows. The related specifics in my situation remain unclear, but it is plausible that this type of dynamic is important for these actions may push fry out of tributary sources and into the mainstem areas. Although I did gather YOY in the mainstem of South Branch of the Raritan River, with the exception of the first field event, the abundance was usually low. Possibly, these young fish were not born in the larger waterbody, but instead were pushed there from their tributary redd areas during high water times and were able to survive the displacement in the larger less turbulent part of the system.

3.5 Conclusions

Recently, after I had finished my infield work, the land owners have opted to not remove the dam structure and rehabilitation has taken place instead. With the newly acquired knowledge of small populations of coldwater salmonids existing in headwater areas I can lend some assistance to the decision making that environmental managers may undertake if this type situation is encountered again in the future. Ultimately, the relative biological costs and benefits for dam razing or rehabilitation must be determined on a case by case situation in attempts to effectively preserve or conserve native populations. This work has specific implications regarding Brook Trout populations. First, with the exception of the Warmwater and Sun Valley Brook tributaries, length-frequency has determined population age structure and consistently identified the existence of YOY individual fish during the three summers of research. Sun Valley Brook did have YOY in two of the three summer surveys, indicating that all of the above dam streams are indeed trout production waters and should be treated as such in regard to the New Jersey Surface Water Quality Standards, N.J.A.C. 7:9B.

Second, the movement of individuals among sections of water and the overall population size estimates indicate that these Brook Trout are a set of linked local populations or a metapopulation. Such a population structure is important in assisting overall species strength in naturally disturbed systems, but may be equally important in anthropogenically altered or fragmented regions. Again, smaller populations in each patch are thought to be less resilient and more vulnerable to threats like invaders and environmental and demographic stochasticity, so migrant fish become critical to long term persistence through recolonization and use of other habitats. Next, since this portion of the watershed had not previously documented trout production waters since originally surveyed in the late 1960s, results imply that population relicts may be found in other regions of New Jersey. This finding is an extremely important outcome, for knowledge of these remnant populations may become valuable in assisting with reestablishment of Brook Trout to other areas of the state and thus ensuring native genetic diversity and an overall strengthening of heritage strains of this once endemic fish. Furthermore, like the suggestions made in Poff et al. (1997) and Zorn and Nuhefer (2007), managers of this watershed should continue to support actions that allow its streams to have the most natural flow regime. By doing so, abnormal flooding and high water flow situations that often follow land use changes are reduced and less likely to wash out fry, weaken year classes, and act to imperil the unique group of Brook Trout in this area. This is an especially important goal to help mitigate scenarios predicted to result from altered hydrologic regimes brought about in the upcoming decades by climate change (Clark et al., 2001; Wenger et al., 2008).

Finally, continued investigations in locations that have not been surveyed before is essential to locating undocumented populations. Catchments with similar geologic and LU/LC characteristics as the thresholds ascertained in Chapter 2 would be a logical place to begin investigating. However, it should be noted that when the catchment area from the dam upward is considered as one large unit this case study area does not meet most of the levels determined in Chapter 2 to find reproducing Brook Trout groups (Table 3-7). The only measure that fell within the suggested LU/LC quantity was observed in agriculture areas. Barren and developed, open water LU/LC, and PIC were higher, while wetland and forest LU/LC was lower. Conversely, the case study BFI was higher.

This last finding is very interesting, for as I conducted my winter in-field surveys many of the tributary streams were observed to take much longer, if ever, to freeze over. It seemed clear that these places were being influenced by a large amount of ground water. When all linked together, these observations suggest that high amounts of underground flow may be buffering against the negative influences from LU/LC factors. Siitari et al. (2011) describes a similar situation taking place in streams that averaged base-flow numbers of 63%. My study area maintained an average of 58% BFI. Both findings are well higher than the suggested ≥55% required for the achievement of excellent (Raleigh, 1982) and ≥50% for good (Raleigh et al., 1986) salmonid quality water. Stanfield et al. (2006) also spoke of the importance of high levels of base-flow to support salmonid populations.

Power et al. (1999) discusses the importance of base-flow in that is offers temperature moderation, while Wiley and Seelbach (1997) related the value of its flow stability. Waco and Taylor (2010) focus on the thermal refuge from summer and winter extremes high base-flow provides for trout, and Trumbo et al. (2014) suggest such characteristics even allow populations to persist in locations that are otherwise too harsh. Base-flow is seen by many as the single most important factor to limiting the existence of Brook Trout (McCormick et al., 1972; Siitari et al., 2011; Kratzer and Warren, 2013). This could also be an explanation as to why Brook Trout persists in the locale despite the potentially unsustainable LU/LC levels that have been previously realized.

Figure 3-1. Headwaters of the Raritan River South Branch study area, Mt. Olive, New Jersey.

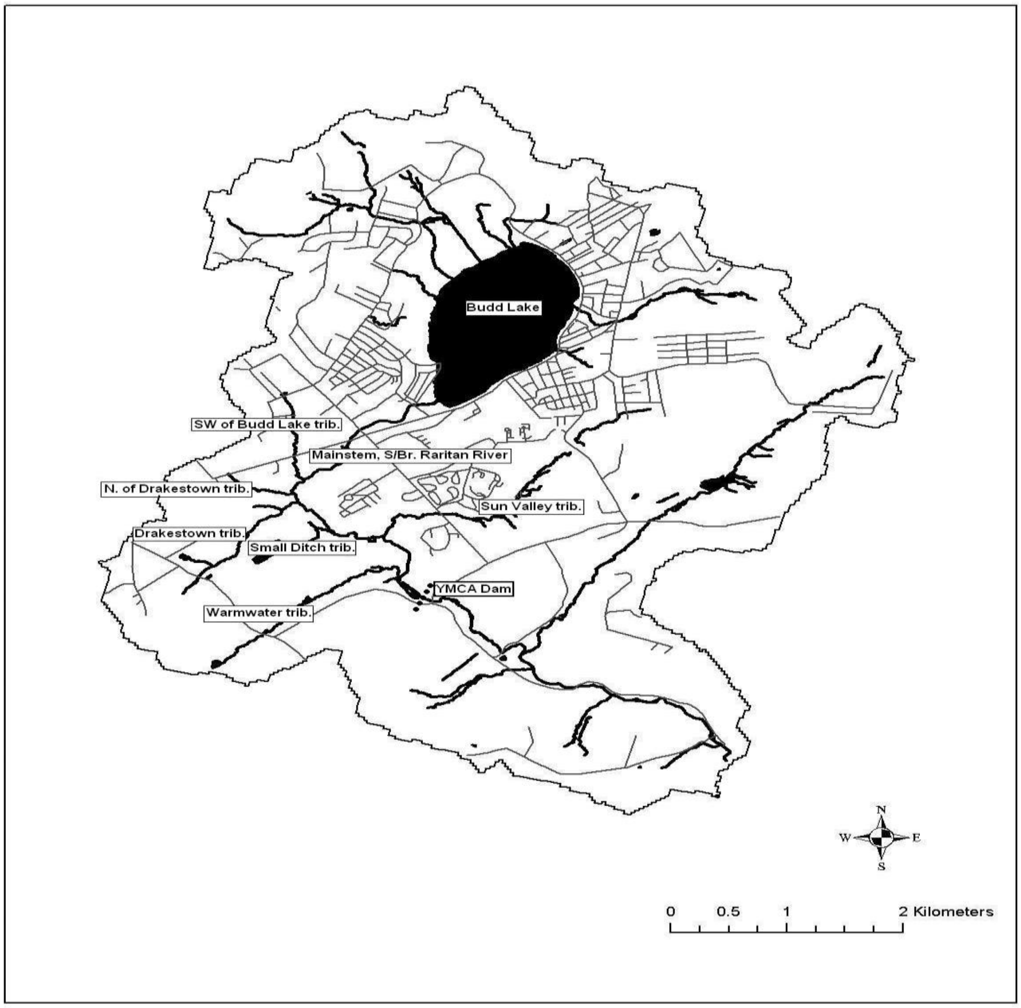


Figure 3-2. Population estimates and total number of moved Brook Trout. Breakdown per waterbody in catchment area above YMCA Dam.

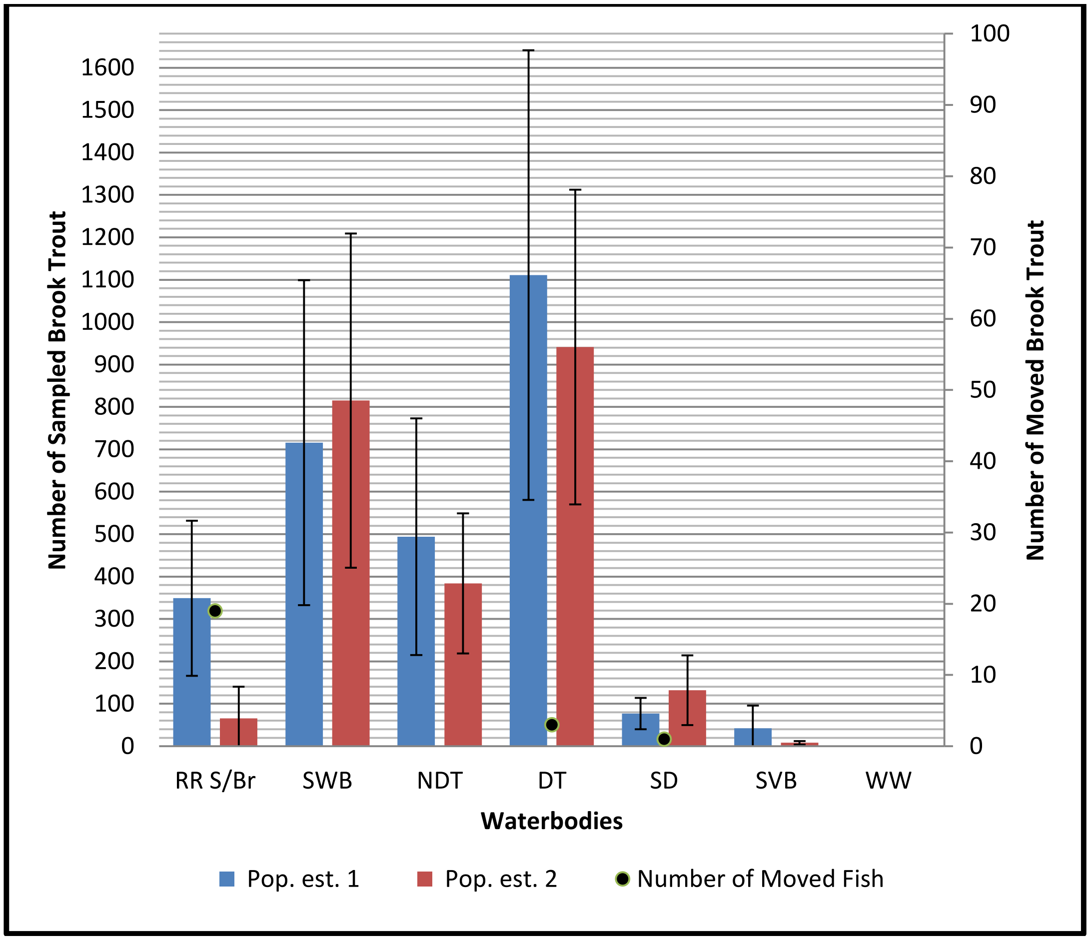


Table 3-1. Population estimates of stream sections above YMCA dam using the Chapman-Peterson strategy.

	Raritan River S/Br	**R.R. S/Br (trib) (SW of Budd Lake)**	**R.R. S/Br (trib) (N of Drakestown)**	**R.R. S/Br (trib) (Drakestown)**	**R.R. S/Br (trib) (Small Ditch)**	**Sun Valley Brook**	**R.R. S/Br (trib) (Warmwater)**	**Total**
Chapman-Peterson pop. est. 1	349±183	716±383	494±279	1,111±530	77±37	42±54	0	3,008±788
Chapman-Peterson pop. est. 2	66±74	815±394	384±165	941±371	132±82	8±4	0	2,618±647
Difference 2 & 1 pop. est.	-283	99	-110	-169	56	-34	0	-390
Average both pop. ests.	207	766	439	1,026	105	25	0	2,813±718

Table 3-2. Mean and median values of Brook Trout in millimeters for seven in-field events above YMCA Dam, Mt. Olive, NJ.

Year	**Su 10**	**W 10-11**			**Sp 11**		**Su 11**		**W 11-12**			**Sp 12**			**Su 12**		
In-Field Event	#1 Mark	#2 Capt.	#2 Recapt.	**#2 Mvd. Recapt.**	#3 Capt.	#3 Recapt.	#4 Mark	#4 Recapt.	#5 Capt.	#5 Recapt.	**#5 Mvd. Recapt.**	#6 Capt.	#6 Recapt.	**#6 Mvd. Recapt.**	#7 Capt.	#7 Recapt.	**#7Mvd. Recapt.**
N	425	345	48	**5**	263	28	336	501	434	56	**6**	503	24	**10**	541	15	**2**
range (mm)	50-254	50-249	71-232	**96-165**	24-236	86-226	48-306	40-306	58-316	68-223	**114-233**	29-318	112-227	**126-245**	50-299	129-210	**165-196**
average (mm)	103	99	115	**120**	110	135	96	95	111	124	**157**	120	151	**181**	104	166	**181**
median (mm)	80	91	100	**116**	110	124	86	84	103	119	**143**	120	144	**176**	85	166	**181**
s	45.3	30.3	38.2	**27.5**	42.9	35	36.0	37.9	33.1	33	**45.5**	45.2	31.9	**31.1**	43.7	26.4	**21.9**

Table 3-3. Comparisons of Brook Trout and Brown Trout length (mm) in surveyed waters 2010-12.

Fish Type	**BKT All**	**BKT Mvd.**	**BNT All**
N	3,012	23	13
Mean (mm)	106	156	268
Median (mm)	98	161	262
Range (mm)	25-318	94-245	156-334
s	41	37	49

Table 3-4. Fish species gathered during official summer field surveys, not including Brook or Brown Trout species. Numbers indicate first, second, or third summer of work when sampled.

Species	**Raritan River S/Br**	**R.R. S/Br (trib) (SW of Budd Lake)**	**R.R. S/Br (trib) (N of Drakestown)**	**R.R. S/Br (trib) (Drakestown)**	**R.R. S/Br (trib) (Small Ditch)**	**Sun Valley Brook**	**R.R. S/Br (trib) (Warmwater)**
American eel (*Anguilla rostrata*)	1						
Banded killifish (*Fundulus diaphanus*)	1,2,3						
Bluegill *(Lepomis macrochirus*)	3						
Blacknose dace *(Rhinichthys atratulus*)	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3
Creek chub (*Semotolus atromaculatus*)	1,2,3	1,2,3	3	1,2,3	3	1,2,3	1,2,3
Chain pickerel (*Esox niger*)	2						
Eastern mudminnow (*Umbra pygmaea*)	1,2,3	2		2,3	1,2,3		1,3
Golden shiner (*Notemigonus crysoleucas*)	2			1			
Largemouth bass (*Micropterus salmoides*)	1,3						1,2
Longnose dace (*Rhinichthys cataractae*)	2	1	2	1,2,3		1,3	3
Margined madtom (*Noturus insignis*)	1,2,3						
Pumpkinseed (*Lepomis gibbosus*)	1,2,3	1		2,3		2,3	2
Readbreast sunfish (*Lepomis auritus*)	1						
Tesselated darter (*Etheostoma olmstedi*)	1,2,3			1,2,3		1,2	1,2,3
White perch (*Morone americana*)	3						
White sucker *(Catostomus commersoni*)	1,2,3	2		1,2,3		1,2,3	1,2,3
Yellow bullhead (*Ameiurus catus*)	1,2,3						
Yellow perch *(Perca flavescens*)	1						

Table 3-5. Rainfall amounts measured in inches at three nearby NOAA recording stations for the summer months (7-July, 8-August, 9-September) for the three years of the study. EWR- Newark Liberty International Airport, ECA- Essex County Municipal Airport, & CTM- Chatham Township.

2010			**2011**			**2012**		
EWR	**precp tot**	**1 day max**	**EWR**	**precp tot**	**1 day max**	**EWR**	**precp tot**	**1 day max**
7	1.93	0.6	**7**	2.04	0.47	**7**	2.28	0.73
8	2.44	0.78	**8**	18.8	6.4	**8**	2.56	0.59
9	3.58	1.21	**9**	8.13	3.18	**9**	3.13	0.94
x̄	2.7	0.9	**x̄**	9.7	3.4	**x̄**	2.7	0.8
ECA			**ECA**			**ECA**		
7	2.95	1.44	**7**	2.57	0.63	**7**	3.46	1.65
8	3.45	1.48	**8**	16.17	5.57	**8**	4.1	1.13
9	3.42	1.09	**9**	7.61	3.48	**9**	3.98	1.65
x̄	3.3	1.3	**x̄**	8.8	3.2	**x̄**	3.8	1.5
CTM			**CTM**			**CTM**		
7	2.39	0.53	**7**	2.52	0.77	**7**	0.79	0.54
8	3.41	1.82	**8**	9.81	2.44	**8**	0.03	0.03
9	3.14	0.92	**9**	6.01	2.36	**9**	1.57	0.77
x̄	3.0	1.1	**x̄**	6.1	1.9	**x̄**	0.8	0.4
x̄	3.0	1.1	**x̄**	8.2	2.8	**x̄**	2.4	0.9

Table 3-6. Headwater Case Study-Raritan River, South Branch above YMCA Dam- Mt, Olive, NJ mark/recapture results and population estimates.

	Raritan River S/Br	**R.R. S/Br (trib) (SW of Budd Lake)**	**R.R. S/Br (trib) (N of Drakestown)**	**R.R. S/Br (trib) (Drakestown)**	**R.R. S/Br (trib) (Small Ditch)**	**Sun Valley Brook**	**R.R. S/Br (trib) (Warmwater)**	**Total (of marked/of recaptured)**
Summer 2010 marked	84	100	100	100	35	6	0	425
Summer 2010 VIE color	red	yellow	green	yellow	red	green	NA	
Summer 2010 VIE location	right	right	left	left	left	right	NA	
Other trout species captured	0	0	0	0	0	0	0	0
Winter 2010-2011 capture	40	77	43	164	16	5	0	345*
Winter recapture w/mark from original stream	9	10	8	14	7	0	0	48
Winter recapture w/mark from another stream	1 LR, 1 LY	0	0	2 RR	1 RR	0	0	5 (1.2%/9.4%)
Other trout species captured	1 BNT	0	0	0	0	0	0	1 BNT
Chapman-Peterson pop. est.	349±183	716±383	494±279	1,111±530	77±37	42±54	0	3,008±788
Spring 2011 capture	18	67	52	116	4	6	0	263
Spring recapture w/mark from original stream	2	12	7	6	1	0	0	28
Spring recapture w/mark from another stream	0	0	0	0	0	0	0	0
Other trout species captured	1 BNT	0	0	0	0	0	0	1 BNT

Summer 2011 capture	3	178	105	180	31	4	0	501
Summer recapture w/mark from original stream	0	0	0	0	0	1	0	1
Summer recapture w/mark from another stream	0	0	0	0	0	0	0	0
Other trout species captured	4 BNT	0	0	0	0	0	0	4 BNT
Summer 2011 marked	3	100	100	100	30	3	0	336
Summer 2011 VIE color	white	blue	purple	blue	white	purple	NA	
Summer 2011 VIE location	left	left	right	right	right	left	NA	
Other trout species captured	0	0	0	0	0	0	0	0
Winter 2011-2012 capture	32	112	56	204	29	1	0	*434
Winter recapture w/mark from original stream	1 LW **(1 RR)	13	14	21	6	0	0	54
Winter recapture w/mark from another stream (** and from a different time frame)	1LB,1LP, 2RB,2RP	0	0	0	0	0	0	6 (1.8%/10%) **7
Other trout species captured	6 BNT	0	0	0	0	0	0	6 BNT
Chapman-Peterson pop. est.	66±74	815±394	384±165	941±371	132±82	8±4	0	2,618±647
Difference 2 & 1 pop. est.	-283	99	-110	-169	56	-34	0	-390
Average both pop. ests.	207	766	439	1,026	105	25	0	2,813
Spring 2012 capture	91	76	46	276	8	6	0	*503
Spring recapture w/mark	1RR	4	10	7	2	0	0	24

from original stream								
Spring recapture w/mark from another stream	1LP,2RB, 3RW,4RP	0	0	0	0	0	0	10 (3%/29%)
Other trout species captured	0	0	0	0	0	0	0	0
Summer 2012 capture	17	56	65	385	12	4	2	*541
Summer recapture w/mark from original stream	0	1	7	7	0	0	0	15
Summer recapture w/mark from another stream	1 WR	0	0	1 RP	0	0	0	2 (0.6%/11.8%)
Other trout species captured	1 BNT	0	0	0	0	0	0	1 BNT

* Total number per all streams includes fish that moved to location where not originally marked and those fish recaptured from different marking event.

**Includes fish from first marking event in second recapture survey, not included in the recapture portion of the population estimate, but included in the capture portion.

Table 3-7. Important geologic and land use/land cover characteristics determined for Raritan River / South Branch Headwater Case Study area and chapter 2 threshold levels calculated as pointing to systems containing reproducing Brook Trout populations. Percentages indicated with an asterisk (*) surpass the suggested necessary levels.

Year	**AG**	**BAR&DEV**	**WET&FOR**	**WAT**	**$\bar{x}$/TOT**	**BFI**	**PIC**
Reproducing Brook Trout Presence Thresholds Determined in Chapter #2							
1972							
TOT	291	40	1439	1	1783	NA	NA
%	17	3	79	0.6	100	NA	NA
2007							
TOT	217	440	1437	26	2120	NA	NA
%	12	22	64	0.8	100	52	4.3
S Br/ Raritan River Headwaters Study Area Values							
1972							
TOT	833	784	3465	400	5482	NA	NA
%	15	14	63	7	100	NA	NA
2007							
TOT	482	2057	2522	421	5482	NA	NA
%	*9	38	46	8	100	*58	9.9

Chapter 4

A Review of New Jersey's Management of Brook Trout Production Waters

Abstract

New Jersey maintains naturally reproducing populations of Brook Trout (*Salvelinus fontinalis*), Brown Trout (*Salmo trutta*), and Rainbow Trout (*Oncorhynchus mykiss*). However, only the Brook Trout is native to the eastern United States. Conservation of this once endemic species has become a regional priority for natural resource managers due to a noted decline in much of its original range. Urgency for ameliorative action in New Jersey has taken on an even greater importance with the recent discovery of heritage strain Brook Trout still surviving in several watersheds. By reviewing current freshwater fishery lotic salmonid management strategies, a more clear understanding of which practices may be helping and which may be hindering the larger goal of expanding the overall range native fish inhabit, as well as the abundance of individuals and self-sustaining populations. With the creation of the Coldwater Fisheries Management Plan, several approaches are offered to bolster populations. However, some accepted practices may be acting to undermine the conservation efforts. Proposals to assist in attaining greater native brook trout sustainability include the establishment of an additional angling regulation which identifies 'Wild Native' status of unique Brook Trout groups and creating stricter land use directives to support more natural flows in the headwater stream sections that hold the most rare populations. Additionally, the curtailing or cessation of stocking domestic salmonids within those same catchments would relieve some of the competitive interactions and genetic introgression/interstock

issues that could limit native survivability. Other suggestions include hatchery operation expansion to include fish of indigenous origin, removal of non-native fish from favorable standing within the State's Wildlife Action Plan, and obtaining new or reallocating current funds to support more research: such as determining the genetic structure specifics of the identified unique Brook Trout strains.

4.1 Introduction

According to Hudy et al. (2005) New Jersey ranks in the top five US locations for percentage of total watersheds where reproducing populations of Brook Trout (*Salvelinus fontinalis*) have been extirpated from their original range. The recent demonstration by Hamilton (2007) that several of the state's flowing waterbodies hold relict populations of the region's only native salmonid is an extremely important discovery. This portion of natural heritage may be direct descendants of the fish that swam in the region's waters upon the retreat of the last glaciation. A link to the ancient past is remarkable, considering how much European settlement of North America changed the continent (Nielsen, 1999; Walter and Merritts, 2008) and altered natural systems. An increase in urbanized land use and a decrease in forested land cover have most recently been noted (Brown et al., 2005; Hasse and Lathrop, 2010) and they have the potential to negatively impact the survival of the only native trout species in New Jersey.

Two other species of trout are known to have reproducing populations in New Jersey's lotic waters (Hamilton and Barno, 2005), but both the Brown Trout (*Salmo* *trutta*) and Rainbow Trout (*Oncorhynchus mykiss*) are non-natives. It is well recognized that the existence of trout in a waterbody strongly correlates with excellent water and habitat quality (Steedman, 1988; Hamilton and Barno, 2005; Ficke et al., 2009). It is also well known that trout require exceptional water and habitat quality to reproduce naturally, with the existence of wild individuals pointing to unspoiled conditions (Raleigh, 1982; Raleigh et al., 1984; Raleigh et al., 1986; Lyons et al., 1996) and minimally impacted watersheds. Furthermore, self-sustaining groups of these fish serve as biological indicators of the overall health of not only the waters in which they inhabit, but for the surrounding lands as well. An observed absence of a previously noted existing wild group can be a cause for concern, as can a drop in overall population numbers or particular age class (e.g., the reduction or loss of young-of-the-year (YOY)) (Fausch, 1988; Schueler, 1994; Karr and Chu, 2000; Fausch, 2007; Steen et al., 2008).

MacCrimmon and Campbell (1969) relate that about 100 years ago Brook Trout were found in abundance throughout most of the northern part of New Jersey, but Hamilton and Barno (2005) and Hudy et al. (2005) suggest that over the last century anthropogenic factors have negatively influenced native trout populations in the state and led to a decline in overall numbers and total watersheds these fish inhabit. Specific problems seen in New Jersey are warming of rivers from urbanization and dam building activities, fragmentation of systems by roads and dams, and competition with introduced non-native fish species (Hamilton and Barno , 2005; Hudy et al., 2005). Hamilton and Barno (2005) also describe that 175 streams or stream sections have been identified as holding wild fish, which equates to about 5% of all of the streams of the state and composes over 1,000 miles (about 1,600 km) of water. The earliest tabulation for stream or stream sections holding wild fish in New Jersey was established at 95 as shown in Soldwedel (1979). According to the New Jersey Division of Fish and Wildlife, Bureau of Freshwater Fisheries (NJDFW-BFF), as of 2012, one hundred fifteen streams or stream sections held reproducing populations of Brook Trout (Figure 4-1) (S. Collenburg, NJDFW Asst. Biologist, personal communication).

Since it is known that Brown and Rainbow Trout have the ability to competitively exclude Brook Trout through displacement due to more aggressive behavior (Fausch and White, 1981; Moore et al., 1983; Waters, 1983; Larson and Moore, 1985; Dewald and Wilzbach, 1992; Lohr and West, 1992), direct predation (Alexander, 1977), higher growth rate (Waters, 1983; Lyons et al., 1996; McKenna et al., 2013), greater fecundity (Clark and Rose, 1997), and capitalizing on erratic flow regime disturbances and related year class disruptions or failures (Waters, 1983; Clark and Rose, 1997; Fausch, 2008); it can be assumed that reproducing populations of all three lotic species are going to interact with each other in New Jersey streams. Additionally, since Brown and Rainbow Trout are known to be tolerant of higher water temperatures (Magoulick and Wilzbach, 1998; Watson, 1999; Zorn et al., 2002; Baird and Krueger, 2003; Wehrly et al., 2003; McKenna et al., 2013)), related loss of forested land cover and altered surface and groundwater flows that follow increases in urbanization necessarily leads to warming of streams, lower overall water quality, and creates a circumstance for native Brook Trout numbers to decline and succumb to population replacement.

Danzmann et al. (1998) indicate that all major groupings of extant phylogenetic Brook Trout clades were present about 100,000 years ago and divergence towards today’s current structure began within the Pleistocene epoch. Remnant Brook Trout populations that are descendants of the original fish that colonized an area after deglaciation are referred to "heritage" strains (Perkins et al., 1993). The identification of heritage strain Brook Trout populations in New Jersey waters warrants further investigation. In the NJDFW BFF Coldwater Fisheries Management Plan (CFMP), Hamilton and Barno (2005) make reference to New Jersey’s Brook Trout as the following: “considered a species of special concern, will be perpetuated and maintained, a preferred species for wild population establishment or re-establishment in waters having suitable habitat achieved by using genetically suitable stock and, in the absence of conservation genetic guidelines, translocations using wild stock may be considered”. The CFMP sets resource management goals including the prospect of this once endemic fish to again sustainably populate New Jersey’s waters. This chapter evaluates the current management practices for lotic salmonids in New Jersey and determines if existing strategies may be supporting or hindering the return of self-sustaining groups of native Brook Trout.

4.2.1 Historical Context

Due to overfishing and environmental degradation associated with the industrial revolution, the late 1800s and early 1900s saw the fisheries of the United States experience the worst conditions in their history (Nielsen, 1999). To help rectify the dire situation, Nielsen (1999) explains that between 1900 and 1950 wildlife managers stocked and poisoned fish, built and modified water bodies, and regulated fish harvest "with the single aim of providing the greatest sustained quantity of fish" to meet the needs of recreational angling and replenish declining fish numbers. This strategy adheres to a philosophy known as maximum sustainable yield (MSY). Stocked fish were considered desirable species, they fulfilled a need, they solved the perceived problem and resource managers very successfully and efficiently repeated this approach. The fact that the cultured and stocked fish were of a hatchery origin (Perkins et al., 1993) was not a consideration at that time. New Jersey was no exception to the trend (Hamilton and Barno, 2005).

Hamilton and Barno (2005) and Hamilton (2007) recount New Jersey's fish culture history. Starting in 1875 the Charles O. Hayford State Fish Hatchery began to produce Brook Trout for release into New Jersey waters after a large drought further compromised the existing native fish populations. In 1882 and 1908, respectively, Rainbow Trout and Brown Trout were also produced at the hatchery and released for angling purposes. The origin of all of these strains is unknown. In 1984, trout propagation was moved from the Hayford Hatchery to the newly constructed Pequest State Trout Hatchery. The Brook Trout raised were from eggs of the Nashau strain gained, along with Brown Trout eggs, from the North Attleboro National Fish Hatchery in Massachusetts, while the Rainbow Trout eggs were obtained from the White Sulfur Springs National Fish Hatchery in West Virginia. Over the last four years, the New

Jersey Division of Fish and Wildlife on average annually stocks streams, rivers, and lakes with close to 596,000 Brook, Brown, and Rainbow Trout (Table 4-1) (NJDFW, 2015).

In the mid-1970s the concept of optimum sustainable yield (OSY) as a natural resource management strategy was formulated. This new approach took into consideration the reality that fisheries are multifaceted by including the biological, ecological, sociological, and economic aspects of the resource (Nielsen, 1999). When using this strategy, no longer was a manager's single aim to maximize physical fish yield. In fact, it was realized that a unique management goal existed for each situation and each fishery. While it may be true that a MSY goal can be simpler to reach, especially concerning stocking a water body with catchable sized fish, but an OSY approach is much more practical in that it considers the fact that aquatic ecosystems are very diverse and the human needs related to them are equally as diverse (Nielsen, 1999). After all, fishery management has been defined as, "the manipulation of aquatic organisms, aquatic environments, and their human users to produce sustained and ever increasing benefits for people" (Nielsen, 1999). This is because in the US, fisheries are public resources that are held in trust by state and federal governments for the general use by all citizens. Reliance on MSY goals is difficult, if not impossible, because variability in populations, environmental conditions, and continuing human impact on natural resources limit the ability of managers to accurately predict fisheries yields, so depletions and extirpations are likely to occur. Goals governed by OSY may be more difficult to reach, but they more rationally allow for attaining sustainability, for every aspect of the involved system is taken into account.

4.2.2 Modern Context

To meet the various needs of anglers in New Jersey, currently the state's lotic waters are managed for salmonids in several ways, including strategies which are aligned as MSY approaches and others which are closely aligned to an OSY strategy. Numerous water bodies are known as put-and-take fisheries where cultured fish are stocked at times of the year when lotic areas are of good temporary quality to allow for limited survival. In these locations anglers are expected to harvest released individuals as it is known that eventually these places will warm to the point that fish not removed will most likely not survive beyond the initial angling timeframe. In other situations waters are considered put-grow-and-take. In these instances, stocked fish are released in places that provide water quality that may allow salmonids to survive the year and hold-over to the next angling season.

Hamilton and Barno (2005) explain that the stocking of non-native or cultured fish species may potentially affect wild trout populations negatively through disease vectors, competitive interactions, and genetic structure of wild versus cultured populations. Others have described similar concerns as well (Krueger and May, 1991; Perkins et al., 1993; Einum and Fleming, 2001). Due to apprehension with cultured genes potentially entering into known wild populations, as well as competitive interactions and other issues, new management strategies have been implemented to the put-grown-and-take releases of the past decades. Hamilton and Barno (2005) explain the specifics as follows: 35 streams or stream sections are presently regulated as Wild Trout

Streams (WTS) and are not stocked with cultured trout. Streams having self-sustaining trout populations that are not designated as a WTS, and have not been stocked with cultured trout since 2000, will not again be stocked. Streams having self-sustaining trout populations that are not designated as a WTS, but have been stocked since 2000 will be evaluated on a case by case basis to determine whether stocking is necessary. The ability of the existing wild population to sustain a desirable fishery is paramount, but if stocking is allowed, then DFW stocking guidelines regarding species selection will be followed.

The guidelines for streams having reproducing trout populations points to stocking efforts with cultured species that minimizes potential inter-specific competition or inbreeding interactions (Table 4-2). Additionally angler regulations have been established to support wild fishery stocks. A minimum nine inch length is required to harvest any trout in the State to protect the typically smaller wild fish as compared to the cultured individuals that have been raised and released at a larger overall size. Furthermore, during the spawning season all WTS fish must be returned to the water unharmed. Finally, a small number of other trout production streams or stream sections are protected under additional special regulations that further limit size and timing of harvest.

At the center of the aforementioned salmonid management plan is the fact that knowledge exists regarding reproducing populations as well as other species present in the numerous lotic systems. Until very recently, this information was hand drawn on USGS topographic quadrangles, but currently the DFW *Fish Track* database that houses all of survey information pertaining to individual water bodies has been linked to geographic information system (GIS) mapping software. As waters are surveyed during the summer sampling season (see Hamilton and Barno (2005) for specifics) and data processed, any noted changes within survey areas can be more easily indicated on summary maps. Furthermore, the New Jersey Surface Water Quality Standards, listed under N.J.A.C. 7:9B that govern the State's flowing waters can also be updated, with any necessary protection adjustments recommended (NJDEP, 2011). Surveys of lotic systems and analysis of data are essential, for without these freshwater fisheries management would rely on outdated information and fisheries sustainability would be compromised.

Revenue for NJDFW fisheries management was approximately $4.7 million in 1997 and, similar to most other states (Ross and Loomis, 1999), supplied from two sources. Eighty percent of the funds came from that year's 341,000 fishing licenses sales and other related fees (e.g., trout stamps) and the remaining twenty percent was collected from federal aid funds (Epifanio, 2000). Federal resources exist mostly in the form of grants available from a 1% to 10% excise tax on the sale of fishing related equipment, some small engine and motorboat fuel, and import duties on tackle, yachts and pleasure boats (USFWS, 2011a). This funding structure was first authorized in 1950 under the Sport Fish Restoration Act (also known as the Dingell-Johnson Act) and expanded in 1984 under the Wallop-Breaux Amendment (USFW, 2014). The program has been slightly altered several times further, with the most recent adjustment in 2005, but the spirit of the plan has remained the same. The largest annual distributions from collected revenues are available to all US states in the form of grants and make up 57% of the total yearly allocations (USFW, 2014).

From the most current information available, annually 33.1 million anglers in the US spent $41.8 billion dollars involved in their various sporting activities (USDOI, 2011). USDOI (2011) also reports that within that same timeframe there are 27.5 million freshwater anglers in the US who spend $25.7 million dollars related to fishing. Additionally, throughout the country, 26% of all freshwater anglers, or $7.2 million people, specifically targeted trout while fishing. USFWS (2013) documented that in the state of New Jersey in 2011, there were about 265,000 total fishing licenses and related stamps holders and whose privileges generated approximately $5 million. The following two years saw similarities in both permit sales and generated revenues for the state. In 2011 the Dingell-Johnson Sport Fish Restoration act apportioned $365 million to US states and territories, with $3.6 million provided to New Jersey (USFWS, 2011b). It is unclear how much money specifically was allocated to freshwater fishery management that year. In his study, Epifanio (2000) found that federal aid grant monies in New Jersey for fisheries management were apportioned as follows: 50% went to fish propagation, 20% was used for research, 5% supported habitat improvement, 5% assisted with regulations, and 20% was used in other areas. Since the data from Epifanio (2000) are almost 20 years old, I sought to determine if this apportionment structure was still in place today.

4.2.3 New Jersey Freshwater Fisheries Funding

Following a similar method as Epifanio (2000) I generated a questionnaire and surveyed the NJDFW Freshwater Fisheries Administrator (Figure 4-2) to better understand the overall management formula of the Bureau of Freshwater Fisheries. Questions were asked regarding the last two fiscal years (2013 and 2014), sent by the US Postal Service, and very graciously responses were provide by mail in the return envelope I supplied in the initial contact. Presented numbers were very similar for both years and the numbers reported here represent an approximate average of both time frames.

New Jersey's budget for the culture and management of freshwater fisheries is approximately $4.05 million annually (Figure 4-3). To support these activities $2.15 million is generated from freshwater fishing license sales and another $995 thousand comes from trout stamp sales. Federal Aid funds from the Sport Fish Restoration Funds amount to $880 thousand and another $25 thousand is provided by the NJ Mosquito Commission for the rearing of fish stocked for mosquito control purposes. The operation of the state's two fish hatcheries costs $2.6 million annually, or 65% of the total funding. Brook, Brown, and Rainbow Trout culture operates on $1.8 million: 45% of the total budget or 69% of monies used for freshwater fish culture. Of the funds put towards raising salmonids, $1.5 million supports trout stocking in lotic systems; 82% of the coldwater hatchery operations allocation and 37% of the entire annual freshwater fishery budget.

Beyond fish culture practices, from the two years of data provided, \$1.4 million is directed towards research and management of freshwater fish. On average about \$233 thousand of Sport Fish monies is set aside for research projects, representing 27% of total federal monies and 6% of the entire apportionment of freshwater funds. Expenditure of funds allocated towards coldwater research varies annually depending on the current focus of activities. In 2013 roughly \$35 thousand and in 2014 \$61 thousand went to coldwater fisheries research. While the numbers provided above are only representative of 2013 and 2014, looking at them as an average the \$48 thousand covers about 20% of the budget for research activities and 1% of the entire freshwater fishery budget. Additionally, yearly about \$1 thousand is used for coldwater fishery habitat restoration, or less than 0.025% of the total budget.

Nationally, on average more than half of total states' budget expenditures for fisheries management is devoted to two main areas: hatchery operations and stocking and analysis of fish population conditions (Ross and Loomis, 1999). On average about 33% of all funds support hatchery and stocking programs (Ross and Loomis, 1999). My findings relate that New Jersey is similar to most other US state's fishery management strategies, with all relying heavily on hatchery production and distribution of cultured fish (Ross and Loomis, 1999). Currently, resource managers are very good at culturing fish, with an average of 596,000 salmonids released into New Jersey waters over the last four years (Table 4-1) (NJDFW, 2015). The process is very efficient and the practice fulfills a publically desired need.

Mather et al. (1995) suggests that “within state fishery agencies nationally, due to current fiscal austerity, expanding job responsibilities, shrinking personnel allocations, and increasing public scrutiny of government activities, time spent on specific management activities must reflect agency priorities”. Allocation of time and money to specific tasks correlates to the perceived importance of fishery management objectives and is based on allocated funding. However, debate surrounds the continued application of domestic fish into lotic systems as the primary management strategy (Garcia-Marin, 1991; Kruger and May, 1991; Einum and Fleming, 2001; reviewed in Araki and Schmid, 2010). Furthermore, it has also been reported that managers have noted obstacles to self-sustaining salmonid populations due to habitat related issues; yet when compared to other activities, personnel time and general funding devoted to habitat protection and restoration is usually very small (Epifanio, 2000). In spite of all this, US coldwater fishery managers rank conservation of native species and protection and enhancement of wild trout as the second and first priority concerns (Born and Stairs, 2003).

4.2.4 Wild Trout in New Jersey

In New Jersey, watersheds that maintain reproducing groups of coldwater fish such as the salmonids are extremely valuable and important resources for the state’s residents (Responsive Management, 2003; 2010). Other states have recognized this as well and have even placed a higher regard on the fact that native Brook Trout are the salmonid present within systems. New York, Pennsylvania, North Carolina, and South

Carolina have all established a category of recognition for the heritage strains of these fish within their borders, but this seems more to have been done to raise public awareness or establish a sense of cultural value for the species and no extra protections or regulations followed the additional designation (Epifanio, 2000).

Currently, New Jersey contains 135 miles of water which have been designated as wild trout streams and afforded more stringent fishing regulations. This quantity represents 20% of all lotic areas within the state which have been identified as having reproducing trout populations. Such places are otherwise known as trout production waters. According to Hamilton and Barno (2005) approximately 140 additional trout production streams are not trout-stocked or regulated as a WTS. Furthermore, the harvest of these wild trout is currently governed by the general statewide regulations, but a need exists to have more stringent regulations controlling the harvest of wild trout in these areas (Hamilton and Barno, 2005). Under N.J.A.C. 7:9B, New Jersey presently holds three general surface water quality standards that relate to salmonids: 1) <u>trout production</u>, used by trout for spawning or nursery purposes during their first summer of life, 2) <u>trout maintenance</u>, used for the support of trout throughout the year, 3) <u>non-trout</u>, not used by trout for production or maintenance purposes (NJDEP, 2011). Other states utilize similar categorization of flowing waters for regulation purposes with some even creating an additional recognition for some waterbodies. Maine and California include stream regulations that build off their existing WTS tenet and connects surface water quality classification structure to protect the heritage strain trout that exist within each state (MDIFW, 2013; CDFW, 2015).

Recent work by Danzmann et al. (1998) uncovered six different major evolutionary phylogenetic clades of Brook Trout in North America. Large genetic differences were found to exist between the southern and northern groups. Populations that were believed to exist outside the zone of influence of the recent glaciation were more genetically heterogeneous and contained members from all evolutionary units, while populations from the previously glaciated areas were made up of only members of three lineages. Furthermore, in support of ideas purported by Moritz et al. (1995), Danzmann et al. (1998) suggest that evolutionary differences among clades detected were quite substantial and therefore certain lineages or populations should be recognized as evolutionary significant units. This research is important for it emphasizes the uniqueness of regional members of the Brook Trout species. Differentiation began in New Jersey upon the northern tier's repopulation upon the recession of the Wisconsinan glaciation about 15,000 years ago (Schmidt, 1986). Brook Trout most likely made their way to the area by traversing the numerous glacial lakes and recaptured streams (Schmidt, 1986; Danzmann et al., 1998; Hall et al., 2002) that comprised the changing landscape (Figure 4-4) (Stanford, 1997). Currently it is unknown, but it is probable that these fish originated from refugia either in the upper Mississippian Valley, the Atlantic Coastal uplands, or Northeastern Coastal locations (Schmidt, 1986; Danzmann et al., 1998).

Similarly, Hayes et al. (1996) indicate that native southern Appalachian Brook Trout are genetically distinct from those that were stocked and determined to be more related to northern lineages. Perkins et al. (1993) found heterozygosity of hatchery

Brook Trout populations to be lower compared to some wild groups, but within the range seen in northeastern US populations. However, this low level of genetic diversity is to be expected as only a few closely related lineages founded the newer species groups upon the recession of the last glacial period (Hayes et al., 1996). Quattro et al. (1990) also found comparable low levels of diversity in their research involving more northern Brook Trout populations.

Such differentiation is possible for as Allendorf and Ryman (1987) state, generally speaking, salmonids have, “a well-documented tendency to evolve genetically discrete, ecologically specialized populations by natural selection over thousands of generations of adaptations to local environmental conditions.” Therefore Perkins et al. (1993) describes a population’s genetic diversity that has evolved through natural selection and other random events as irreplaceable. Furthermore, a high likelihood exists that this genetic material will be necessary for future environmental changes and any loss of current heritable resources simplifies the overall genetic structure through non-native mixing will create lasting implications (Perkins et al., 1993). Others have also identified population specific traits existing between different groups of the same salmonid species (Krueger and Menzel, 1979; Garcia-Marin, et al., 1991; Van Offelen et al., 1993; Kriegler et al., 1995; Letcher et al., 2007).

As has been demonstrated to occur, the loss of regional or local genetic diversity from supporting nonnative or hatchery deployed salmonid introductions should be a concern (Allendorf and Leary, 1988; Ferguson, 1990; Hayes et al., 1996). Any actions that potentially assist in eroding the strength of heritage populations need to be considered with the costs versus benefits in mind. This is especially central to decisions that are under the control of resource managers, such as whether an area should be stocked or not, and if so, what is the appropriate level. Krueger and May (1991) discuss the many negative ecological and genetic effects introduced salmonids may impart to native fish including competition, predation, habitat alteration, and indigenous species gene pool alteration. Gene mixing from wild and hatchery strains of the same salmonid species does not always take place (Krueger and Menzel, 1979; Hayes et al., 1996; LeClair et al., 1999; Hansen, 2002). Several reasons exist for why gene exchange does not occur, including differences in indigenous population size compared to the number of stocked individuals, reduced fitness of hatchery reared individuals, and poor record keeping (Hayes et al., 1996), but the fact that gene mixing can occur should be cause for concern (Almodovar et al., 2001; Humston et al., 2012).

As a result, hatchery salmonids can develop reproducing populations, either of the same species native to an area (Garcia-Marin, 1991, Humston et al., 2012) or of a non-native variety (Larson and Moore, 1985). Compared to wild fish, often the larger size and more aggressive behavior of hatchery fish lead to an initial competitive advantage and ultimately displacement of native individuals, frequently rather quickly (Bachman, 1984; Einum and Fleming, 2001). Wild fish abundance has also been shown to stay depressed in stocked waters for years after the initial release (Vincent, 1975; Cornett et al., 2004), potentially due to the original displacement event followed by the hatchery fish themselves not surviving long term due starvation, predation, and poor general fitness (Vincent, 1960; Mason, et al., 1967; Bachman, 1984; Garcia-Marin, 1991; Weiss and Schmutz, 1999; Einum and Flemming, 2001; Hansen, 2002; reviewed in Araki and Schmid, 2010). Einum and Fleming (2001) suggests that many empirical studies clearly illustrate that fish density in streams may not show the positive intended response from stocking and fish populations may actually decrease as a result from purposeful releases. Conversely, others have shown that increases in total fish abundance and general size of individuals occurs in wild populations when waters are no longer stocked (Vincent, 1975; Bachman, 1984; Vincent, 1987; Bachman et al., 1989; Carlin et al., 1991; Gougeon, 1991; Cornett et al., 2004).

Introgression and interstock crossing of hatchery genes into wild populations also directly weakens fish population genetics by removing the natural heterozygosity that has develop over thousands of year and allowed for the group to survive (Krueger and May, 1991). Additionally, indirect genetic concerns exist when wild fish are outcompeted by stocked individuals, or naturalized non-natives, and their distribution gets restricted to headwater stream sections. Essentially population isolation occurs and such segregation increases the possibility for an outright loss of the local assemblage as population size dwindles, the overall gene pool decreases, and the potential for genetic bottlenecks and/or genetic drift situations increases (Krueger and May 1991; Wofford et al., 2005; Morita et al., 2009).

It is clear that hatchery fish have been shown to be detrimental to wild fish populations through ecological and genetic interactions (Einum and Fleming, 2001; Araki and Schmid, 2010). NJDFW managers have created some protection for WTS populations, but the presently employed hatchery program may effectively be working against preserving natural populations. Others have noted a similar situation taking place (Garcia-Marin, 1991). Hanski and Gilpin (1991) and Hanski and Simberloff (1997) discussed that the conservation of a species can begin to take place only after an understanding of the dynamics of the specific situation has been learned. Consequently, to set conservation priorities for New Jersey Brook Trout, population genetics must first be determined. Once this is known, the best way to manage stocks can then be implemented.

4.2.5 Analysis of Salmonid Resource Management

The search for heritage strain Brook Trout that was started by Hamilton (2007) needs to be built upon and all streams with reproducing Brook Trout populations should have their genetic structure assessed and mapped (sensu Perkins et al., 1985; Moritz et al., 1995; as reported in SCDEDP, 2013). If NJDFW does not have the resources or staff to meet this need, then a relationship with a University capable of processing existing or future genetic samples should be developed to complete the task. A better understanding of the depth and range of the heritage group can lead to effective management strategies. Hamilton (2007) described wild Brook Trout in New Jersey as being genetically similar to each other, but it remains unclear how these fish fit into the clades identified by Danzmann et al. (1998). Comparisons of the uncovered population genetics should be completed to identify regional and local relationships of New Jersey Brook Trout. Population genetic analysis can also assess whether hatchery reared individuals are contributing to wild stocks or whether these fish are reproductively isolated from the native population.

As evidenced through genetic mapping, Rogers and Curry (2004) and Kanno et al. (2011) demonstrated that when restrictions are absent, Brook Trout move throughout and populate all parts of stream systems, whether the catchments are in large open-river watersheds or in smaller headwater locales. Hamilton (2007) also noted this type of genetic structuring within some New Jersey populations, as did Perkins et al. (1993) in New York and Jones et al. (1996) in eastern Canada. Partly for these reasons it is recommended that the primary management unit size to protect the unique characteristics of heritage strain Brook Trout populations be set at the individual river basin dimension (Perkins et al., 1993). To further assist with this conservation goal, it is suggested that at least two populations from each major river basin be protected at as high of an effective population size as possible to ensure preservation of unique characteristics.

Currently the NJDFW does not stock WTS. However, it is known that when possible, trout will move great distances to meet their life history needs (Clapp et al., 1990; Meyers et al., 1992; Riley et al., 1992; Gowan et al., 1994; Gowan and Fausch, 1996). In order to heed the suggestions by Perkins et al. (1993) related to heritage strain fish management units, any streams near to WTS and connected to the larger waterbody within in the river basin should also not be stocked. It is understandable that such a plan may generate some discontent among anglers. For this reason NJDFW should consider expanding the state’s fish propagation program in two ways.

First, a plan to include identified heritage Brook Trout strains can help bolster the natural gene pools, as well as assist in bringing abundance numbers and overall range of genetic relicts up, much like New York State currently employs (Ernst and Lewthwaite, 2011). While it can be assumed that concern for disease introductions may be an issue, such an idea may be worthy for others have reported that wild fish progeny raised in a hatchery setting show higher mortality during rearing, but survive better when reintroduced into the natural environment (Vincent, 1960; McLaren, 1979; Garcia-Marin et al., 1991). Ultimately such fish remain in the systems much longer and once established, the process can then be used to propagate heritage stocks for repopulation elsewhere. Another cost saving advantage that can be garnered from this strategy is that repeated stocking events are less likely to be necessary due to the higher survival rates of the heritage groups.

Second, if resource users are dissatisfied with stocking eliminations, potentially different non-reproductive fish strains (FFSBC, 2004) could be released at the watershed's periphery. Triploid or all-female populations of fish could be generated in a hatchery with the intent of stocking in locations farthest from the WTS under protection. In this compromise scenario, concerned anglers have an opportunity to catch larger fish and the WTS populations have one of the two concerns removed that surround fish stocking. The hatchery modified fish have an inability to breed, so genetic introgression/interstock issues are removed, but the uneasiness related to resource competition remains.

Programmatic savings from the need to stock less often or fish overall can then possibly be put toward investigations into the problems that have altered catchments and related instream habitat to the point that natural salmonid reproduction can no longer occur (Vincent, 1987; Almodovar et al., 2001). Additionally, funds may even be available to take corrective actions in disturbed catchments or for land acquisition to keep such deterioration from occurring.

Hayes et al. (1996) suggest that native Brook Trout be reestablished in streams that historically held them, but no longer do, with introduced native fish from the same watershed population. As stated by Perkins et al. (1993), such naturalization of new self-sustaining groups in new habitats is key to aiding in preservation of species and genetic diversity. Hayes et al. (1996) continued that the active removal of the system's previously hybridized fish is unnecessary, due to the ultimate loss of some important heritage genetics, as well as the high financial cost. Additionally, as demonstrated by Almodovar et al. (2001), in less than a decade non-native genes were no longer part of the population genetics once stocking was halted. Hayes et al. (1996) continue that populations should be eradicated from places that support only hatchery origin stocks and replaced with fish of native origins.

The life history of Brook and Brown Trout are very similar in many ways. It is because of this fact that issues have arisen when the two species have been anthropogenically brought together on the North American continent. Watson (1999) states, "the two fish have evolved to fill almost identical niches on either side of the Atlantic…their diets are much the same…they spawn at the same time of year in broadly similar habitats and tolerate almost identical ranges of temperature." Because of their specific requirements these fish are most likely found in similar lotic environments.

Diglio (2014) notes that within the last 30 to 40 years, New Jersey waters supporting Brown Trout reproduction have increased substantially, while those for Brook Trout have not shown similar growth. Land use and land cover characteristics undoubtedly play a role in the presence, absence, and abundance of reproducing populations of Brook and Brown Trout (Table 4-2). However, recent work by McKenna et al. (2013) suggests that a more important factor than habitat in tipping the balance in favor of the non-natives over the natives is due to the repeated Brown Trout stocking and the competition for limited resources that follow the introductions. These researchers contend that wild Brook Trout populations may even be able to recover upon the cessation of stocking.

In New Jersey, Brook Trout and Brown Trout are both valuable sport fish, as McKenna et al. (2013) note is also true in other states. Fish stocking is an important tool to meet angler needs (Jones et al., 1996). However, the fact that the non-native Brown Trout, along with New Jersey's other stream stocked salmonid the Rainbow Trout, have made the list of the world's 100 most invasive alien species cannot be ignored (Lowe et al., 2000). Specifically related to New Jersey, it also should not be ignored that part of the NJDFW funding is tied to the State Wildlife Action Plan (SWAP) (see Niles et al., 2004), an overriding blueprint for how the agency manages wildlife resources. The strategy of the SWAP is to address the importance of all species within the state beyond those that are controlled as game. This plan acts to include those species that are considered rare, threatened, or endangered. Furthermore, even though all are subject to freshwater fishery game regulations, the document notes the importance of New Jersey's coldwater salmonid species and issues surrounding related aquatic systems. Presumably because of their need for unspoiled habitat and water quality, repeatedly throughout the document Brown Trout and Rainbow Trout are noted as being species of special concern. Furthermore, Brook Trout are noted as being a species of regional priority.

As the SWAP comes up for periodic review and reassessment, eight elements are required to be addressed (Table 4-3). To meet the many goals concerning species conservation delineated in the SWAP, several prevailing strategies are as follows:

> "-Inventory and monitor all endangered, threatened, and special concern wildlife and fish species…; especially those with data gaps.
> -Maintain ecological integrity of natural communities and regional biodiversity by controlling invasive species…
> -Protect, enhance, and restore coldwater fish habitat and ecosystems.
> -Conserve and enhance native, wild trout populations at optimum levels."

It seems likely that the BFF is capable of meeting many of the goal necessities. However, in light of the above listed conservation approaches, the SWAP makes no reference to the importance that heritage strain Brook Trout are swimming in New Jersey's lotic systems. It seems the current BFF stocking program acts to undermine the native Brook Trout related SWAP goals and greater conservation of the species seems unlikely.

Fish propagation is expensive (McKenna et al., 2013) and stocking cessation potentially saves funds (PFBC, 2011). This is especially true for places that repeatedly require fish replenishment to maintain a fishery. The literature has demonstrated positive results on wild fisheries with curtailing such releases (Vincent, 1975; Bachman, 1984;

Vincent, 1987; Bachman et al., 1989; Carlin et al., 1991; Gougeon, 1991; Cornett et al., 2004) and adjustment of some WTS regulations would go a long way to moving toward more sustainable lotic fisheries. Hatchery fish may be able to be placed in other more appropriate locations or newly freed up funds can be diverted to investigate more OSY based strategies. Coupled with the recent advance of GIS, available money may be able to support research that advances the understanding of what are the root causes for coldwater salmonid declines.

4.2.6 Suggestions for Greater Brook Trout Sustainability

Previously unknown populations of reproducing trout are still being uncovered in New Jersey and known groups are annually noted as undergoing abundance, age-class, or even species changes (Diglio, 2014; Diglio and Bologna, 2012). To move forward with creating sustainable Brook Trout populations the following suggestions are offered:

-1) Designate lotic “Native Wild” trout water status where appropriate. Begin with those populations of wild Brook Trout that were identified in Hamilton (2007) that have the possibility for heritage group existence. Next continue to assess the 115 current steams or stream sections known to hold self-sustaining populations that have no known history of stocking or may be separated by natural or man-made barriers. Samples from these places can have their genetic structures analyzed for markers that suggest an indigenous strain. Interestingly, California presently has eight streams or related systems noted with the heritage status (CDFW, 2015). Management of species based on their genetic differentiation among populations has been reported to be used successfully in other cases (Hall et al., 2002).

-2) Cease or dramatically curtail stocking of domestic lineage salmonids in the systems that hold the 115 naturally reproducing Brook Trout groups. Perkins et al. (1996) sets the management unit for salmonid genetic conservation at the river basin size, but this may be unrealistic in New Jersey due to angler concerns. However, discussions amongst all interested stakeholders could set the appropriate watershed dimension to realistically achieve this goal. However, it is important to note that all three of New Jersey's lotic salmonids are known to travel long distances to meet their life history needs (Clapp et al., 1990; Meyers et al., 1992; Riley et al., 1992; Gowan et al., 1994; Gowan and Fausch, 1996) so the closer the catchment to the basin size the better the protections.

-3) Move funding from the fish propagation and distribution program to more research oriented efforts. Depending upon the determined catchment size for stocking cessation surrounding any wild Brook Trout groups, fewer fish may be required to be produced at the hatchery. The details would have to be worked out, but the savings from the purchase of less feed alone could be substantial enough (PFBC, 2011) to see funds diverted to other areas for use. Specifically, field surveys in locations that have yet to be sampled at a scale that might allow for undocumented native groups to be discovered as was recently demonstrated in Diglio and Bologna (2012). If dedicated funds are unable to be moved from fish propagation toward other purposes it seems sensible to at least re-allocate the extra fish to put-and-take areas.

-4) Investigate ways for more federal grant money research opportunities to be explored. The questionnaire results I obtained and supporting personal communication shows a good deal of money is budgeted for use that is obtained from the Sport Fish Restoration grant. Specifically, about $232 thousand is available, but due to a small staff roughly only $80 thousand is actually used. This amounts to a large surplus that might otherwise be used for more investigations. Possibly additional staff might be hired or relationships with Universities can be developed to create internships where stipends are available to complete work. Examples of research projects that could be investigated include the previously suggested molecular genetics project or to even recreate the Hamilton (2007) study but have the focus be on wild Brown Trout populations. It would be very interesting to see if these fish show a similar relatedness trend as New Jersey’s Brook Trout do. Furthermore, follow up surveys can be conducted to see how WTS Brook Trout populations have changed since stocking was halted. This could serve as the foundation for the rationale to curtail stockings in some segments and redirect hatchery reared individuals to more appropriate locations

-5) Investigate the possibility of raising heritage lineage Brook Trout for stocking in appropriate locations. Others have noted the progeny of wild fish raised in the hatchery environment fare better than those of domestic origin upon their release (Vincent, 1960; Garcia-Marin et al., 1991). Taking advantage of such an outcome may lead to two benefits. First, areas receiving the stocking will most likely require less future effort due to the greater ability of the transplants to flourish under the local conditions with which they have become adapted to over the multiple generations of being in the system. Furthermore, a much greater potential exists for these fish to develop self-sustaining populations. Second, by selecting the proper broodstock to include the ‘heritage’ lineage genetic structure, the efficiencies within the State hatchery system can be maximized. Potential savings from other areas of the hatchery operation or newly secured Federal Grant funds can be put toward this project.

-6) Use GIS to test the LU/LC threshold values for trout reproduction waters based on all data points within the *Fish Tracks* database system. From the procedures outlined in Chapter 2, the data pool can now go beyond simply those that had matching survey locations between the historical and modern time frames. Expansions should include all catchments where trout production is known. Tests can check for differences between individual species and a separate look can be taken that pools LU/LC for all trout in combination. An additional focus for this project would be to understand the characteristic make-up of the catchments containing reproducing Brook Trout in potential ‘heritage’ type situations.

-7) Seek ways to push for develop LU/LC codes in ‘Wild Native’ Brook catchments that go beyond the current Surface Water Quality Standards, N.J.A.C. 7:9B, protections. Pending legislation in other places that will soon offer greater protection to identified important heritage populations (MDIFW, 2013) can be used as a model for how New Jersey can proceed with this strategy. Category 1 and Freshwater 1 designations come with 150 to 300 buffers along stream riparian zones, but suggestions that these may not offer enough of a safeguard to aquatic residents exist as characteristics on the landscape scale can have important and lasting influences as well (Steedman, 1988; Vondracek et al., 2005; Hudy et al., 2008). This especially may hold true for LU/LC alterations that change ground and surface flow regimes. Like the suggestions made in Poff et al. (1997) and Zorn and Nuhefer (2007), managers of these unique watersheds should continue to support and push for greater actions that allow streams to have the most natural flow regime. By doing so, abnormal flooding and high water flow situations that often follow land use changes are reduced and less likely to wash out fry, weaken year classes, and act to imperil the unique group of Brook Trout in this area. Such concerns are especially important in light of the predicted scenarios resulting from altered hydrologic regimes brought about by climate change (Clark et al., 2001; Wenger et al., 2008).

4.3 Conclusions

Through implementation of these management strategies, strides can be made to incorporate an OSY based approach to freshwater fishery management in New Jersey. Freshwater fishery management is beholden to a multitude of interested resource users and decisions for the best pathway forward need to include stakeholders from social, economic, and environmental avenues. The use of OSY strategies can allow for this to occur. However, with any type of change, progress will occur slowly, especially in regards to an adjustment of philosophical foundations. Significant ecological, cultural and bequeathed value surround those parts of our natural heritage that contain irreplaceable characteristics. For that reason, additional protection and conservation should be afforded to the self-sustaining groups of New Jersey’s Brook Trout that are connected to an indigenous lineage. By doing so, the opportunity for heritage strain Brook Trout sustainability is viable. With the proper management some “human effects on ecological and evolutionary processes can be minimized” (Moritz et al., 1995) and unique populations of our precious natural resources have a higher likelihood of being saved.

Figure 4-1. Locations for New Jersey's lotic wild Brook Trout waters as of 2012.

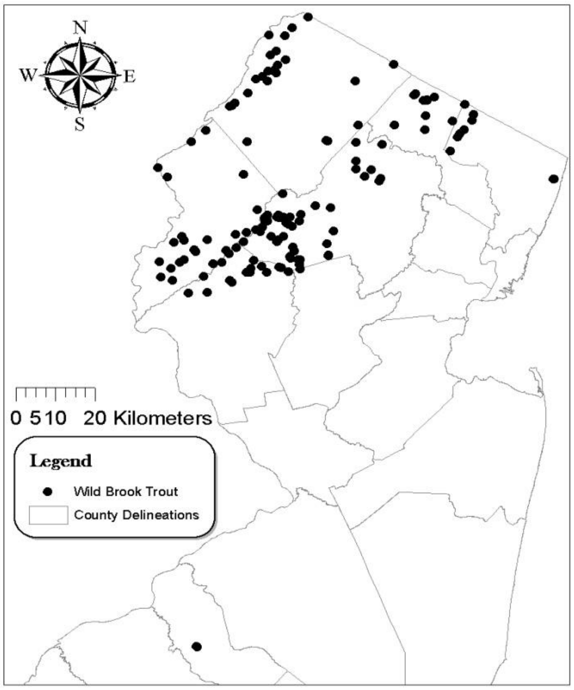
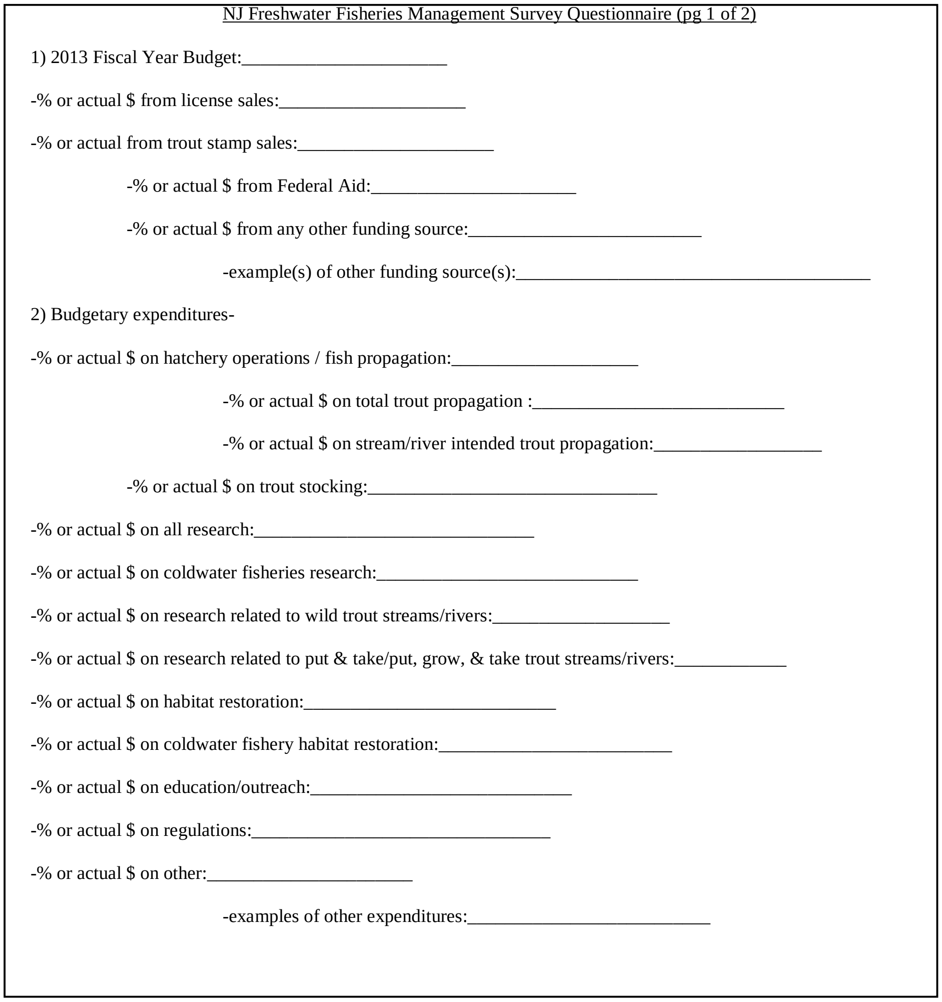


Figure 4-2. Survey questionnaire. Sent to NJDFW Bureau of Freshwater Fisheries regarding yearly revenues and expenditures.



NJ Freshwater Fisheries Management Survey Questionnaire (pg 1 of 2)

1) 2013 Fiscal Year Budget:______________________

-% or actual $ from license sales:____________________

-% or actual from trout stamp sales:_____________________

-% or actual $ from Federal Aid:______________________

-% or actual $ from any other funding source:_________________________

-example(s) of other funding source(s):______________________________________

2) Budgetary expenditures-

-% or actual $ on hatchery operations / fish propagation:____________________

-% or actual $ on total trout propagation :___________________________

-% or actual $ on stream/river intended trout propagation:__________________

-% or actual $ on trout stocking:_______________________________

-% or actual $ on all research:______________________________

-% or actual $ on coldwater fisheries research:____________________________

-% or actual $ on research related to wild trout streams/rivers:___________________

-% or actual $ on research related to put & take/put, grow, & take trout streams/rivers:____________

-% or actual $ on habitat restoration:___________________________

-% or actual $ on coldwater fishery habitat restoration:_________________________

-% or actual $ on education/outreach:____________________________

-% or actual $ on regulations:________________________________

-% or actual $ on other:______________________

-examples of other expenditures:__________________________

Figure 4-3. New Jersey Freshwater Fisheries Funding Schematic- All figures represent the average of only the 2013 and 2014 funding years. Actual year to year allocations vary depending on different project needs and focus areas. M= million dollars, k= thousand dollars, (#%) = % of total budget, (*#%) = % of previous dollar amount

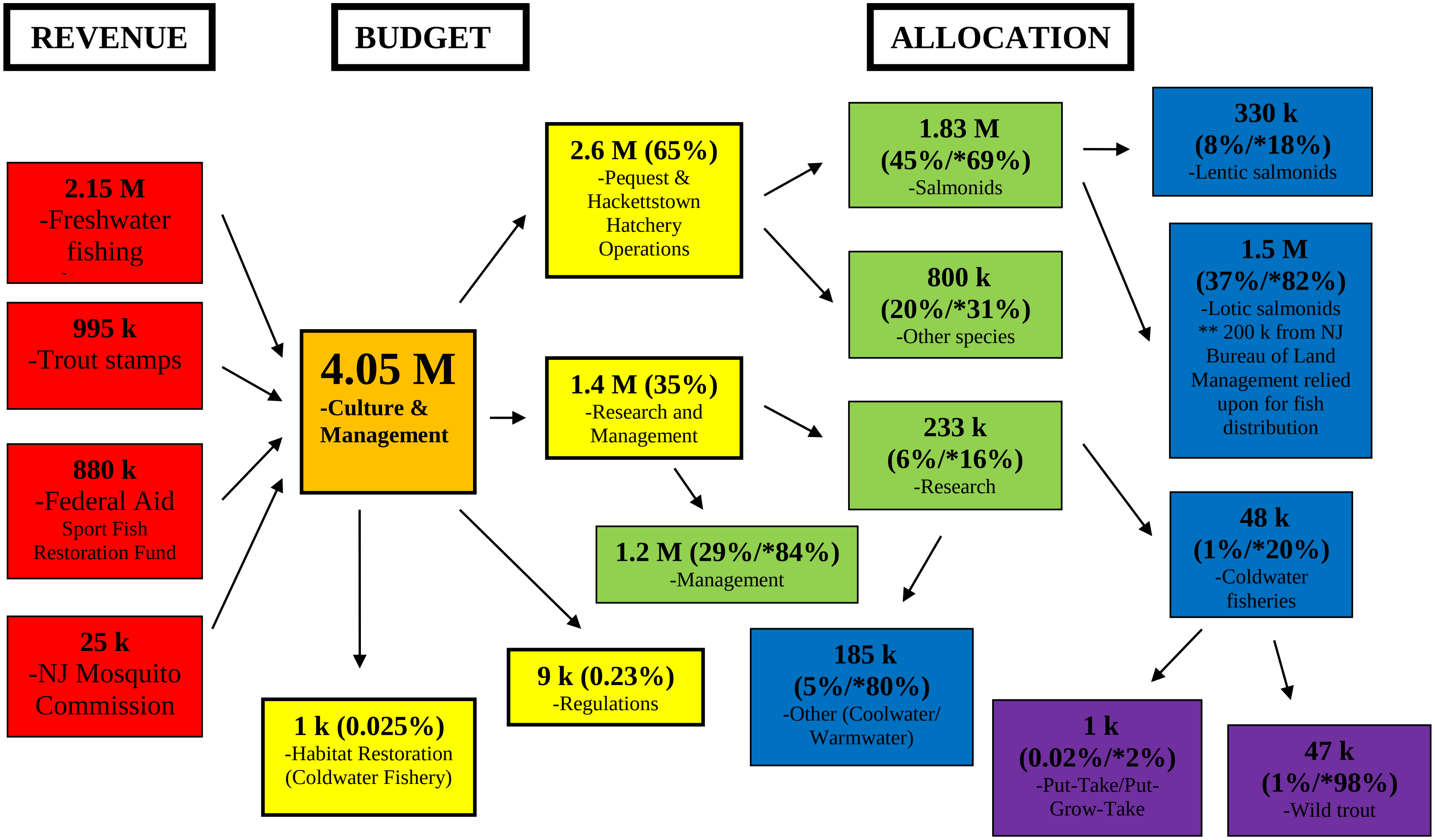


Figure 4-4. Glacial Lakes and Ice Margins related to the recession of the Wisconsinan glaciation. Presented in Stanford (1997). Note the amount of interconnected glacial-lake, glacial-lake outflow, and glacial-stream drainage area suggested to be the pathways Brook Trout repopulated northern New Jersey after glacial ice recession occurred.

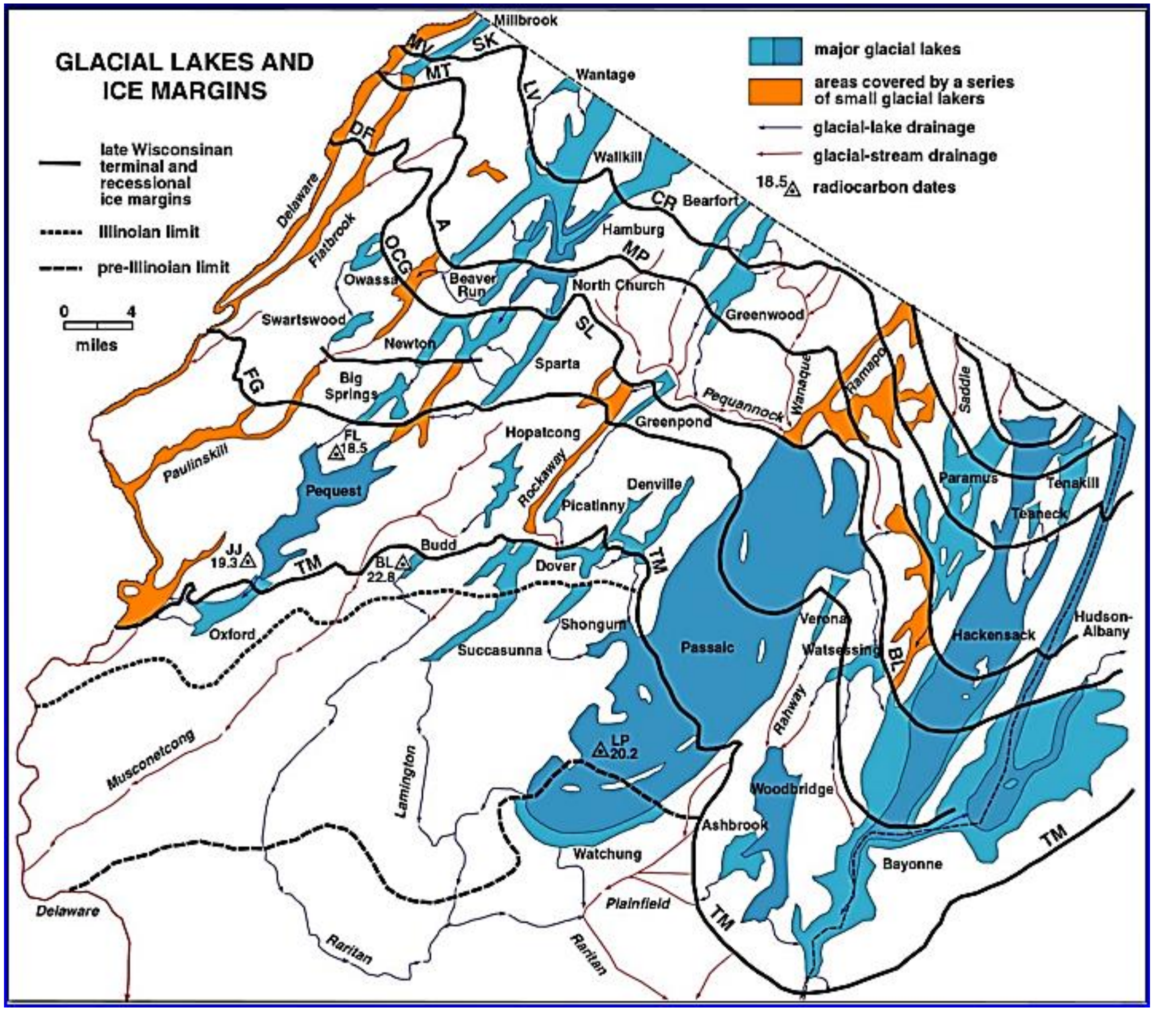


Table 4-1. New Jersey Division of Fish and Wildlife cultured salmonid stocking summaries over the last four years by season and species. Adapted from NJDFW (2015). BKT- Brook Trout, BNT- Brown Trout, RBT- Rainbow Trout

	2014	**2103**	**2012**	**2011**	**mean**
Spring (BKT, BNT, & RBT)	370,675	614,833	620,262	619,160	556,233
Fall (BKT, BNT, &/or RBT)	26,760	19,980	22,225	21,390	22,589
Sea Run (BNT only)	8,600	NA	15,840	15,849	13,430
Winter (BNT & RBT)	13,340	4,810	5,010	5,000	7,040
TOTAL	419,375	639,623	663,337	661,399	595,934

Table 4-2. As seen in Hamilton and Barno (2005), specifics related to acceptable NJDFW cultured salmonid species stocking in known lotic trout production water bodies.

Reproducing trout species	**Acceptable cultured trout species**
brook	rainbow
brown	brook and/or rainbow
rainbow	brook and/or rainbow
brook and brown	rainbow
rainbow and brown	brook and/or rainbow
brook and rainbow	rainbow or brook (opposite of dominant wild species)

Table 4-3. NJDFW State Wildlife Action Plan procedural goals, as seen in Niles et al. (2004).

EIGHT (8) REQUIRED ELEMENTS of the WILDLIFE ACTION PLAN

1. Information on the distribution and abundance of species of wildlife
2. Descriptions of locations and relative condition of key habitats and community types
3. Descriptions of problems and priority research and survey efforts
4. Descriptions of conservation actions
5. Proposed plans for monitoring
6. Descriptions of procedures to review the strategy
7. Coordinating the development, implementation, review and revision of the plan with Federal, State, and local agencies and Native American tribes
8. Broad public participation

Chapter 5

Assessment of New Jersey Trout Production Systems: Moving Towards Sustainability

5.1 Introduction

The Eastern Brook Trout (*Salvelinus fontinalis)* has had substantial declines in presence, abundance, and coverage related to its original range in North America (Hudy et al., 2005; Hudy et al., 2008). Anthropogenic stressors are considered the primary threats and are generally most to blame for the noted deterioration (Fausch et al. 2006). Hamilton and Barno (2005) and Hudy et al. (2005) suggest that over the last century the most important factors influencing native trout populations within New Jersey are increases in human induced land use practices. Specific problems seen in New Jersey are warming of rivers from urbanization and dam building activities, fragmentation of systems by roads and dams, and competition with introduced non-native fish species. MacCrimmon and Campbell (1969) relate that about 100 years ago Brook Trout were found in abundance throughout most of the northern part of the state and Hudy et al. (2005) has ranked the New Jersey in the top five US locations for percentage of total watersheds where these fish have been extirpated.

New Jersey maintains natural groups of three trout and char species: Brook Trout, (*Salvelinus fontinalis),* Brown Trout (*Salmo trutta*), and Rainbow Trout (*Oncorhynchus mykiss*). Finding each species within a lotic system indicates high levels of water quality and habitat (Raleigh, 1982; Raleigh et al., 1984; Raleigh et al., 1986). Identifying young-of- the-year (YOY) of each species is even more notable for such self-sustaining groups point to water and habitat of immensely high quality (Hamilton and Barno, 2005). Because of their need for waters and habitat of the highest quality (Steedman, 1988; Wehrly et al., 2003; Ficke et al., 2009), Brook Trout are seen as the most sensitive of New Jersey's three wild stream salmonid species and extremely susceptible to environmental changes. Locating Brook Trout YOY is exceptionally indicative of pristine systems and surrounding watersheds. Any observed absence of a previously noted existing wild group can be a cause for concern, as can a drop in overall population numbers or particular age class, especially the reduction or loss of YOY (Fausch, 1988; Schueler, 1994; Karr and Chu, 2000; Fausch, 2007; Steen et al., 2008). Due to these changes, Brook Trout have become a species of great conservation concern (DeWeber and Wagner, 2015) and natural resource managers across the fish's original range seek solutions to help reverse the negative trend. With this motivation in mind I conducted research to add to the cause and help make strides towards seeing this once endemic species again sustainably populating the watershed of New Jersey.

5.2 A Movement Towards Sustainability

To understand the problem of Brook Trout decline it is essential to have an idea of the severity of the problem. Chapter 2 quantitatively evaluated population level changes in all species of self-sustaining or wild salmonids in New Jersey. While the sets of historical and modern data that were compared did not include every catchment within the state, the sample was large enough to identify important LU/LC thresholds related to P/A of reproducing lotic salmonid species. Care must be taken if one is to generalize these findings across the region, but nonetheless the identified values are still significant. At the most basic level, this research suggests that the range of reproducing Brown Trout populations is expanding, while Rainbow and Brook Trout groups have all decreased slightly.

Furthermore, correlations and *t*-tests were run to see if relationships existed between species' presence or absence (P/A) within survey locations, land use or land cover characteristics (LU/LC), and other hypothesized abiotic factors influential to salmonid life history. Results showed that LU/LC catchment value thresholds exist at < 12% agriculture, < 22% barren and urban, > 64% wetland and forest, and < 4-6% impervious to allow for natural Brook Trout reproduction. Similarly, values assigned for Brown Trout reproduction include the following; < 14% agriculture, < 27% barren and urban, > 58% wetland and forest, and < 5-7% impervious cover. While these figures are similar to findings others have identified, never were specifics such as these determined for New Jersey. As previously mentioned, the data set only included sites that were paired in that they were sampled historically and again in a more modern time frame so much of the state was left out. However, the employed methods proved useful and should be relied upon again to test all New Jersey catchments with reproducing salmonids to understand larger state trends.

Within the context of changing salmonid population structure is an additional realization that Brook Trout of an ancestral heritage strain do still exist in New Jersey.

To me this is a remarkable find, considering how much watersheds have been altered since European settlement (Nielsen, 1999; Brown et al., 2005; Hasse and Lathrop, 2010). Such a find brings along with it an even greater responsibility in that these fish contain irreplaceable components of natural heritage (Perkins et al., 1993) and their preservation or conservation is of the utmost importance. To that end, Chapter 3 of this thesis outlines the discovery and investigation of a previously undocumented wild Brook Trout metapopulation. A very high likelihood surrounds this group as being of a heritage lineage due to the fact that it has remained intact after being essentially cut-off from the larger system almost 100 years ago (Hilbert, 2001) and it exists in close proximity to another known relict population (Hamilton, 2007). Such a find is important because this population can be used as broodstock to repopulate other stream sections deemed appropriate for such releases (Perkins et al, 1993; Hayes et al., 1996).

Finally, a qualitative assessment of freshwater fishery management as it relates to lotic salmonids in New Jersey was undertaken. Not surprisingly, the strategies practiced for overseeing the resources are not uncommon throughout the rest of the country (Mather, 1995; Nielsen, 1999; Ross and Loomis; 1999; Epifanio, 2000; Hamilton and Barno, 2005; USDOI, 2011; USFW, 2014). Much success has come from making use of policies that are founded on the maximum sustainable yield concept (Nielson, 1999). Perhaps nowhere is this more evident than with the vast commitment that has been made to stocking trout of domestic origin (NJDFW, 2015). Such releases have been pulled back when self-sustaining fish have been identified to exist within a stream section. Additionally, a more restrictive Wild Trout Stream regulation status gets assigned to each waterway, but recent suggestions relate that more should be done to protect wild groups, especially those of an indigenous lineage (Perkins et al., 1993). Salmonids can travel large distances to meet their life history needs, as shown in Chapter 3 and illustrated by others (Clapp et al., 1990; Meyers et al., 1992; Riley et al., 1992; Gowan et al., 1994; Gowan and Fausch, 1996). If reproducing Brook Trout populations are to be more protected, domestic releases should take into account the potential for stocked fish to make their way into locations that are ultimately connected, with more thought to the relative distance of the two groups.

Furthermore, the State Wildlife Action Project (SWAP) that is a foundation for protecting all species of concern in New Jersey is currently undergoing a reassessment process (Niles et al., 2004). The framework of the SWAP is excellent, but it may actually be undermining the greater protection of Brook Trout. While other strategies presented in the plan invoke the outright removal of invasive and other non-native species, special consideration has actually been assigned to non-native Brown and Rainbow Trout. Both species are known to competitively exclude natives, and as Chapter 2 of this thesis illustrates, the range of Brown Trout is expanding, many times at the expense of indigenous groups. Adjustments to the SWAP should reflect a different status for non-native trout species.

Moreover, the work started by Hamilton (2007) should be completed by mapping the genetic structure for all 115 of New Jersey's identified wild Brook Trout groups (sensu Perkins et al., 1985; Moritz et al., 1995; as reported in SCDEDP, 2013). However, until this can be finished, through the use of stocking records, places that contain wild natives and have never had domestic fish releases should be considered for a new regulatory “Wild Native” rank. A similarly named and equally important level currently exists in California (CDFW, 2015), and includes eight streams or stream systems.

As it is likely that New Jersey will have a minimal number of watersheds harboring heritage strain Brook Trout, additional special status will not have to be provided on a large scale. In this regard, LU/LC regulations in the catchments above each group should also acknowledge the existence of something special below. As Poff et al. (1997) and Zorn and Nuhefer (2007) purport, managers of these places should support actions that allow for the most natural flow regime in streams. By doing so, abnormal flooding and high or low water flow situations that often follow land use changes are reduced and it is less likely fry will be threatened by such extremes that weaken year classes, and act to further imperil the area’s unique Brook Trout. Such goals remain essential, especially with the predicted hydrologic alterations believed to follow expected climate change scenarios (Clark et al., 2001; Wenger et al., 2008).

Finally, management of freshwater fishery salmonid resources in New Jersey exists with a firm foundation in MSY strategies. More funding can be reallocated to research oriented avenues with the cessation or curtailing of domestic origin stocking. If this concept proves too controversial, other stocking strategies can be employed that reduce the harm to wild fish. The generation of alternative reproduction domestic fish strains can assist in fulfilling this need, as does hatchery rearing and releasing heritage origin fish. If all of this proves too daunting, new or creative ways can be implemented to take advantage of Federal Funds that might otherwise go unused. Much research can be conducted from available grants by graduate students, academia professionals, or resource managers.

5.3 Summary and Recommendations

Presently, New Jersey's holds 115 wild Brook Trout populations. Some of these groups are known to be of heritage origin. Strategies should be employed to assist with the expansion of native groups and all populations need further protection to prevent further declines. Valuable LU/LC thresholds have been identified to support salmonid reproduction and should guide conservation efforts. Following a similar process, all of the catchments where natural salmonid reproduction occurs should be tested to create a more wide ranging sample and allow for greater generalization of the characteristics. A reinvestment in mapping wild trout genetics should begin, for such knowledge can drive many other activities. To help expand indigenous populations, examples of future work include the following: repopulation of streams with appropriate stocks, developing hatchery operations to specifically raise progeny of wild fish for release. Relief for natives can also be provided through a reassessment of current stocking strategies such as the lowering or cessation of stocking catchments with known unique populations. Furthermore, knowledge related to the damage non-native fish can cause should be reflected in New Jersey's SWAP upon reestablishment. Finally, the devotion of more funds to research based activities that focus on projects like the genetic lineage mapping, investigating reasons for catchment decline, monitoring of LU/LC threshold values within the most important locations, or for outright habitat improvement or land acquisition are all possibilities. Prior to European settlement of North America Brook Trout maintained self-sustaining populations for thousands of years (Danzmann et al., 1998) in the eastern United States. With some adjustments to general lines of thinking and taking advantage of new knowledge steps can be taken to assist with making the natural process of sustainability more common again.

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Appendix A Specifics of Historical vs. Modern Trout Production Waters Sample Sites

Table A-1. Sites, observed species presence and absence and abundance numbers in New Jersey Trout production inventory/re-inventory study, (historical) 1968-1977 and (modern) 2001-2010. Yellow color & BKT = Brook Trout, Brown color & BNT = Brown Trout, and pink color & RBT = Rainbow Trout.

Site	Date	BKT_YOY	BNT_YOY	RBT_YOY	YOY tot/183m	YOYper m	site	date	BKT_YOY	BNT_YOY	RBT_YOY	YOY tot/150m	YOYper m
Bear Brook	7/21/1970	3	0	0	3	0.016	Bear Brook	7/8/2004	1	0	0	1	0.007
Bear Swamp Brook	8/13/1968	10	0	0	10	0.055	Bear Swamp Brook	7/15/2003	4	0	0	4	0.027
Beatty's Brook	6/22/1970	32	0	0	32	0.175	Beatty's Brook	8/14/2001	7	11	0	18	0.12
Beerskill Creek	8/30/1968	20	0	0	20	0.109	Beerskill Creek	8/10/2004	11	0	0	11	0.073
Big Flat Brook	9/18/1968	2	0	0	2	0.011	Big Flat Brook	7/27/2005	1	0	0	1	0.007
Black Brook	8/4/1969	23	0	0	23	0.126	Black Brook	8/14/2003	0	1	0	1	0.007
Black Creek (trib.) (McAfee)	7/29/1970	30	1	0	31	0.169	Black Creek (trib.) (McAfee)	7/26/2005	34	0	0	34	0.227
Brass Castle Creek	8/5/1970	4	16	0	20	0.109	Brass Castle Creek	7/17/2001	12	38	0	50	0.333
Buckhorn Creek	7/17/1970	0	1	0	1	0.005	Buckhorn Creek	7/16/2002	0	0	0	0	0
Burnett Brook	8/7/1969	0	24	0	24	0.131	Burnett Brook	8/16/2002	0	20	0	20	0.133
Capoolong Creek	6/26/1969	0	2	0	2	0.011	Capoolong Creek	8/12/2002	0	2	0	2	0.013
Clove Brook (B)	8/13/1968	10	0	0	10	0.055	Clove Brook (B)	7/25/2003	25	0	0	25	0.167
Cold Brook	7/31/1969	0	4	0	4	0.022	Cold Brook	8/22/2002	0	60	0	60	0.4
Cooley Brook	9/1/1970	22	7	0	29	0.158	Cooley Brook	8/26/2010	10	0	0	10	0.067
Dawson's Brook	8/12/1969	28	0	0	28	0.153	Dawson's Brook	7/29/2005	0	18	0	18	0.12
Delaware River (trib.) (Holland)	9/8/1970	0	12	0	12	0.066	Delaware River (trib.) (Holland)	7/10/2002	0	17	0	17	0.113
Dunnfield Creek	8/6/1970	2	7	0	9	0.049	Dunnfield Creek	9/3/2004	4	59	0	63	0.42
Electric Brook	7/30/1970	3	0	0	3	0.016	Electric Brook	8/15/2007	8	0	0	8	0.053
Flanders Brook	8/14/1969	12	0	39	51	0.279	Flanders Brook	8/30/2004	0	13	38	51	0.34

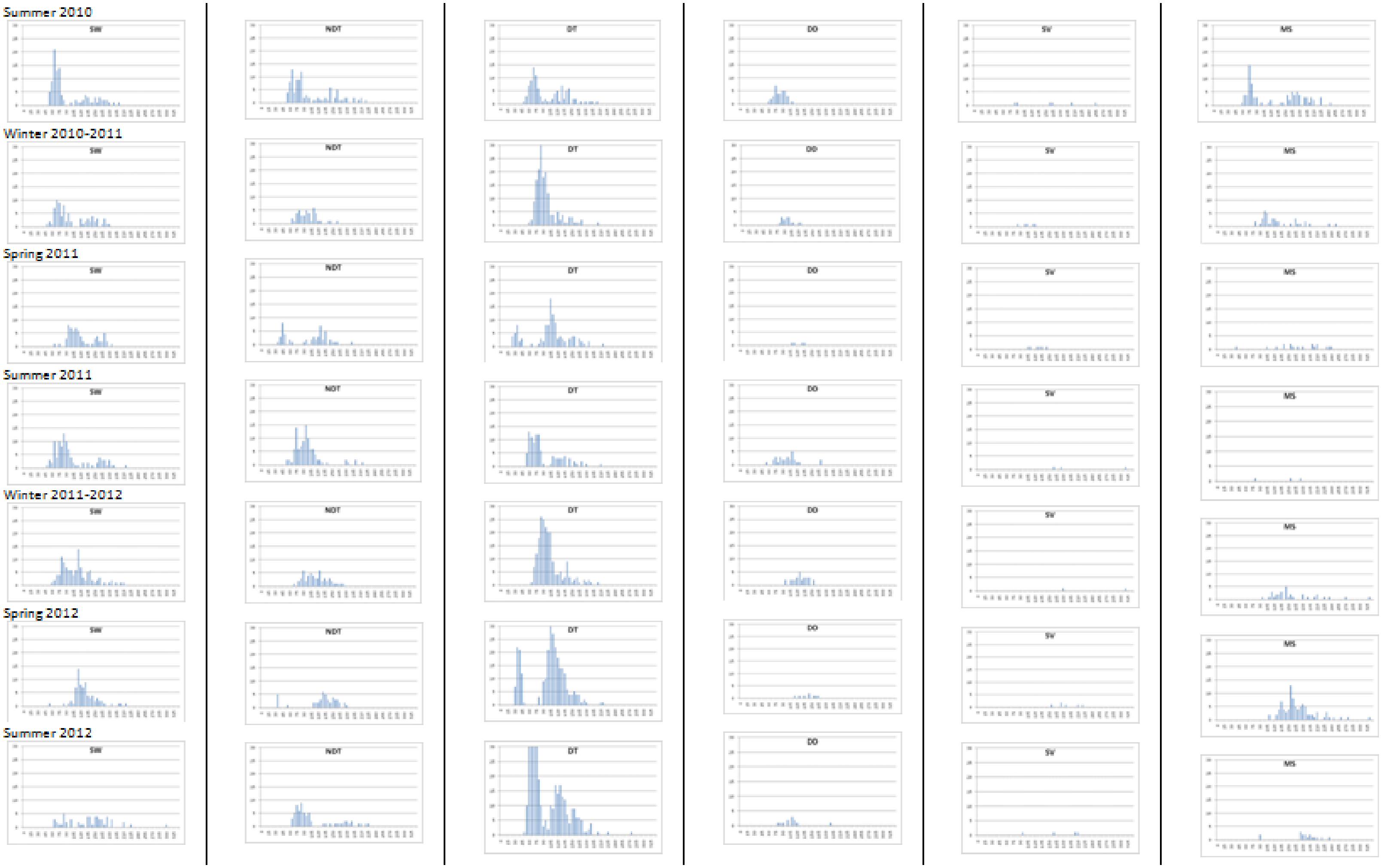
Frog Hollow Brook	8/13/1970	4	0	32	36	0.197		Frog Hollow Brook	7/14/2005	85	0	0	85	0.567
Green Brook (Passaic)	9/1/1970	0	8	0	8	0.044		Green Brook (Passaic)	7/18/2003	32	0	0	32	0.213
Hacklebarney Brook	9/18/1970	6	0	0	6	0.033		Hacklebarney Brook	7/19/2005	47	0	0	47	0.257
Hances Brook	8/5/1970	5	0	0	5	0.027		Hances Brook	7/29/2004	16	0	0	16	0.107
Harmony Brook	8/13/1969	0	6	0	6	0.033		Harmony Brook	7/15/2010	0	2	19	21	0.14
Herzog Brook	8/6/1969	8	6	0	14	0.077		Herzog Brook	7/9/2004	0	55	0	55	0.367
Hewitt Brook	9/1/1970	0	2	0	2	0.011		Hewitt Brook	8/26/2010	3	0	0	3	0.02
Hickory Run	9/12/1969	0	0	14	14	0.077		Hickory Run	8/23/2002	59	0	0	59	0.393
Hollow Brook	8/5/1969	0	6	0	6	0.033		Hollow Brook	7/12/2005	1	23	0	24	0.16
India Brook (A)	8/12/1969	6	0	0	6	0.033		India Brook (A)	7/21/2005	53	3	0	56	0.373
India Brook (B)	8/12/1969	0	6	0	6	0.033		India Brook (B)	7/28/2005	1	58	0	59	0.393
Indian Grave (Grove) Brook	7/23/1969	0	0	0	0	0		Indian Grave (Grove) Brook	7/19/2007	0	0	137	137	0.913
Jackson Brook	8/28/1969	0	38	0	38	0.208		Jackson Brook	8/18/2010	0	24	0	24	0.16
Lamington (Black) River (A)	8/11/1972	0	0	0	0	0		Lamington (Black) River (A)	7/17/2003	1	0	0	1	0.007
Lamington (Black) River (B)	7/25/1969	0	1	0	1	0.005		Lamington (Black) River (B)	7/27/2005	0	6	0	6	0.04
Ledgewood Brook	8/14/1969	0	22	0	22	0.12		Ledgewood Brook	9/13/2002	1	57	0	58	0.387
Little Brook	9/12/1969	0	0	0	0	0		Little Brook	7/13/2007	5	51	0	56	0.373
Lommasons Glen Brook	7/13/1970	26	0	0	26	0.142		Lommasons Glen Brook	8/10/2001	30	0	0	30	0.2
Macopin River	8/20/1969	0	0	0	0	0		Macopin River	8/31/2010	0	3	0	3	0.02
Mill Brook	6/30/1970	12	0	0	12	0.066		Mill Brook	6/29/2005	137	0	0	137	0.913
Mine Brook (Morris) (A)	8/6/1970	0	0	0	0	0		Mine Brook (Morris) (A)	7/24/2009	24	0	0	24	0.16
Mulhockaway Creek (A)	8/4/1969	0	0	0	0	0		Mulhockaway Creek (A)	8/13/2002	0	14	0	14	0.093
Mulhockaway Creek (B)	7/9/1971	0	16	0	16	0.087		Mulhockaway Creek (B)	8/12/2002	0	28	0	28	0.187
Musconetcong River (trib.) (Changewater)	9/4/1970	3	0	0	3	0.016		Musconetcong River (trib.) (Changewater)	8/17/2005	3	6	0	9	0.06

Musconetcong River (trib.) (Franklin)	9/4/1970	5	0	0	5	0.027	Musconetcong River (trib.) (Franklin)	7/21/2005	9	24	0	33	0.22
Musconetcong River (trib.) (Port Murray)	8/5/1970	16	0	0	16	0.087	Musconetcong River (trib.) (Port Murray)	7/20/2004	73	1	0	74	0.493
Norton Brook	9/4/1970	4	0	10	14	0.077	Norton Brook	8/15/2003	1	2	0	3	0.02
Parker Brook	8/27/1968	20	0	0	20	0.109	Parker Brook	8/24/2004	0	0	0	0	0
Paulins Kill (trib.) (Emmons Station)	8/27/1970	0	7	0	7	0.038	Paulins Kill (trib.) (Emmons Station)	8/15/2002	0	0	0	0	0
Paulins Kill East Branch	7/23/1970	0	0	1	1	0.005	Paulins Kill East Branch	8/24/2005	0	0	0	0	0
Peapack Brook	7/25/1969	0	37	0	37	0.202	Peapack Brook	9/13/2002	0	10	0	10	0.067
Pequannock River (trib.) (Copperas Mtn.)	8/20/1969	36	38	0	74	0.404	Pequannock River (trib.) (Copperas Mtn.)	8/11/2010	15	3	0	18	0.12
Pequannock River (B)	8/6/1968	0	1	1	2	0.011	Pequannock River (B)	9/12/2007	0	36	0	36	0.24
Pohatcong Creek	6/29/1970	2	2	0	4	0.022	Pohatcong Creek	7/15/2004	0	46	0	46	0.307
Pophandusing Creek	7/17/1970	0	0	0	0	0	Pophandusing Creek	7/17/2009	0	3	0	3	0.02
Raritan River N/Br	8/5/1969	0	0	0	0	0	Raritan River N/Br	7/30/2008	0	3	0	3	0.02
Raritan River S/Br	8/25/1969	0	0	0	0	0	Raritan River S/Br	8/28/2007	0	2	0	2	0.013
Rinehart Brook	8/12/1969	8	22	0	30	0.164	Rinehart Brook	7/26/2004	0	99	0	99	0.66
Rockaway Creek, N/Br. (B)	7/15/1969	0	7	0	7	0.038	Rockaway Creek, N/Br. (B)	8/24/2004	0	24	0	24	0.16
Schooley's Mountain Brook	8/5/1970	8	0	0	8	0.044	Schooley's Mountain Brook	8/11/2005	15	0	0	15	0.1
Shawanni Creek	8/11/1970	1	0	0	1	0.005	Shawanni Creek	8/19/2005	0	0	0	0	0
Shimers Brook	6/18/1970	0	2	0	2	0.011	Shimers Brook	7/22/2005	0	0	0	0	0
Spring Mills Brook	8/10/1970	0	5	0	5	0.027	Spring Mills Brook	8/7/2001	0	35	0	35	0.233
Stephensburg Creek	8/5/1970	10	0	0	10	0.055	Stephensburg Creek	7/30/2002	75	0	0	75	0.5
Stonehouse Brook	8/26/1969	0	0	0	0	0	Stonehouse Brook	7/31/2003	0	42	0	42	0.28

Stony Brook (Morris)	8/22/1969	6	32	0	38	0.208		Stony Brook (Morris)	7/14/2005	3	10	0	13	0.087
Stony Brook (Sussex)	8/11/1970	12	0	0	12	0.066		Stony Brook (Sussex)	7/23/2004	21	0	0	21	0.14
Sun Valley Brook	9/18/1970	8	0	0	8	0.044		Sun Valley Brook	7/29/2004	2	0	0	2	0.013
Trout Brook - Hacklebarney S.P.	8/7/1969	14	0	0	14	0.077		Trout Brook - Hacklebarney S.P.	7/20/2001	119	0	0	119	0.793
Trout Brook – Middleville	8/26/1970	2	0	0	2	0.011		Trout Brook - Middleville	7/14/2004	0	7	0	7	0.047
Trout Brook (Tranquility)	7/22/1970	35	0	0	35	0.191		Trout Brook (Tranquility)	8/11/2005	0	0	0	0	0
Turkey Brook	8/18/1969	28	0	0	28	0.153		Turkey Brook	8/21/2001	28	0	0	28	0.187
Van Campens Brook	8/30/1968	0	1	0	1	0.005		Van Campens Brook	7/18/2005	1	18	17	36	0.24
West Brook	7/24/1968	0	0	43	43	0.235		West Brook	8/11/2010	0	0	71	71	0.473
West Portal Brook	6/17/1970	0	18	0	18	0.098		West Portal Brook	7/8/2002	5	96	0	101	0.673
Whippany River (trib.) (Brookside)	8/13/1969	0	0	2	2	0.011		Whippany River (trib.) (Brookside)	7/8/2010	0	10	36	46	0.307
Whippany River (trib.) (Mendham)	8/13/1969	0	0	8	8	0.044		Whippany River (trib.) (Mendham)	7/23/2002	0	0	1	1	0.007
Whippany River (A)	8/13/1969	0	8	0	8	0.044		Whippany River (A)	7/15/2010	0	27	1	28	0.187
Whippany River (B)	8/7/1969	0	0	0	0	0		Whippany River (B)	9/25/2002	0	4	0	4	0.027
White Brook	6/18/1970	2	0	0	2	0.011		White Brook	7/28/2005	28	8	0	36	0.24
Wilhoughby Brook	8/4/1969	4	0	0	4	0.022		Wilhoughby Brook	8/7/2001	1	41	0	42	0.28
						6								16
total times P		41	32	9	82	average/m				42	46	8	96	average/m
total times A		39	48	71	158	0.069				38	34	72	144	0.204
Totals		80	80	80	240					80	80	80	240	

Appendix B Brook Trout length-frequency histograms.

Figure B-1. Y-axis indicates number of fish and x-axis fish length in mm. Season, year, and stream abbreviation indicated.



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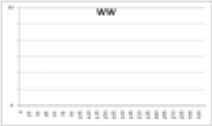
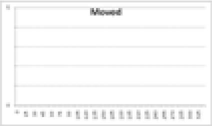
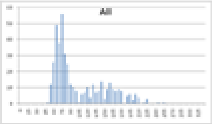
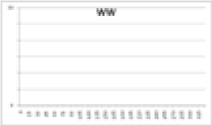
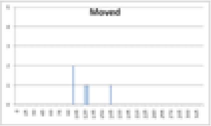


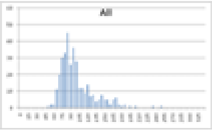




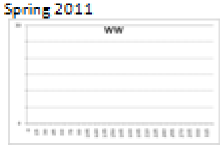
Winter 2010-2011

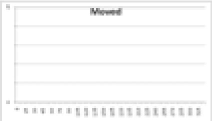


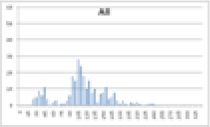




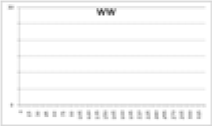
Spring 2011

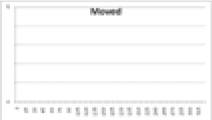


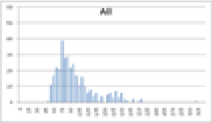




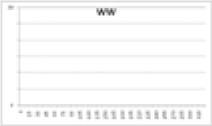
Summer 2011

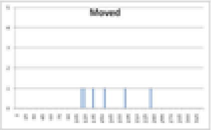


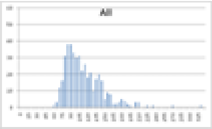




Winter 2011-2012







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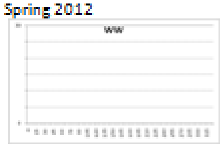

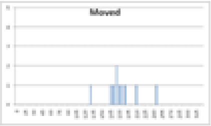

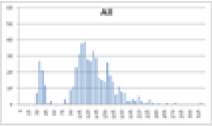

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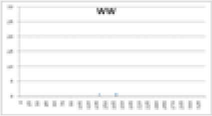
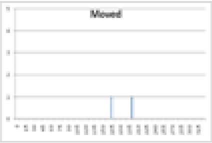
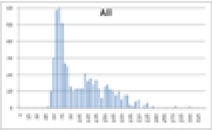
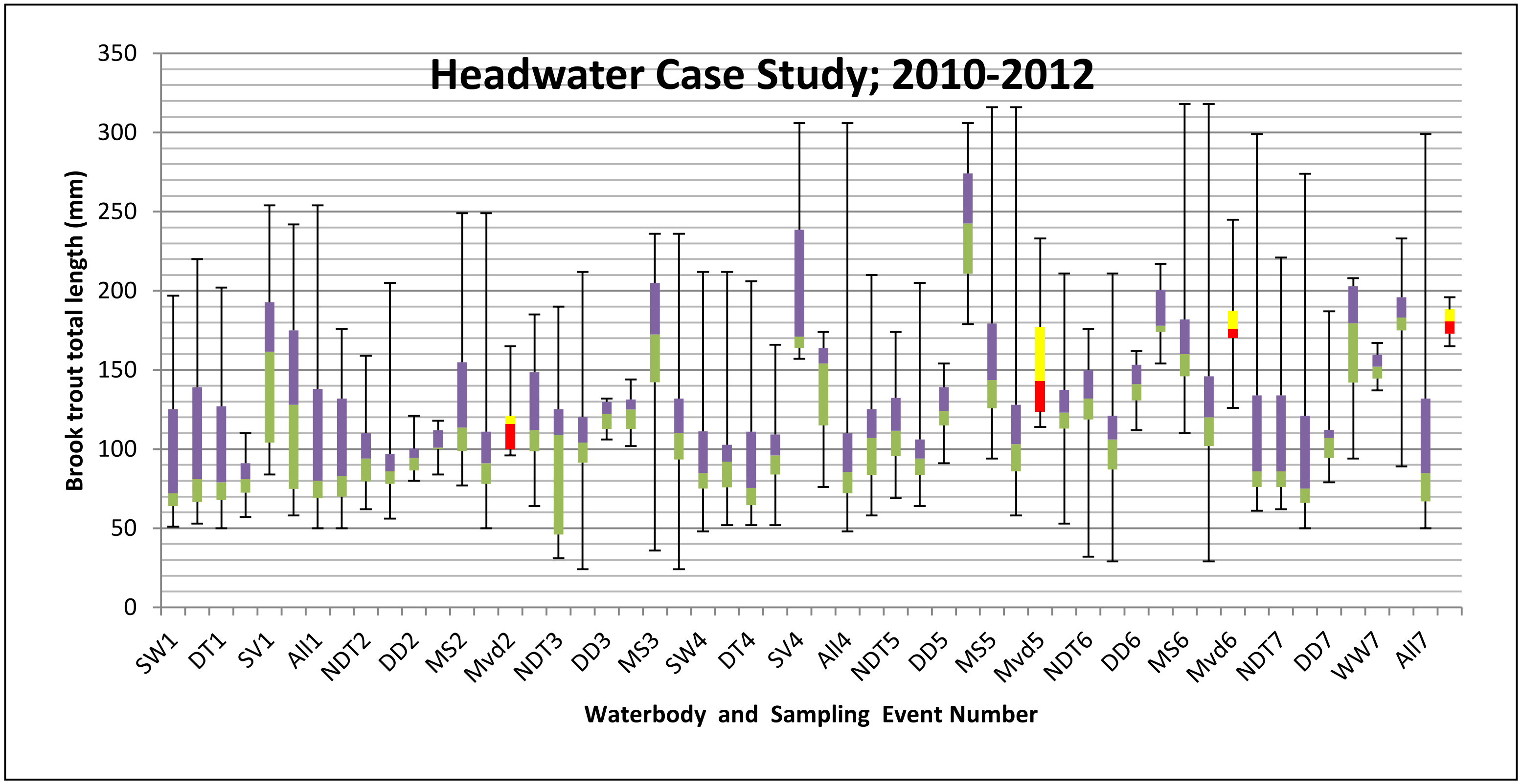






Appendix C Box and Whisker plots for headwater stream segment and Brook Trout length

Figure C-1 All lengths measures in millimeters. Numbers near each abbreviation indicate in-field event. Error bars illustrate minimum and maximum range of fish lengths, green area equals first quartile, purple area equals the third quartile, interface between the two represents the median value. Mved abbreviation represents the size of fish that were recaptured in a stream different than where initially marked. In these instances, the red area represents the first quartile and the yellow area is the third quartile values.



Appendix D Breakdown for findings of historical vs. modern salmonid species

Table D-1. Historical (H) 1968-1977 and modern (M) 2001-2010 data sets for NJ trout production lotic waters.

A: BKT:

H	**M**	**Present either time**	**Present both times**	**Absent both times**	**Loss-10**	**Gain-11**
present 41/80	present 42/80	52/160	31/160	28/80	3: BKT to BNT	2: NT to BKT
absent 39/80	absent 38/80				3: BKT & BNT to BNT	2: BNT to BKT
					3: BKT to NT	1: RBT to BKT
					1: BKT& RBT to RBT&BNT	4: BNT to BNT & BKT
						1: BNT to BNT, RBT & BKT
						1:NT to BKT & BNT

B: BNT:

H	**M**	**Present either time**	**Present both times**	**Absent both times**	**Loss-7**	**Gain-21**
present 32/80	present 46/80	53/160	25/160	27/80	2: BNT to BKT	7: NT to BNT
absent 48/80	absent 34/80				2: BNT & BKT to BKT	1:NT to BKT & BNT
					3: BNT to NT	3: BKT to BNT
						7: BKT to BKT & BNT
						1: RBT to RBT & BNT
						1:BKT&RBT to BNT&RBT
						1:BKT&RBT to BKT&BNT

[redacted]						
C: RBT:	[redacted]					
H	**M**	**Present either time**	**Present both times**	**Absent both times**	**Loss-5**	**Gain-4**
present 9/80	present 7/80	13/180	4/180	68/80	1: RBT to BKT	1: NT to RBT
absent 71/80	absent 73/80				1: RBT & BKT to BKT	2: BNT to BNT & RBT
					1: RBT & BNT to BNT	1: BNT to BKT, BNT & RBT
					1: RBT & BKT to BKT & BNT	
					1: RBT to NT	
[redacted]			[redacted]			
D: NT:	[redacted]					
H	**Change**				**M**	**Change**
11/80	2:to BKT				7/80	3:from BKT
	1:to BKT&BNT					3:from BNT
	1:to RBT					1:from RBT
	7:to BNT					