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Relative Abundance and Spatial Distribution of Lepomid Sunfishes in the Peace River

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Relative Abundance and Spatial Distribution of Lepomid Sunfishes in the Peace River

by

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A thesis submitted in partial fulfillment of the requirements of the degree of Master of Science
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ABSTRACT

This study examines spatially continuous sampling data in order to investigate patterns of abundance and distribution of three recreationally important sunfish species—bluegill, redear, and spotted sunfish—along the mainstem of the Peace River, a large softwater river located in southwest Florida. A total of 467 electrofishing transects were sampled biannually from spring 2008 to spring 2010. Sampling sites ranged from the headwaters of the Peace River in Polk County, FL to the oligohaline waters located in Charlotte County, FL. All fish were collected with boat mounted electrofishing gear, and aquatic habitat and physiochemical water quality measurements were recorded at each transect. Pearson’s correlation coefficient and conical correspondence analysis were used to interpret relationships between sunfish abundance and associated environmental variables. Results showed that relative abundance of sunfish varied significantly between the upper, middle, and lower basins of the river. Distance from headwaters, conductivity and macrophyte coverage were all significant predictors of relative species abundance. Spotted sunfish were found closer to the headwaters and were positively associated with higher amounts of aquatic vegetation. Redear were most common in the middle basin and were most associated with changes in conductivity. Bluegill were relatively more abundant further downriver where conductivities were higher. Woody debris was strongly associated with fish abundance for all species but did not significantly
explain the variance in species composition between locations in the river. The result of this study can be used by fisheries professionals to better manage sunfish populations in the Peace River and other lotic systems.
CHAPTER 1:  
INTRODUCTION

The family Centrarchidae contains 34 recognized species (Cooke & Philipp, 2009) including many popular sport fish such as bass, bream, and crappie. The genus Lepomis is the most diverse within the family, containing 13 species. They are commonly referred to as the Sunfish family because of the bright breeding colors of the males in many species. Lepomids, which include bluegill, redear and spotted sunfish, are native throughout most of eastern North America and are among the most common fish in freshwater systems where they occur (Collingsworth & Kohler 2010). Lepomid sunfish are ecologically important and play an important role in shaping freshwater communities where they are abundant. They serve as predators of small fish and invertebrates as well as forage for larger top level predators. They are also economically important in that they are among the most highly sought after freshwater fish by recreational anglers and are important in commercial aquaculture for sport fish stocking (Cooke & Philipp, 2009).

Because of their popularity as a sport fish, sunfish are often the focus of many fishery management plans. Many lakes and ponds are managed extensively for sunfish and much is known about their population ecology in these systems (Cooke & Philipp, 2009). Rivers however, are dynamic systems
which can cover large geographic areas and a wide range of habitats, making them much more difficult to manage. In order to properly manage sunfish populations within river systems, it is important to know their distribution and relative abundance along the length of the water body (Kohler & Hubert, 1993). Traditional management practices typically sample several small reaches which are then often extrapolated to give estimates of abundance for the entire river system (Zorn et al., 2002). However, this method fails to recognize the dynamic nature of riverine systems and may result in inaccurate measures of abundance for different areas along the river (Fullerton et al., 2010). An alternative approach in fisheries management is based on the River Continuum Concept, which stresses the importance of a longitudinal dimension to river ecosystems and acknowledges a shift of environmental variables and biological communities, from the headwaters to the river mouth (Vannote et al., 1980). Though this concept has revolutionized the way fisheries biologists study fish communities in rivers, few studies have focused on the abundance and distribution of sunfish in softwater riverine systems. Softwater streams, also referred to as 'blackwater streams', are among some of the most abundant stream habitats found in Florida. Yet, these low nutrient systems are vulnerable to human disturbances such as water withdrawals, mining activities, and nutrient loading from agriculture run-off and urban development (FFWCC, 2005). With such threats continuing to rise, further research is needed in these systems to determine how these threats could affect fish abundance and species composition in these systems.
This study bridges this data gap by examining spatially continuous sampling data (Fausch et al., 2002; Torgerson et al., 2006) in order to investigate patterns of abundance and distribution of three recreationally important sunfish species—bluegill, redear, and spotted sunfish—along the main-stem of the Peace River, a large softwater river located in southwest Florida. Specific research questions included: (1) Does the abundance and species composition of Lepomid sunfishes change from headwaters to river mouth, or are they fairly evenly distributed throughout the watershed? (2) Do all three species of sunfish in this study prefer similar habitats, or is there evidence of niche partitioning? (3) What environmental variables might influence sunfish relative abundance and composition along the length of the river? To answer these questions, spatial patterns of relative abundance for bluegill, redear, and spotted sunfish were examined on a river-wide scale and within the 3 sub-basins (upper, middle, and lower) that comprise the main-stem of the Peace River. Size structure, species composition, and associated habitat were also examined. Longitudinal profiles of fish abundance were plotted according to distance downstream in order to find trends in sunfish abundance that may be harder to detect at larger scales.

The literature review, provided in Chapter 2, includes background information on selected sunfish species including: identification, distribution, age and growth, preferred habitat, reproduction, and diet. The literature review then discusses environmental and habitat factors that can influence the distribution and abundance of sunfish as well as their estimated home ranges. Finally, the importance of sunfish in aquatic ecosystems is described, along with their
importance to humans in commercial and recreational fisheries. The remainder of
the thesis is structured as follows. Chapter 3 describes the specific objectives of
this research. Chapter 4 provides a description of the study area and river
basins. Chapter 5 explains data collection and sampling methodology used for
this study. Results of the analysis are presented in chapter 6, while a discussion
of the findings is provided in chapter 7. Finally, conclusions, limitations, and
management implications are presented in chapter 8.
CHAPTER 2:

LITERATURE REVIEW

Redear Sunfish (*Lepomis microlophus*)

*Identification*

Redear are the largest of the Lepomid sunfishes and are distinguished from other species by the bright red to orange margin on the outer edge of their ear flap and by their long pointed pectoral fins. Their bodies are laterally compressed and ovate in shape and are more robust when compared to other species. Their color varies, but is generally a bronze to light olive green with specks of red and orange, and they may have five to ten dusky vertical bars on their sides (McClane, 1978; Page & Burr, 1991).

*Distribution*

Redear sunfish are native to the southeastern U.S. along the Gulf and Atlantic drainages from South Carolina to Texas; and throughout the Mississippi river drainage north to Illinois. This species has been widely stocked into lakes and ponds, and it is now established throughout many areas of the United States, including Florida (Page & Burr, 1991; Cooke & Philipp, 2009).

*Age and Growth*

Redear sunfish are the largest species, typically reaching lengths over 200 mm and weights over 300 g (Roberg, 1986; Carlander, 1997; Warren, 2009).
Size at age one ranges from 30-180 mm with a median size of 86.5 mm (Carlander, 1977; Warren, 2009). The largest redear ever caught weighed in at 2.48 kg (IGFA, 2010). On average redear live less than seven years but fish as old as eleven years have been documented (Roberg, 1986; Sammons, Partridge, & Maceina, 2006; Warren, 2009).

**Habitat**

Redear are found in all types of freshwater habitats including lakes, ponds, reservoirs, and slow moving rivers and streams with sand, mud or shell-covered substrate (Twomey et al., 1984; Page & Burr, 1991; Warren, 2009). They have the ability to tolerate high salinities up to 20 ppt and can acclimate quickly (<1hr), allowing them to inhabit brackish portions of coastal rivers and streams better than most other centrarchids (Peterson, 1988). Adults are often found offshore in deeper water near submerged structure such as stumps and woody debris (Twomey et al., 1984). Smaller juveniles are most abundant in shallow shoreline areas with high amounts of aquatic vegetation (Twomey et al., 1984; Collingsworth & Kohler, 2010).

**Reproduction**

Redear sunfish are fast growers and can reach maturity between their first and second year of life (Twomey et al., 1984; Warren, 2009). Like all centrarchids, male redear will excavate a small depression in firm substrate such as sand, shell, clay, or gravel (Twomey et al., 1984). Males will provide all the parental care and guard the eggs and fry from potential predators for about a week after they hatch (Twomey et al., 1984). Redear are community spawners
and nest in colonies in shallow open water, generally deeper than other Lepomis species (Warren, 2009). In Florida, spawning occurs in spring and early summer from March to September (Clugsten, 1966; Twomey et al., 1984).

**Diet**

Adults are primarily molluscivorous with specially adapted jaws for crushing hard bodied prey such as snails and mussels (Huckins, 1997; Warren, 2009). Due to their preference for snails, they have earned the nickname “shellcracker” among fishermen. Though the bulk of their diet consists of snails, they are opportunistic bottom feeders and will prey upon a variety of benthic invertebrates and crustaceans (Huckins, 1997; VanderKooy, Rakocinski & Heard, 2000). Juveniles feed largely on zooplankton and soft bodied benthic invertebrates (VanderKooy, Rakocinski & Heard, 2000) but undergo a shift in diet to more hard-bodied prey around 75 mm in length (Warren, 2009).

**Bluegill** (*Lepomis macrochirus*)

**Identification**

Bluegill sunfish get their name from the blue coloration on their operculum, or gill cover. Adult males can also take on a distinct dark blue coloration during the breeding season. Color in this species varies more than all other sunfish and changes with age, sex, and environment (McClane, 1978). Bluegills have small mouths and very compressed oval to almost round bodies usually with dark vertical bars on their sides. They are easily distinguished from other species by the large black spot on the rear of their dorsal fin (Page & Burr, 1991).
Distribution

The bluegill sunfish is native east of the Rocky Mountains from Minnesota south to northern Mexico, east along the gulf and Atlantic coast states and north to the Great Lakes drainage (Page & Burr, 1991; Cooke & Philipp, 2009). Their popularity with fish stocking programs has greatly expanded their current range making them the most widely distributed of all centrarchid species. They can now be found in all U.S. states excluding Alaska, plus parts of northern Mexico and southern Canada (Cooke & Philipp, 2009).

Age and Growth

The bluegill is the second largest species of Lepomis. The median size after the first year is 55 mm with a range of 18-122 mm (Carlander, 1977; Delp et al., 2000; Paukert, Willis & Glidden, 2001; Warren, 2009). They often attain sizes greater than 200 mm and average less than 400 g (Carlander, 1977; Sammons & Maceina, 2009) with the largest bluegill weighing in at 2.15 kg (IGFA, 2010). They can reach a maximum age of twelve years but generally live less than seven years (Carlander, 1977; Delp et al. 2000; Paukert, Willis & Glidden, 2001).

Habitat

Bluegills are found in high abundance in warm-water lentic environments including ponds, lakes and reservoirs (Warren, 2009). In lentic systems they are found in shallow areas along the shoreline containing large amounts of aquatic vegetation (Stuber & Gebhart, 1982; Paukurt & Willis, 2002). In slow-moving rivers and streams, they can be found in backwater and low flow areas with sand, mud or gravel bottoms (Stuber & Gebhart, 1982). Adults are abundant along
shoreline habitats near large woody debris, snags, and aquatic vegetation but will also spend time in open water (Stuber & Gebhart, 1982; Paukurt & Willis, 2002). Juveniles are most abundant in shallow densely vegetated areas (Collingsworth & Kohler, 2010). They can tolerate moderate salinities (up to 18 ppt) and have the ability to acclimate quickly to changing salinities (Peterson, 1988; Peterson et al., 1993). They are also tolerant of hypoxic conditions <2 mg/l (Knights, Johnson, & Sanheinrich, 1995) and high water temperatures >40˚C (Beitinger et al., 2000).

Reproduction

Bluegill sunfish can reach maturity in their first or second year (Stuber & Gebhart, 1982). Size at maturity varies and ranges from 73 to 172 mm (Warren, 2009). Spawning generally occurs from March through September in Florida when water temperatures are between 17-31 degrees Celsius and peaks around May to June (Stuber & Gebhart, 1982). Males build and defend nests in large dense colonies that are excavated in sand, mud or gravel substrate that are found in shallow areas away from cover (Stevenson, Momot, Svoboda, 1969; Avila, 1976; Stuber & Gebhart, 1982).

Bluegill reproduction is interesting in that the males of this species can have three alternate mating strategies. Gross and Charnov (1980) described these as parental, sneaker and satellite males. They found that the “parental” males built and defended nests, as well as provided all the care for the eggs and fry. These males tended to grow to larger sizes before reaching maturity. “Sneaker” males were smaller lighter colored males that tended to mature
quicker. These males darted into a parental males nest and would quickly release sperm in an attempt to fertilize some of the eggs. “Satellite” males or female mimics (Domniney, 1980) tended to have coloration and behavior similar to female bluegills. These males would slowly approach a nest and fertilize eggs alongside the female and parental male. Their use of female mimicry kept the parental males from chasing them away (Domniney, 1980; Gross & Charnov, 1980).

**Diet**

Bluegills are generalists when it comes to feeding. Juveniles feed predominantly on zooplankton but will also take small soft bodied invertebrates (Stuber & Gebhart, 1982). Adults will consume a wide variety of prey from zooplankton in pelagic habitats to invertebrates in littoral habitats (Olsen, 2003; Warren, 2009). The majority of their diet includes insects, amphipods, crustaceans, fish eggs, mollusks, small fish, and even some plant material (Flemer & Woolcott, 1966; Olsen, 2003; Stuber & Gebhart, 1982; VanderKooy, Rakocinski & Heard, 2000).

**Spotted Sunfish (**_Lepomis punctatus_**)**

**Identification**

Spotted sunfish are a smaller species distinguished by the many rows of black specks that cover their bodies and by their small rounded pectoral fins. Their bodies are ovate and laterally compressed but thick. Color is generally olive green to brown (McClane, 1978; Page & Burr, 1991).
Distribution

The spotted sunfish has the smallest range of the three species examined. They are found along the southeastern U.S. from Cape Fear, North Carolina, south along the gulf coast drainages, throughout Florida to eastern Texas, and north throughout the Mississippi basin (Page & Burr 1991; Cooke & Philipp, 2009).

Age and Growth

They are a small species averaging less than 150 mm and typically only reach a size of 30-50 mm by age one (Caldwell et al., 1957; Warren, 2009). No IGFA world records are kept for the species due to its small size, however several states keep official records. The Florida state record is 207 mm and 376g (FFWCC, 2010). Few studies have looked at age and growth, but they are estimated to live an average of four or more years (Warren, 2009).

Habitat

This species is most abundant in rivers and streams (Hill and Cichra, 2005; Dutterer & Allen, 2008) but can be found in other freshwater habitats including lakes, ponds and flooded wetlands (Page & Burr, 1991; Hill and Cichra, 2005; Warren, 2009). In Florida they are abundant in spring fed streams and rivers (Caldwell et al., 1957) and throughout the everglades (Clugsten, 1966; Loftus and Kushlan 1987). Spotted sunfish are most abundant in shallow water around complex habitat including rootwads, snags, and dense aquatic vegetation (Hill and Cichra, 2005; Dutterer & Allen, 2008). They can tolerate low to
moderate salinities (12 ppt) (Peterson, 1988) and are commonly found in oligohaline environments (Loftus & Kushlan, 1987; Hill & Cichra 2005).

**Reproduction**

Spotted sunfish reach maturity between ages one and two and a length of around 55 mm (Hill & Cichra 2005; Warren, 2009). They tend to be more solitary nesters compared to other species but will aggregate when suitable spawning habitat is limited (Carr, 1946). Males excavate nests in sand or gravel in shallow water near the shoreline (Carr, 1946, Warren, 2009). Spawning in Florida occurs March through November, peaking in May through August, at temperatures of around 18-33 degrees Celsius (Clugston 1966; Warren, 2009). In spring fed streams in Florida, the constant year round temperatures may allow year round spawning (Caldwell et al., 1957).

**Diet**

Spotted sunfish are aggressive opportunistic feeders that prey largely on invertebrates which they glean off the water surface, bottom structure, and aquatic plants (Warren, 2009). Insects make up the majority of their diet, but they also feed on a variety of aquatic larvae, beetles, amphipods, chronomids, and snails (Hill & Cichra, 2005; Warren, 2009).

**Factors Affecting Sunfish Abundance and Distribution**

**Physical Habitat**

Water quality and physical habitat are two important factors that can affect the distribution and abundance of riverine fishes (Kohler & Hubert, 1993; Crook &
Robertson, 1999). Common physical habitat features in riverine systems include aquatic vegetation and submerged woody debris such as stumps, logs, and snags. Studies have shown that aquatic macrophytes serve as important forage and refuge locations for fish by offering cover from predators (Savino & Stein, 1982) and providing rich foraging sites for invertebrate food resources (Rozas & Odum, 1988; Thorp, Jones, & Kelso, 1997). Dense aquatic vegetation forms complex habitats that offer refuge to smaller fish by providing many hiding locations and by physically excluding larger predators, thus reducing predator-prey interactions (Savino & Stein, 1982). Insect larvae and other invertebrates are found on leaves and stems of submerged aquatic vegetation in higher abundance than surrounding non-vegetated areas providing optimum foraging sites for many fish species (Rozas & Odum, 1988; Thorp, Jones, & Kelso, 1997).

Many studies have shown a positive relationship between aquatic vegetation and fish abundance (Killgore et al., 1989; Lobb and Orth, 1991; Collingsworth and Kohler, 2010). A study by Collingsworth and Kohler (2010) showed that vegetated habitats had higher juvenile sunfish densities than non-vegetated habitats in a Midwestern reservoir. Lobb and Orth (1991) found that the highest proportion of small fish, including centrarchids, occurred in backwaters and around emergent and submerged vegetation in a large warmwater stream in West Virginia. In the Potomac River, Killgore et al. (1989) also found higher fish densities among submerged vegetation than in areas without.
Submerged woody debris can also have a positive effect on fish abundance in similar ways to aquatic vegetation. Lobb and Orth (1991) found that densities of fish were highest in and around snag habitats. Lehtinen et al. (1997) also noted that fish biomass and abundance was higher among woody debris than in bare habitats and that larger more complex woody debris habitats held greater fish biomass than smaller less complex habitats. Experimental studies that removed woody debris from sections of warmwater rivers showed a decrease in fish biomass compared to uncleared sections (Angermeier & Karr 1984).

Woody debris can create complex structures that provide cover, foraging areas, and refuge from high currents in lotic systems (Crook & Robertson, 1999; Dolloff, 2003). Complex woody debris structures may physically exclude predators in a similar way to dense macrophyte stands. They also provide overhead cover and visual obstruction thereby reducing predator-prey interaction (Savino and Stein 1982; Crook & Robertson, 1999). A study by Benke et al. (1985) showed that woody debris served as an important stratum for non-burrowing invertebrates in lowland rivers and that the invertebrates associated with woody debris were an important food source for several fish species. Snag habitat was an important source of food for Lepomid sunfish and snag fauna comprised around 60% of the diet for redbreast, bluegill, and spotted sunfish (Benke et al., 1985). Submerged woody debris have also been shown to provide refuge from high current velocity in lotic systems by reducing stream flow and
creating pools and eddies where fish can rest and minimize energy costs (Crook & Robertson, 1999; Dolloff, 2003).

**Water Quality**

Important water quality variables in riverine systems include temperature, dissolved oxygen, salinity, conductivity, and turbidity. Differences in water quality along a river gradient can affect the distribution and abundance of fish species (Reash & Pigg, 1990). Temperature can limit the geographic distribution of species on a broad scale or within an individual lake or river (Jackson, Peres-Neto, & Olden, 2001). Water temperature can affect fish growth rates and is an important factor in determining when spawning occurs (Belk, 1995). High water temperatures can cause physiological stress and can also lower dissolved oxygen (DO) levels in the water (Jackson, Peres-Neto, & Olden, 2001). Areas with low DO create stressful respiratory conditions which may lead to fish kills if DO levels drop below tolerance levels. Differences in tolerances to low DO may help determine fish assemblages along a gradient of oxygen conditions (Cooper & Washburn, 1949). Rutherford, Gelwicks and Kelso (2001) found that spatial variations in DO levels had a strong impact on the distribution of fishes in the lower Atchafalaya River Basin in Louisiana. Some fish species may actively avoid areas of low DO. A study in backwater lakes of the upper Mississippi River found that radio-tagged bluegills moved out of areas where DO levels had dropped to low (Knights, Johnson, & Sandheinrich, 1995).

Salinity is a measure of total dissolved salts in the water and is generally expressed as part per thousand (ppt). Most fish species are adapted to a
particular range of salinities. This is the reason why fish are generally classified as freshwater or saltwater species. Dissolved salts affect the osmoregulatory ability of aquatic species. Differences in the relative abundances of estuarine sunfishes may reflect varying interspecific osmoregulatory efficiencies (VanderKooy, Rakocinski, & Heard, 2000). Salinity levels in a water body can limit the distribution of fish species based on their differing salinity tolerances (Peterson, 1988). The ability to acclimate quickly to changing water conditions allows certain species to further penetrate into systems where daily tidal changes occur (Peterson, 1988).

Total dissolved solids (TDS) is defined as the amount of dissolved material in water (Kimmel & Argent, 2010). These dissolved materials include salt and mineral ions that can come from naturally occurring sources such as surrounding soils and rock or from human activities. Examples of human sources include runoff from fertilizers and agriculture, waste water discharges, and the salting of roads in winter. Natural fluctuation occurs in tidal portions of rivers where saltwater mixes with freshwater. Conductivity or specific conductance is one way to measure total dissolved solids. It is usually measured in microsiemens per centimeter (µs/cm), and is defined as the ability of water to transmit an electrical current. Conductivity is proportional to the amount of dissolved solids in the water. High levels of dissolved solids can be harmful to aquatic organisms by increasing salinity levels and other toxic ions in the water and may limit the abundance or distribution of less tolerant species (Chapman, Bailey & Canaria, 2000; Weber-Scannell & Duffy, 2007; Kimmel & Argent, 2010).
Turbidity is a physical characteristic of water and is used as a general measure of water clarity. Turbidity levels vary with the amount of suspended particulates such as silt, organic matter and plankton in the water. High levels of turbidity can decrease submerged aquatic vegetation and can affect predator-prey interactions by forcing small fish to use less complex open water habitats (Miner & Stein, 1996). In an experimental study by Miner and Stein (1996) the reaction distance for both largemouth bass and bluegill decreased with higher turbidity. Bluegill sunfish in clear water preferred shallow water as a refuge from a potential predator, but in higher turbidities they used deeper water. Their results demonstrated that turbidity influenced habitat use of juvenile bluegills, and that turbid water may serve as visual cover for small fish in the absence of complex habitat by reducing the reaction distance of predators (Miner & Stein, 1996).

Home Range

Several studies have examined the home ranges of sunfish in lotic environments. Home range is typically defined as the smallest area in which an animal spends 95% of its time (Downs and Horner, 2009). The majority of sunfish tend to be fairly sedentary (Gatz and Adams, 1994; Gunning and Shoop, 1963) while a small number of fish have been documented to move long distances (Gatz and Adams, 1994). In Louisiana streams, Gunning and Shoop (1963) found that bluegill home ranges were typically less than 38 m long. In Tennessee streams however, Gatz and Adams (1994) found 3 bluegill and one redbreast sunfish that had home ranges of up to 17 km in length. These seemed to be rare
exceptions and overall, two-thirds of all fish were recaptured <100 m away between captures. Several sunfish were even recaptured multiple times in the same 50 m stretch of stream over a six month period (Gatz and Adams, 1994).

**Importance of Sunfish**

*Ecological*

Sunfish are often the dominant mid to top-level predators in freshwater fish communities (Cooke & Philipp, 2009). Their presence and high abundance can influence community structure (Hambright et al., 1986; Hambright & Hall, 1992) and food web dynamics (Stein, DeVries & Dettmers, 1995) in freshwater systems. Outside of their native range, sunfish can negatively impact native species of fish, amphibians and invertebrates through direct predation or competition for food and habitat resources (Hecnar & M’Closkey, 1997; Marchetti, 1999; Huckins et al., 2000; Declerck et al., 2002; Maezono, et al., 2005). Lepomid sunfishes are predators of small fish and invertebrates but also serve as prey for many larger piscivores (Cooke & Philipp, 2009). They are an important food source for largemouth bass and are often stocked together in sport fisheries management of lakes, reservoirs, and ponds (Modde, 1980). Because of their preference for mollusks, redear sunfish have even been recommended as biological control of snails and mussels in lakes and ponds (Wang et al., 2003).
Commercial Fisheries

Commercial fishing for centrarchids was historically important in North America from the mid-nineteenth century through much of the twentieth century. The largest of these fisheries was on Lake Okeechobee in Florida which was closed in 1981 (Schramm et al., 1985). Most of these freshwater commercial fisheries have been closed due to overfishing or for the protection of gamefish species which are important in recreational fisheries. Limited commercial fisheries for centrarchids still exist in some states and tribal nations in U.S. and Canada (Cooke & Philipp, 2009). Sunfish are also important in commercial aquaculture. They are prized by many as a food fish but currently only a small percentage of production is being raised for food markets. Most sunfish production is dedicated to the sport fishing market and they are usually stocked into lakes and ponds as gamefish for recreational anglers or as forage for bass (Morris and Mischke, 2003).

Recreational Fisheries

Sunfish are among the most targeted sport fish in North America. Often referred to as panfish by anglers, they are well known as excellent table fare. While the largemouth bass may be the most popular among sport fishermen, the bluegill most likely accounts for more individual catches than any other freshwater gamefish in North America (Warren, 2009). Redear sunfish are regularly stocked with bluegill and bass, and are probably the second most popular panfish among anglers due to their large size, often reaching a pound or more. Spotted sunfish, although small in size, are consistently part of the panfish
creel in many Florida waters (Warren, 2009). Like other panfish they make fine table fare, though they don’t often reach edible size. Spotted sunfish are popular among stream anglers for their willingness to strike a wide variety of baits and lures.
CHAPTER 3:
RESEARCH OBJECTIVES

The purpose of this study is to examine spatially continuous sampling data in order to document longitudinal patterns of abundance for three native Lepomid sunfishes and their associated physiochemical habitats, throughout the main-stem of the Peace River in Florida. As few previous studies have focused on the abundance and distribution of sunfish in softwater riverine systems, a goal of this research is to bridge this knowledge gap by providing information that can ultimately improve management strategies for these recreationally important fish species. Specific research objectives include:

(1) Document the spatial distribution and relative abundance of
   *L. macrochirus, L. microlophus, and L. punctatus* in the Peace River.

(2) Compare relative abundance, species composition, and size structure of
    sunfish in each of three sub-basins making up the main-stem of the Peace River.

(3) Evaluate relationships between relative sunfish abundance and
    associated environmental variables.
CHAPTER 4:
STUDY AREA

The Peace River is the largest softwater river in southwest Florida. Beginning just south of Lake Hancock in Polk County at the confluence of Peace Creek and Saddle Creek, the Peace flows southwest for approximately 170 km through Polk, Hardee, Desoto, and Charlotte Counties, before finally emptying into the Charlotte Harbor Estuary. The Peace River watershed drains an area of approximately 5,959 km² (FDEP, 2007). It is a low gradient river dropping only 30 meters in elevation from its headwaters to its discharge point into Charlotte Harbor (SWFWMD, 2002). The highest river flows often occur during the rainy season,

Figure 1. Peace River study area showing the upper, middle, and lower basins as delineated by the Southwest Water Management District (2002,2005,2010).
peaking in late summer to early fall, with the lowest flows generally occurring during the spring time dry season.

**Peace River Basins**

There are nine sub-basins comprising the Peace River watershed, each varying in their hydrologic, geologic, vegetative, and land use characteristics (FDEP, 2007). All of the sub-basins have varying degrees of man-made impacts including phosphate mining, agriculture and urban development (FDEP, 2007). Three of these sub-basins encompass the main-stem of the Peace River. For the purpose of this study, the main-stem of the river was divided into three separate basins, the upper, middle, and lower Peace (Figure 1). The boundaries of each were based on those defined in previous studies by the Southwest Florida Water Management District (SWFWMD, 2002, 2005, 2010). The zonation of the river takes into account the changing physicochemical water quality and habitat factors along the length of the river and allows for comparisons between the three basins. The next section gives a more detailed description of the three different basins of the Peace River.

**Upper Peace River**

The upper Peace River basin is located between the USGS gauging site near Bartow at the northern end and the gauging site in Zolfo springs at the southern end (SWFWMD, 2002). The river is shallow and narrow here and has high amounts of aquatic vegetation such as hydrilla and water hyacinth. The upper Peace is very different above and below the Ft. Meade area. From Bartow
to Ft. Meade the river substrate is mostly sand and silt, and the river is bordered
with cypress and hardwood swamps (SWFWMD, 2002). Below Ft. Meade the
river becomes much more incised. Karst features such as springs and sinks can
be found throughout this basin. Limestone bedrock is more prominent in the river
bed and the river here is bordered by seasonally flooded forest (SWFWMD,
2002). At the headwaters of the Peace River is Lake Hancock, a hyper-eutrophic
lake with very poor water quality. Water releases from the lake flow into the river,
often degrading water quality in the upper Peace (PBS&J, 2007). Phosphate
mining and agriculture have had a large impact on the upper Peace River basin.
Approximately 77% of the basin has been developed with 33% from mining, 37%
from agriculture, and 7% from urban land use (PBS&J, 2007). Groundwater
withdrawals from these land use practices have caused some reaches of the
upper river to stop flowing during recent dry seasons (PBS&J, 2007; FDEP,
2007).

Middle Peace River

The middle Peace River basin is located between the USGS Zolfo Springs
gage to the north and the Arcadia gage to the south (SWFWMD, 2005). The river
channel in this section of the Peace is well defined and steeply incised in many
places. Upland and wetland forests are found along the river banks and
limestone bedrock, gravel, and sand are the predominant substrate found in the
river bed (SWFWMD, 2005). This basin has been mainly impacted by agriculture
land use including citrus crops and pastureland. Approximately 60% of this basin
has been developed with 56% coming from agriculture, 3% from urban land use, and less than 1% mining (PBS&J, 2007).

**Lower Peace River**

The lower Peace River basin is the portion of the river below the USGS gauge at Arcadia to where it flows into Charlotte Harbor (SWFWMD, 2010). In this section of the river the channel becomes less incised and the floodplain widens with the river channel becoming braided closer to the river mouth (SWFWMD, 2010). Sediment on the river bed here is mostly composed of sand and mud. The tidal portion of the river fluctuates with seasonal flows but can extend up to 26 miles upstream from the river mouth (SWFWMD, 2010). Plant communities change along the Lower Peace River from upland forest near Arcadia, to freshwater wetlands and marsh in the middle, to brackish and saltmarsh communities in the lower reaches, and finally mangroves near the river mouth (SWFWMD, 2010). While this basin has the highest percentage of urbanized land, it is the least developed of the three basins. Over 51% of the land has been developed with 27% coming from urban land use and 24% from agriculture and pasture land. There has been no phosphate mining in this basin of the river (PBS&J, 2007).
CHAPTER 5:

METHODS

The following methods were used to evaluate the spatial distribution and relative abundance of bluegill, redear, and spotted sunfish in the Peace River. This chapter describes the sampling protocol for fish, habitat, and water quality sampling. Lastly, the different analysis techniques including the appropriate statistical tests used for this study are described in detail.

Sampling Design:

The information used in this study was obtained with permission from a three year fish community study on the Peace River conducted by the Florida Fish and Wildlife Conservation Commission (Call et al., 2011). Data for this study was collected during five biannual sampling events from 2008 to 2010 during which time I served as part of the field crew for three of the five sampling periods. The number of transects per river basin and sampling season is provided in (Table 1). Sampling points were randomly generated at a density of three sites per every four river kilometers along the centerline for the entire Peace River. The number of points actually sampled varied with water levels at time of sampling and by accessibility with boat mounted electrofishing gear. A small area of river was inaccessible due to low water and a series of log jams that excluded a ~10 km section of river between Ft. Meade and Homeland. During low water
conditions, three sites were selected per one river kilometer. The number of sites sampled was proportional to the number of accessible river kilometers at time of sampling. At each sampling location, a handheld global positioning system (GPS) was used to record the exact coordinates for each transect. Physicochemical water quality parameters, habitat metrics, and fish data were collected at each site.

Table 1. Number of 8m² transects by reach and sampling season.

<table>
<thead>
<tr>
<th>Basin</th>
<th>Spring 08</th>
<th>Fall 08</th>
<th>Spring 09</th>
<th>Fall 09</th>
<th>Spring 10</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper Peace</td>
<td>21</td>
<td>37</td>
<td>18</td>
<td>35</td>
<td>24</td>
<td>135</td>
</tr>
<tr>
<td>Middle Peace</td>
<td>23</td>
<td>37</td>
<td>24</td>
<td>30</td>
<td>37</td>
<td>151</td>
</tr>
<tr>
<td>Lower Peace</td>
<td>38</td>
<td>31</td>
<td>43</td>
<td>36</td>
<td>33</td>
<td>181</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>82</strong></td>
<td><strong>105</strong></td>
<td><strong>85</strong></td>
<td><strong>101</strong></td>
<td><strong>94</strong></td>
<td><strong>467</strong></td>
</tr>
</tbody>
</table>

**Fish Sampling**

Transects of 4x2 meters (8m²) were sampled along a randomly chosen shoreline (left or right bank) with an electrofishing boat equipped with a Smith-Root 9.0 or 5.0 GPP electrofishers. Transects were sampled using pulsed direct-current and followed FWC standardized sampling protocol in determining amperage goals for electrofishing (Bonvechio, 2007). Boat mounted electrofishing is one of the most effective methods for sampling freshwater fish in non-wadeable streams (Kohler & Hubert, 1993). An electric current sent into the water temporarily stuns fish passing within the electric field. This allows the two field biologists on the front of the boat to collect the stunned fish using ¼” mesh dip-nets and place them into a temporary holding tank until the transect is completed. Sampling effort was a function of area (m²) (not time) and all transects were sampled with three passes forward and back. Transect
boundaries were marked with two marker buoys prior to the start of
electrofishing. All fish species within the transect were collected, identified to
lowest possible taxa, measured to the nearest millimeter total length, and
weighed in grams before being released unharmed. However, this study only
uses the data for the three sunfish species of interest: bluegill, redear, and
spotted sunfish.

Water Quality Sampling

Water quality parameters including dissolved oxygen (mg/l), salinity (ppt),
and conductivity (µS/cm) were measured at all sampling transects with a Yellow
Springs Instrument YSI 556 Multi-Probe System. Readings were recorded at the
surface for all sites and on the bottom if water depths were greater than one
meter. Water velocity (m/s) was measured with a Swoffer 3000 flow meter.

Habitat Sampling

Habitat parameters recorded at each transect included depth, in stream
vegetation, and submerged woody debris. A minimum and maximum depth was
recorded in meters for all transects. Percent area coverage (PAC) was used to
quantify in stream macrophytes. All macrophytes were grouped into three main
categories: submersed, emergent, and floating. The PAC for each category was
recorded first and then combined for a total PAC for the entire transect.

Woody debris habitat in each transect was quantified and given a
weighted score. Submerged woody debris such as snags, stumps, logs, root-
wads and cypress knees were counted up to twenty pieces according to diameter
class (inches): (<1”), (1-3.9”), (4-9.9”), and (>10”). An estimated woody debris count of (21-50), (51-100), and (>100) was assigned if there were more than twenty pieces. The habitat score (HAB) was calculated as a simple index to compare the quality of woody debris habitats between sites. It was adapted from Dolloff et al. (1993) and Wheeler and Allen (2003). The number of pieces for each size class was multiplied by a weighting factor so that a larger 10” piece was given a higher habitat value than a smaller 1” piece. The weighting factors from smallest size class to largest were 1, 3, 7, and 10 respectively. Therefore, 10 one inch pieces would be equivalent to one 10 inch piece. For the higher estimated counts, a mean of 35.5 and 75.5 pieces was assigned for the (21-50) and (51-100) categories, and a count of 100 pieces was assigned for the (>100) category. The HAB score was calculated as the sum of the weighted woody debris counts.

Analysis

The Peace River was divided into three zones (upper, middle, lower) based on watershed sub-basin delineations in order to compare relative abundance, size structure, and community composition of sunfish among the different river basins. Relative abundance is useful for making temporal or spatial comparisons among fish populations (Kohler & Hubert, 1993; Guy and Brown, 2007). Catch per unit effort (CPUE) was used as a measure of relative abundance to minimize any bias in sampling effort between river basins. Fish CPUE is used to relate total abundance to a measure of sampling area, distance or unit of time. For each transect in this study, the CPUE was calculated as the
number of fish per \( (m^2) \). Mean CPUE was then calculated for all fish in the upper, middle, and lower Peace River basins and according to species.

To examine spatial distributions and patterns of sunfish abundance, a geographical information system (GIS) software program, ArcGIS 9.3 (ESRI, 2009), was used for plotting sampling locations (Figure 2) and for creating species distribution maps for bluegill, redear and spotted sunfish. Distribution maps show abundances of sunfish at each transect using proportional-sized symbols to represent the number of fish caught at each 8\( m^2 \) sampling location. Each transect was mapped as a point location and used to represent information on fish abundance and habitat characteristics at that site. Patterns in the distribution and abundance of each sunfish species were also examined by plotting their relative abundance per transect along a longitudinal profile of the river. Stream network distances were calculated between sampling points and were used to determine the distance in kilometers downstream from the start of the river located at the confluence of Peace and Saddle Creeks.
Spatial patterns of relative abundance were examined by graphing the mean CPUE for each species by river basin (upper, middle, lower). Sunfish CPUE and habitat variables were also plotted verses distance downstream to help identify spatial trends along longitudinal profiles of the river. A moving average trendline was added to smooth out fluctuations in the data so that patterns or trends could be seen more clearly. A moving average trendline takes a set number of data points, averages them, and uses the average value as a point in the trendline (Microsoft Cooperation, 2011). This procedure allows the analyst to better visualize longitudinal trends in fish abundance. This method of viewing longitudinal profiles of spatially continuous data was adapted from Fausch et al. (2002) and Torgerson et al. (2006).

In addition, length frequency histograms were created to explore differences in the size structure of sunfish between river basins. Length frequency histograms show the number of sunfish in each size class. Relative frequency distributions (\%) were used to show the proportion of fish collected in each length category and are useful for comparing length categories that contain different sample sizes (Guy and Brown, 2007).

**Statistical Analysis**

Statistical analysis was performed using R statistical software, version 2.72 (R Development Core Team, 2007) to evaluate the influence of water quality and habitat variables on the relative abundances of sunfish within the Peace River and its sub-basins. Prior to analysis, all variables including fish abundance, habitat, and water quality measurements were evaluated for normality and
appropriate transformations were applied to reduce variances and the effects of outliers. First, one way analysis of variance (ANOVA) was used to compare mean abundances of sunfish species between the three river basins and by season (significance level set at $p \leq .05$). When significant differences were found, Tukey’s Honestly Significantly Different (HSD) Post Hoc test was then used to make pairwise comparisons to determine which basin means were significantly different from one another. A separate ANOVA compared mean abundance of all fish between basins.

Second, Canonical Correspondence Analysis (Ter Braak, 1986) was used to determine the relationships between sunfish community abundance data and location (distance downstream), habitat (macrophyte cover and woody debris score), and physicochemical water quality parameters (depth, flow, dissolved oxygen, and conductivity). In conducting the analysis, pairwise associations among variables were evaluated prior to modeling and highly correlated variables (flow and depth) were eliminated to minimize problems with collinearity. Canonical Correspondence Analysis (CCA) is a multivariate ordination method used to relate community composition to known variation in the environment (Ter Braak, 1986). This technique identifies environmental gradients in ecological data which are useful for describing and visualizing habitat preferences among assemblages of species using an ordination diagram (Ter Braak and Verdonschot, 1995). Essentially, CCA examines how environmental factors affect the relative abundance of species based on their percent composition at each site. As such, CCA is only valid for samples with at least 1 sunfish, and it only
evaluates how environmental factors influence changes in proportional abundance rather than determining which factors affect presence or absence of species. For that reason, the CCA was supplemented with simple correlation analysis in order to evaluate the significance of habitat scores—insignificant in the CCA—in predicting presence or absence of sunfish.
CHAPTER 6:

RESULTS

Fish Abundance and Distribution

A total of 1,920 sunfish were collected (540 bluegill, 315 redear, and 1,065 spotted sunfish) from 467 sampling locations throughout the river (Tables 1 & 2). Mean CPUE of individual species varied between the different river basins (Table 2, Figure 3). Spotted sunfish were the most abundant species river-wide (0.284 fish/m² ± 0.021 SE). The next most abundant species overall was the bluegill sunfish (0.145 fish/m² ± 0.015) followed by redear which was the least abundant species in the river (0.085 fish/m² ± 0.007).

Table 2. Number of fish collected and Catch per unit effort (CPUE) by basin for each species. (CPUE = mean number of fish per m²) with standard errors (SE).

<table>
<thead>
<tr>
<th>BASIN</th>
<th>Bluegill</th>
<th>Redear</th>
<th>Spotted Sunfish</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number</td>
<td>CPUE ± (SE)</td>
<td>Number</td>
</tr>
<tr>
<td>Upper</td>
<td>57</td>
<td>0.059 ± (0.011)</td>
<td>57</td>
</tr>
<tr>
<td>Middle</td>
<td>210</td>
<td>0.168 ± (0.029)</td>
<td>143</td>
</tr>
<tr>
<td>Lower</td>
<td>273</td>
<td>0.189 ± (0.028)</td>
<td>115</td>
</tr>
<tr>
<td>ALL</td>
<td>540</td>
<td>0.145 ± (0.015)</td>
<td>315</td>
</tr>
</tbody>
</table>

Figure 3. Mean relative abundance (fish/m²) of bluegill *L. macrochirus*, redear *L. microlophus*, and spotted sunfish *L. punctatus* by river basin.
Spotted sunfish were commonly found throughout the majority of the Peace River, and were only absent from the most downstream sampling locations in this study (Figures 4a-4d). Highest mean CPUE occurred in the upper basin (0.451 fish/m² ± 0.047) followed by the middle (0.326 fish/m² ± 0.038) and then the lower Peace River basin (0.120 fish/m² ± 0.018). Relative abundance seemed to decline from the upper to lower river (Figure 3), and was nearly 4 times higher in the upper basin than in the lower.

Bluegill sunfish were distributed throughout most of the Peace River and were most commonly found in the mid to lower river (Figures 5a-5d). In addition to being absent from the most downstream sampling locations, there were also large gaps between catches in the upper to middle portion of the river. Mean CPUE was contrary to spotted sunfish and tended to increase from the upper to lower river. Bluegill were most abundant in the lower river (0.189 fish/m² ± 0.028) followed closely by the middle (0.168 fish/m² ± 0.029) and was lowest in the upper basin (0.059 fish/m² ± 0.011). Mean relative abundance was over three times greater in the lower Peace than in the upper.

Redear were the least abundant sunfish overall and in all three basins. While redear catches were considerably lower than bluegill, they were much more evenly distributed throughout the river with fewer zero catches in the mid to upper portion of the river (Figures 6a-6d). Highest mean abundance occurred in the middle basin (0.113 fish/m² ± 0.013) followed by the lower basin (0.079 fish/m² ± 0.011) and was lowest in the upper (0.058 fish/m² ± 0.013).
Sunfish community composition or the relative species abundance (%) varied between the three river basins. Differences between the basins are illustrated in (Figure 7). Spotted sunfish were the dominant species found in the upper basin and they comprised close to 80% of the catch. Bluegill and Redear were both uncommon in this basin and only made up about 10% of the total catch each. In the middle basin, spotted sunfish were still the most common sunfish species at 54%, but bluegill and redear now made up 27% and 19% of the community, respectively. In the lower river basin, bluegill were now the most common sunfish species at nearly 50%. Spotted sunfish comprised only about 30% of the sunfish in this basin, with redear making up about 20%.
Figure 4a. Spatial distribution of spotted sunfish (*Lepomis punctatus*) in the Peace River, Florida, during spring 2008 through spring 2010. Circles indicate where samples were taken, and the size of the circle indicates the number of fish collected per 8m² electrofishing transect. The graph depicts a longitudinal profile of the river showing the number of fish caught per transect versus the distance downstream. Upper basin = 0-58 km; Middle basin = 58-110 km; Lower basin = 110-160 km.
Figure 4b. Spatial distribution and abundance (number of fish collected per 8m² electrofishing transect) for spotted sunfish (Lepomis punctatus) in the upper Peace River basin.
Figure 4c. Spatial distribution and abundance (number of fish collected per $8m^2$ electrofishing transect) for spotted sunfish (*Lepomis punctatus*) in the middle Peace River basin.
Figure 4d. Spatial distribution and abundance (number of fish collected per 8m² electrofishing transect) for spotted sunfish (*Lepomis punctatus*) in the lower Peace River basin.
Figure 5a. Spatial distribution of bluegill sunfish (*Lepomis macrochirus*) in the Peace River, Florida, during spring 2008 through spring 2010. Circles indicate where samples were taken, and the size of the circle indicates the number of fish collected per 8m² electrofishing transect. The graph depicts a longitudinal profile of the river showing the number of fish caught per transect versus the distance downstream. Upper basin = 0-58 km; Middle basin = 58-110 km; Lower basin = 110-160 km.
Figure 5b. Spatial distribution and abundance (number of fish collected per 8m² electrofishing transect) for bluegill sunfish (*Lepomis macrochirus*) in the upper Peace River basin.
Figure 5c. Spatial distribution and abundance (number of fish collected per 8m² electrofishing transect) for bluegill sunfish (*Lepomis macrochirus*) in the middle Peace River basin.
Figure 5d. Spatial distribution and abundance (number of fish collected per 8m² electrofishing transect) for bluegill sunfish (*Lepomis macrochirus*) in the lower Peace River basin.
Figure 6a. Spatial distribution of redear sunfish (*Lepomis microlophus*) in the Peace River, Florida, during spring 2008 through spring 2010. Circles indicate where samples were taken, and the size of the circle indicates the number of fish collected per 8m² electrofishing transect. The graph depicts a longitudinal profile of the river showing the number of fish caught per transect verses the distance downstream. Upper basin = 0-58 km; Middle basin = 58-110 km; Lower basin = 110-160 km.
Figure 6b. Spatial distribution and abundance (number of fish collected per 8m² electrofishing transect) for redear sunfish (*Lepomis microlophus*) in the upper Peace River basin.
Figure 6c. Spatial distribution and abundance (number of fish collected per 8m² electrofishing transect) for redear sunfish (*Lepomis microlophus*) in the middle Peace River basin.
Figure 6d. Spatial distribution and abundance (number of fish collected per 8m² electrofishing transect) for redear sunfish (Lepomis microlophus) in the lower Peace River basin.
Figure 7. Sunfish composition by basin. Percent composition equals the total number of fish per basin/total number of fish per species. Upper Peace = spotted sunfish (79%), bluegill (11%), redear (10%). Middle Peace = spotted sunfish (54%), bluegill (27%), redear (19%). Lower Peace = spotted sunfish (31%), bluegill (49%), redear (20%).
Size Structure

Differences in the size structure of sunfish populations were examined by plotting length frequency histograms for each species and comparing mean total lengths (TL) between basins (Figure 8). Exact measurements of mean lengths (mm) with standard errors can be found in (Table 3). Bluegill sunfish in the Peace River ranged in size from 2-25 cm TL with a mean size of ~10 cm. Bluegill size range was similar throughout the river. Fish in both the lower and middle basins averaged close to 10 cm, with fish in the upper basin being slightly larger at ~13 cm. Redear were the largest of the sunfish and ranged in size from 2-35 cm TL. The mean length for all redear was ~13 cm with the largest in the middle (15 cm) and upper (13 cm) basins, and smallest in the lower (11 cm). Spotted sunfish were the smallest of the three species ranged in size from 1-19 cm TL. Mean length in the Peace River was ~9 cm, with fish in the lower basin averaging slightly smaller at ~8 cm.

Table 3. A comparison of the minimum, maximum, and mean total lengths of sunfish between river basins. Measurements are TL in mm ± (standard error).

<table>
<thead>
<tr>
<th>BASIN</th>
<th>Bluegill</th>
<th>Redear</th>
<th>Spotted Sunfish</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>Min-Max</td>
<td>Mean</td>
</tr>
<tr>
<td>Upper</td>
<td>129 ± (7)</td>
<td>39 - 236</td>
<td>129 ± (10)</td>
</tr>
<tr>
<td>Middle</td>
<td>96 ± (3)</td>
<td>27 - 253</td>
<td>152 ± (7)</td>
</tr>
<tr>
<td>Lower</td>
<td>95 ± (3)</td>
<td>26 - 245</td>
<td>108± (7)</td>
</tr>
<tr>
<td>All</td>
<td>98 ± (2)</td>
<td>23 - 253</td>
<td>132 ± (4)</td>
</tr>
</tbody>
</table>
Figure 8. Length frequency histograms by basin for bluegill, redbar, and spotted sunfish collected in the Peace River from spring 2008 to spring 2010. The histograms show the proportion of fish collected in each cm group (total length). N = number of fish measured.

Longitudinal Profiles of Fish Abundance

Moving average trendlines showed a unique perspective of sunfish relative abundance along the length of the Peace River (Figure 9). The trendlines average CPUE across 8 sampling locations to smooth out the variation between individual transects, thereby displaying a more accurate depiction of fish abundance along a particular section of the river. River-wide trends in sunfish abundance matched those found in (Figure 3, Table 2), while the peaks and troughs in the trendline showed areas of higher and lower abundance for smaller reaches along the river.
Bluegill CPUE averaged (< 0.05 fish/m²) for approximately the first 50 km downstream. Between 50 and 90 km, mean CPUE increased slightly to around (0.08 fish/m²). A sharp increase in mean CPUE occurred at around 95 km which continued downstream for the next 50 km (0.23 fish/m²), with alternating areas of higher and lower abundance. No bluegill were collected past 145 km downstream in this study.

Redear abundance followed similar downstream patterns to bluegill, except that their CPUE varied much less between transects. Mean CPUE for the first 50 km was similar to bluegill at (< 0.05 fish/m²). There was also an increase in mean CPUE between 50 and 70 km to (0.1 fish/m²). This was followed by a slight decrease in CPUE until another increase at around 95 km downstream. Mean CPUE for the next 50 km was close to (0.11 fish/m²), with alternating areas of higher and lower abundance. No redear were collected beyond 144 km.

Spotted sunfish showed very different patterns of abundance compared to bluegill and redear. Contrary to other species, spotted sunfish were most abundant in the first 50 km with a CPUE of (0.5 fish/m²). From around 50 to 80 km there was a slight downward trend in mean CPUE (0.28 fish/m²) followed by a sharp increase at around 80 to 90 km downstream. There is another downward trend in CPUE starting around 95 km downstream which continued to the river-mouth. Around 95 km seems to be a crossover point where bluegills and redear increase in abundance and spotted sunfish decrease. Mean CPUE for this 50 km section was only (0.17 fish/m²). No spotted sunfish were collected beyond 140 km downstream.
Figure 9. Longitudinal profiles of mean fish abundance for bluegill, redear and spotted sunfish. The scatter plots show the catch per unit effort of each sampling location versus distance downstream. Moving average trendlines were added to smooth out fluctuations in the data so that patterns of relative abundance could be seen more clearly. Upper basin = 0-58 km; Middle basin= 58-110 km; Lower basin = 110-160 km.
Longitudinal Profiles of Habitat and Water Quality Variables

Longitudinal profiles of two habitat and two water quality variables were plotted versus distance downstream to look for patterns and trends along the course of the Peace River (Figure 10). Conductivity (µs/cm) showed a strong increasing trend starting around 95 km downstream which continued to the river mouth. This is most likely attributed to saltwater intrusion upstream due to the daily tidal influence in this part of the river. Values were also higher in the spring compared to the fall sampling seasons. This can be attributed to lower flows during the springtime dry season which allows saltwater to penetrate further upstream. The upper and middle portion of the river varied little between 20 and 90 km, with only a few small spikes in conductivity levels in the upper most reaches.

Dissolved oxygen (mg/l) did not vary much across the river but showed a slight upward trend from the upper (5.5 ± 0.2 SE) to middle basin (7.6 ± 0.2) followed by a weak downward trend from the middle to lower basin (7.2 ± 0.2). Seasonal differences were much more evident with spring samples being on average 2 mg/l higher than fall samples. Since dissolved oxygen is correlated with temperature, it makes sense that the cooler spring time water temperatures would result in higher DO levels.
Figure 10. Longitudinal profiles of available habitat and water quality parameters including conductivity (µS/cm), dissolved oxygen (mg/l), total macrophyte coverage (%), and woody debris (habitat score). The scatter plots show recorded values at all sampling locations verses distance downstream. Plots on the right show values according to season. Trendlines were added to the plots on the left to show longitudinal patterns more clearly. Upper basin = 0-58 km; Middle basin = 58-110 km; Lower basin = 110-160 km.
The percent area coverage (PAC) of in-stream macrophytes was also plotted for each transect. Plots showed that in stream vegetation varied along the course of the river from the upper to lower basins. Mean macrophyte coverage was highest in the upper basin (34%) followed by the middle (24%), and had the smallest percentage in the lower basin (11%, SE ≤ 3 for all basins). A strong downward trend in macrophyte coverage was seen from the upper river to around 80 km downstream with a distinct drop in macrophytes at around 45 km. A sharp increase occurred at around 90 km downstream which was followed by another downward trend in mean macrophyte coverage to the river mouth. This decrease in macrophytes coincided with increasing conductivity levels at the same location downstream.

Woody debris habitat was quantified by assigning a habitat score which estimated the relative amount of woody debris (i.e. snags, stumps, logs) found in each transect. Woody debris habitat along the Peace River was fairly consistent across all basins. The trendline shows evenly distributed highs and lows of woody debris habitat throughout the majority of the river. When mean scores between basins are compared there is small decrease in habitat score from approximately (100 ± 10 SE) in the upper and middle basins, to (74 ± 6) in the lower basin. There was no difference in mean habitat scores between seasons.

**Comparison of Fish, Habitat, and Water Quality Profiles**

A comparison of longitudinal profiles of fish abundance with longitudinal profiles of habitat factors revealed several associations between the two (Figures 9 and 10). Trendlines for spotted sunfish and macrophyte coverage showed a
strong positive association between macrophytes and spotted sunfish CPUE. Peaks and troughs in macrophyte coverage coincided with similar peaks and troughs for spotted sunfish CPUE. Both graphs also showed matching downward trends from the upper to lower river. A positive association between conductivity and bluegill abundance, and to a lesser extent redear, can also be seen in the plots. Low conductivities matched low CPUE for bluegill and redear in the upper river. Several small spikes in conductivity in the upper river coincided with similar spikes in bluegill CPUE. The most noticeable trend is the large increase in conductivity starting at around 95 km which coincides with a similar increase in both bluegill and redear CPUE. Spotted sunfish CPUE declines at the same location, suggesting that there may be a negative association between conductivity levels and spotted sunfish abundance. Associations between dissolved oxygen and habitat plots were harder to detect in the scatter plots and will be better interpreted using canonical correspondence analysis.

**Statistical Analysis**

Separate ANOVAs were run for each sunfish species in order to compare mean abundances between the three river basins and by season (Table 4). Significant differences in abundance were found for all three species between river basins ($p \leq .01$). Mean abundance between the fall and spring sampling seasons was similar and only varied for bluegill sunfish ($p = .001$). A separate ANOVA compared mean abundance of all fish between basins. The ANOVA showed that there was no significant difference in total fish abundance between
basins \((p = .54)\). In other words, the mean number of fish per \(m^2\) for all species combined was not significantly different between river basins.

Table 4. Results of ANOVA comparing mean abundance of individual sunfish species between basins and seasons. NS = not significant.

<table>
<thead>
<tr>
<th>Sunfish Species</th>
<th>Df</th>
<th>Sum Sq</th>
<th>Mean Sq</th>
<th>F</th>
<th>P</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Spotted Sunfish</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Basin</td>
<td>2</td>
<td>568.80</td>
<td>284.40</td>
<td>25.142</td>
<td>&lt; 0.0001</td>
<td>***</td>
</tr>
<tr>
<td>Season</td>
<td>1</td>
<td>1.70</td>
<td>1.70</td>
<td>0.152</td>
<td>0.6964</td>
<td>NS</td>
</tr>
<tr>
<td><strong>Bluegill Sunfish</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Basin</td>
<td>2</td>
<td>90.60</td>
<td>45.30</td>
<td>7.068</td>
<td>0.0009</td>
<td>***</td>
</tr>
<tr>
<td>Season</td>
<td>1</td>
<td>67.34</td>
<td>67.34</td>
<td>10.507</td>
<td>0.0013</td>
<td>**</td>
</tr>
<tr>
<td><strong>Redear Sunfish</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Basin</td>
<td>2</td>
<td>14.29</td>
<td>7.15</td>
<td>4.620</td>
<td>0.0103</td>
<td>*</td>
</tr>
<tr>
<td>Season</td>
<td>1</td>
<td>0.14</td>
<td>0.14</td>
<td>0.094</td>
<td>0.7599</td>
<td>NS</td>
</tr>
</tbody>
</table>

Tukey’s HSD test was used Post Hoc to find where significant differences occurred between the three river basins. Spotted sunfish abundance was significantly higher in both the upper and middle river basins compared to the lower basin \((p < .0001)\). Spotted sunfish were also significantly more abundant in the upper basin than in the middle basin \((p = .034)\). Bluegill abundance appeared to be opposite that of spotted sunfish, being significantly higher in the both the middle \((p = .011)\) and lower \((p = .001)\) basins compared to the upper Peace River. There was no significant difference between the lower and middle river basins for bluegill \((p = .827)\). Mean abundance of redear sunfish varied the least between river basins, with significant differences only occurring between the upper and middle Peace River \((p = .008)\). Redear abundance in the lower river basin did not differ significantly between the upper \((p = .117)\) or middle \((p = .458)\) basins.
Pearson’s correlation coefficient and conical correspondence analysis (CCA) were used to interpret relationships between sunfish abundance and associated environmental variables. The results of the CCA analysis (Figure 11, Table 5) summarize spatial trends in relative species abundance in relation to environmental variables. The CCA ordination diagram (Figure 11) shows differences in species preferences along constrained linear combinations of environmental gradients (Ter Braak and Verdonschot, 1995). Sunfish species are represented by points which represent the optimal location or ‘niche’ of a species in regards to its distribution along an environmental gradient. Variables including location (distance downstream from headwaters), habitat (macrophyte cover and woody debris) and water quality parameters (dissolve oxygen, and conductivity) are represented by arrows which point in the direction of the highest values. Longer arrows tend to represent more important variables. The length of the arrow is proportional to the rate of change, so a longer arrow indicates a larger change, and the smaller the angle between the arrow of the variable and the ordination axis, the stronger the correlation (Ter Braak, 1986).

The eigenvalues (Table 5) show how much variance is expressed on each axis. A total of 23% of the variance can be explained by the constrained variables in the CCA with, 22.5% accounted for on the first axis. Results of an ANOVA determined that only the first axis (CCA1) of the biplot was significant in explaining variation between relative species abundance (\( p = .005 \)). The second axis was not significant (\( p = .940 \)) and will not be interpreted further.
The first axis (CCA1) is best described by the distance gradient downstream. Distance ($p = .01$) being a ‘true’ gradient, is significant in explaining much of the variance in relative species abundance. There was a strong positive association between bluegill and distance downstream, and a strong negative association between spotted sunfish and distance downstream. In figure 11, a clear separation can be seen between the species along this axis, with spotted sunfish in the upper, redear in the mid to lower, and bluegill in the lowest part of the river.

Table 5. Results of a Canonical correspondence analysis (CCA) showing eigenvalues, species scores and biplot scores for constraining variables on axis 1 and axis 2.

<table>
<thead>
<tr>
<th>Eigenvalues and their contribution to the mean squared contingency coefficient</th>
<th>CCA1</th>
<th>CCA2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eigenvalues</td>
<td>0.1762</td>
<td>0.0034</td>
</tr>
<tr>
<td>Accounted</td>
<td>0.2254</td>
<td>0.2299</td>
</tr>
</tbody>
</table>

Species scores

<table>
<thead>
<tr>
<th>Species</th>
<th>CCA1</th>
<th>CCA2</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPOTTEDSUN</td>
<td>-0.3689</td>
<td>-0.0115</td>
</tr>
<tr>
<td>REDEAR</td>
<td>0.2778</td>
<td>0.1271</td>
</tr>
<tr>
<td>BLUEGILL</td>
<td>0.5587</td>
<td>-0.0517</td>
</tr>
</tbody>
</table>

Biplot scores for constraining variables

<table>
<thead>
<tr>
<th>Variable</th>
<th>CCA1</th>
<th>CCA2</th>
</tr>
</thead>
<tbody>
<tr>
<td>HABSCORE</td>
<td>0.1230</td>
<td>-0.4387</td>
</tr>
<tr>
<td>PMACROCOV</td>
<td>-0.2360</td>
<td>0.7116</td>
</tr>
<tr>
<td>AVDOMGL</td>
<td>0.1847</td>
<td>-0.2722</td>
</tr>
<tr>
<td>AVCONDO</td>
<td>0.2955</td>
<td>0.4881</td>
</tr>
<tr>
<td>DISTANCE</td>
<td>0.9959</td>
<td>0.0115</td>
</tr>
</tbody>
</table>

Conductivity (avcondo, $p = .01$) and percent macrophyte coverage (pmacrocov, $p = .04$) were both significant environmental variables in the CCA analysis. Conductivity was positively correlated with the first axis and thus distance. Redear sunfish were most closely associated with changes in
Percent macrophyte coverage was negatively correlated with axis 1 and distance. Spotted sunfish were positively associated with macrophyte coverage. Macrophyte coverage tended to be higher in the upper Peace and was associated more with spotted sunfish than with other species. The remaining variables, dissolved oxygen (avdomgl) and woody debris score (habscore) were positively correlated with axis 1 and distance but were not statistically significant in explaining variance among species in this model (p > .05).

One reason woody debris habitat was not significant is that the CCA does not analyze sites without fish. So, the habitat score doesn’t explain overall variation in relative species abundance at sites with fish, but may explain fish abundance. Species abundance is defined as the number of individuals per species, whereas relative species abundance refers to the evenness of distribution of individuals among species in a community (Stirling & Wilsey, 2001; Enc. Britannica, 2011). When a correlation (Pearson’s R) is done between species abundance and habitat score, we find that woody debris habitat is strongly correlated with fish abundance for all three species. Habitat score was significant for bluegill (r = .21, p < .0001), redear (r = .20, p < .0001), and spotted sunfish (r = .22, p < .0001). Woody debris habitat was associated with fish abundance similarly for all species; therefore it does not significantly explain variation in the relative composition of species. Differences in relative abundance are better explained by distance from headwaters, conductivity, and percent macrophyte coverage.
Figure 11. Canonical correspondence analysis (CCA) ordination diagram with species and environmental variables (arrows). Species locations are the approximate centers of their distributions along linear combinations of environmental variables. The CCA explains 23% of variation in relative species abundance. Only the first axis (CCA1) was significant ($p = .005$) and explained 22.5% of the variance.
CHAPTER 7:

DISCUSSION

This study provides evidence of longitudinal zonation among Lepomid sunfishes, from headwaters to the river mouth, in the Peace River. In addition, this study identifies several environmental factors as being significant predictors of sunfish abundance and composition in a large softwater river. Longitudinal zonation of stream fishes is well documented in ecology, particularly in streams with gradients in environmental variables such as temperature, salinity, elevation, water velocity and dissolved oxygen (Cooper & Washburn, 1949; Whitton, 1975; Rahel and Hubert, 1991; Ostrand & Wilde, 2002; McGarvey & Hughes, 2008). All species are generally constrained to a particular range of environmental variables that are within their physiological limitations. This range of environmental variables, along with a combination of additional habitat factors, defines where a species can exist, and is generally referred to as a species ‘niche’ (Hutchinson, 1957). The realized niche of a species also takes into account species interactions such as competition and predation, which can further limit the area a species can successfully occupy (Hutchinson, 1957). Changes in environmental factors that are associated with a species can result in increases or decreases in their relative abundance and ultimately may reduce or expand the areas in which they can be found (Brown, 1984).
This study shows that while bluegill, redear and spotted sunfish are distributed throughout the majority of the Peace River study area, their relative abundances varied significantly between river basins. Bluegill and spotted sunfish differed the most, with contrasting patterns of abundance from the upper to lower river basin. Spotted sunfish CPUE was highest in the upper basin and generally declined downstream, whereas bluegill CPUE was lowest in the upper basin and generally increased downstream. Redear CPUE was also lowest in the upper river but peaked in the middle basin.

While mean CPUE for each species varied significantly between river basins, the mean CPUE of all fish did not. This indicates that total sunfish CPUE (bluegill + redear + spotted) did not differ between basins, but that the percentage of each species making up that total varied considerably. This suggests an overlap in general habitat preference between sunfish, but that certain conditions may be favoring one species over another in different locations along the river. Slight differences in each species niche should determine where in the river they are located. If favorable habitat conditions are found and relative abundance is low or absent, this could indicate that there are other limiting factors at work such as competition between species or a lack of prey availability (Sammons, Partridge, & Maceina, 2006; Sammons, & Maceina, 2009). This may be limiting each species to areas in which they are most adapted.

Results of this study show that aquatic macrophytes and woody debris are important predictors of sunfish abundance in the Peace River. These findings however are not new to fisheries science and the association between sunfish
abundance and complex physical habitats such as aquatic vegetation and woody debris has long been documented in numerous studies (Angermeier & Karr, 1984; Killgore et al., 1989; Lobb, & Orth, 1991; Lehtine, Mundahl, & Madejczyk, 1997; Crook, & Robertson, 1999; Paukert, & Willis. 2002; Dutterer, & Allen. 2008). Longitudinal zonation among Lepomid sunfish has also been observed before in other studies focusing on community analysis of riverine fishes (Pyron, & Taylor, 1993; Williams, Toepfer & Martinez, 1996; Herlihy, Hughes & Sifneos, 2006; McGarvey & Hughes, 2008; Call et al., 2011). This study differs in that it focuses solely on examining fish-habitat relationships between three congeneric sunfish with overlapping niches, in order to better understand which factors are most important in determining relative species abundance among sunfish in a coastal softwater river.

The CCA ordination revealed differences in habitat selection among bluegill, redear, and spotted sunfish along several environmental gradients in the Peace River. Distance downstream was strongly correlated with axis 1 and was a strong predictor of relative species abundance. Distance however, is not an environmental factor in itself, but can be used to help explain other environmental variables that have gradients that change with distance downstream. The two significant variables that correlated with distance were macrophyte coverage and conductivity. Macrophyte coverage was negatively correlated with distance and conductivity was positively correlated. The two other factors, dissolved oxygen and woody debris, were not significantly correlated with distance and did not strongly predict relative species abundance. To better explain this we can
examine the longitudinal profiles for those factors and see that they are relatively similar across the river with no significant gradients downstream or upstream. The Pearson’s correlation coefficient showed that while woody debris habitat is not significant in explaining the variation in species composition, it is associated with fish abundance, but similarly for all species. This does not mean that woody debris habitat does not contribute to the variance in community composition, but that it is just not a significant predictor variable.

The ordination diagram created in the CCA (Figure 11) shows the mean weighted centers of the species across all variables (Ter Braak, 1986). The position of a species along an environmental gradient shows how that species responds to conditions of that variable in relation to the other species (Ter Braak and Verdonschot, 1995). Spotted sunfish were most strongly associated with macrophytes and were found in areas with the highest percentage of macrophyte cover. This positive association can also be seen in the longitudinal plots of fish abundance and habitat (Figures 9, 10). This makes sense since the upper river had higher amounts of macrophytes compared to the lower river, and macrophytes were negatively correlated with distance downstream. Dutterer and Allan (2008) showed that spotted sunfish used both woody debris and aquatic plants, but preferred more complex habitats compared to the available habitat. Due to their smaller size, spotted sunfish may prefer dense vegetation for hiding places from predators over less complex logs or stumps (Savino & Stein, 1982; Dutterer & Allan, 2008; Collingsworth & Kohler. 2010). Aquatic Macrophytes may
also serve as foraging areas for spotted sunfish which are primarily insectivorous (Caldwell et al., 1957; Hill & Cichra, 2005; Warren, 2009).

Conductivity was also a significant predictor of species relative abundance in the Peace River. Redear and bluegill were both positively associated with conductivity and both species were more commonly found in locations with higher than average conductivities for the river. Spotted sunfish were negatively associated with conductivity and were more commonly found in locations with lower conductivities. The results of the CCA match those found in the longitudinal profiles of fish abundance and conductivity (Figures 9, 10). Mean trendlines showed that as conductivity increased, so did the CPUE of bluegill and redear. An opposite trend was seen for spotted sunfish which declined as conductivities increased.

The findings of this study correspond with studies that examined salinity tolerance and osmoregulatory ability of different Lepomids. Salinity is directly proportional to conductivity, so when salinity increases so does conductivity. Peterson (1988) noted the differences in salinity tolerance between centrarchids, and tested how quickly they could acclimate to changing salinity gradients such as those found in tidal portions of rivers and estuaries. The ability to acclimate quickly to changing water conditions allowed certain species to further penetrate into systems where daily tidal changes occur. The redear sunfish had the highest salinity tolerance and was also able to acclimate very quickly (<1hr) compared to spotted sunfish which had a lower salinity tolerance and acclimated relatively slowly (12-72 hrs) (Peterson, 1988). Bluegill were also found to have a high a
salinity tolerance and were able to acclimate quickly to changing salinities (Peterson, 1988; Peterson et al., 1993). Both bluegill and redear sunfish may be better adapted to the brackish waters of the lower Peace River because of their greater osmoregulatory abilities. Longer acclimation times for spotted sunfish means that they may never become fully acclimated in diurnal tidal systems such as those found in the lower basin of the Peace River (Peterson, 1988).

Bluegill sunfish generally prefer slow moving backwaters and low flows (Stuber & Gebhart, 1982). These were much more common in the flood plains of the lower Peace than in the steeply incised middle and upper river. Bluegill are more of a generalist in their diet and are also known to prey on large amounts of zooplankton (Stein et al., 1995; Vanderkooy et al., 2000). The river becomes much wider and deeper in the lower river basin and bluegill may be able to capitalize on the larger open water habitat in this section of the river using this feeding strategy.
CHAPTER 8:
CONCLUSIONS

In answering the proposed research questions, this study shows that: (1) all three species of sunfish were distributed throughout the majority of the Peace River. However, relative abundance and species composition changed from headwaters to river mouth and differed significantly between the upper, middle, and lower river basins. (2) All three species shared similar habitat requirements and were most abundant in locations with complex habitat such as woody debris and aquatic macrophytes. Woody debris habitat was strongly correlated with fish abundance for all three species but did not significantly explain the variance in species composition among sites. Evidence for niche partitioning among species was evident in the results of the analysis. Mean CPUE of all sunfish collected per site did not differ between basins, but species composition did. Differences were most evident between bluegill and spotted sunfish which showed opposite trends in abundance throughout the river. Differences in relative species abundance along the length of the river showed that each species may have a preferred niche along different environmental variables that were correlated with distance downstream. (3) Conductivity and macrophyte coverage were both significant predictors of relative species abundance in the Peace River. Spotted sunfish were most positively associated with macrophyte coverage and preferred
locations with higher amounts of aquatic vegetation and lower conductivities which were more common in the upper Peace River. Redear and Bluegill were positively associated with conductivity and preferred locations in the lower to middle Peace River where conductivities were generally higher.

**Limitations**

While this research examined several associated environmental variables such as conductivity, dissolved oxygen, macrophyte coverage, and woody debris habitat, it did not take into account all possible biotic and abiotic factors that may influence sunfish abundance and distribution in the river. Thus, the study was limited in its ability to fully explain the patterns observed in sunfish relative abundance. Only 23% of the variance in species composition was explained in the CCA ordination. A small percentage of habitat and water quality factors were measured in this study and the CCA was limited to explaining variance among species composition for those factors alone. Biological interactions with other species such as predation, competition, or prey availability were not examined in this study and can only be assumed to contribute to some of the variance. Many large piscivores such as largemouth bass, common snook, gar, and bowfin are also found in the Peace River and may reduce sunfish abundance or composition where they are abundant (Polis & Holt, 1992). Competition from invasive species such as tilapia may also influence sunfish populations in the river (Brooks & Jordan, 2010). Further research focusing on these and other factors is suggested to fully understand what influences sunfish relative abundance and distribution in softwater riverine habitats.
Management Implications

The results of this study can be used by fisheries professionals to better manage sunfish populations in the Peace River and other lotic systems. The longitudinal profiles of fish and habitat variables proved to be a useful tool in identifying patterns in sunfish relative abundance across different sized reaches of the river. Locations showing peaks or troughs in fish abundance could be investigated further to better understand which environmental factors significantly influence fish abundance in these areas. Areas of low fish abundance could indicate reaches that are near a pollution source or are lacking essential fish habitat.

Associated environmental factors can help managers predict where species are most likely to occur along a river and can help determine how changes to these ecosystems will affect species abundance and composition in the future. Likewise, changes in species composition can indicate changes in environmental conditions. For example, continued reductions in river flows due to water withdrawals or drought, could lead to increased saltwater intrusion in the lower portions of coastal rivers. This may result in a reduction of spotted sunfish in these locations due to their negative association with conductivity levels. Similarly, an increase in conductivity levels in softwater rivers, due to urban or agricultural runoff, may result in an increase in bluegill or redear relative abundance which is positively associated with conductivity levels.
LITERATURE CITED


Argent, D. G., and W. G. Kimmel. 2010. Influence of navigational lock and dam structures on adjacent fish communities in a major river system. River Research and Applications


