Impacts of the Invasive White Perch on the Fish Assemblage of Kerr Reservoir, Virginia

by

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ABSTRACT

The white perch (*Morone americana*) is a highly successful invader of freshwater systems, with negative consequences to some resident fishes. White perch are ovivores and may prey upon as well as compete with juvenile sportfishes. Since 1988, an introduced population of white perch has proliferated in the 19,790-ha Kerr Reservoir, NC-VA, potentially threatening popular sport fisheries for largemouth bass (*Micropterus salmoides*), crappie (*Pomoxis* spp.), and self-sustaining striped bass (*Morone saxatilis*). Trophic relationships between white perch and resident sportfish were examined in the Kerr Reservoir system to determine the white perch's impact on them.

Striped bass eggs were found in the stomach contents of white perch collected from the Roanoke River during their concurrent spawning runs in May, and at times egg predation was intense (frequency of egg occurrence in white perch individuals up to 100 %). However, modeling simulations indicated that observed densities of white perch in the Roanoke River during the peak spawning period of striped bass (May) were too low to have a substantial effect on striped bass recruitment. Crappie eggs were found in the diets of white perch collected from Kerr Reservoir during April, but the significance of this predation was not determined.

Trophic overlap (Schoener's Index) was high (> 0.5) between age-0 white perch and age-0 crappie, largemouth bass, and striped bass in June, but only remained high between white perch and crappie in the remainder of the growing season (July – September). After June, largemouth and striped bass were primarily piscivorous, whereas white perch and crappie remained primarily invertivorous. Trophic overlap was high between adult white perch and adult crappie (> 0.6), but not between white perch and any other species of adult sportfish.

The utilization of white perch by adult piscivores (Ictalurids, *Pomoxis* spp., Moronids, and Percids) as a food source was low (< 2% of diets by weight). Piscivorous sportfish primarily ate clupeids, which are highly abundant in Kerr Reservoir.

Analysis of sportfish performance before (1974 – 1987) versus after (1996 – 2005) white perch establishment indicated no change in abundance and growth of striped bass and largemouth bass. Performance data for crappie prior to white perch introductions were unavailable, but observed egg predation by and trophic overlap with white perch suggests that crappie have the highest potential to suffer deleterious interactions with the white perch. Abundance of white bass has significantly declined in years since white perch introductions. Future research in Kerr Reservoir should concentrate on interactions between white perch and these two species.

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INTRODUCTION

Reservoirs present challenging problems for fishery managers because of their variable ecological conditions (Summerfelt 1999). Most are built primarily for the purposes of hydroelectric generation, flood control, and/or water storage rather than for a fishery. Because of their design, reservoirs generally have limited littoral areas, steep depth contours, and water fluctuations that limit productivity in littoral zones (Hayes et al. 1999). These systems are prone to invasions of non-native species because resident riverine fishes may have a difficult time establishing viable populations in systems with limited littoral zones. Consequently, fishery managers often stock apparently suitable fish species to fill perceived vacant niches and meet management objectives (Kohler et al. 1986). Non-native introductions can have a dramatic effect on resident fish populations, creating instable and unpredictable environments (Magnuson 1976). In recent years, non-native species have been defined as "invasive" if their introduction has the potential to cause environmental or economic harm (Clinton 1999). Invasions by non-native species occur by many means other than agency stockings. Canal and river systems, unauthorized angler stockings, and bait-bucket introductions are all channels for invasion of non-natives (Li and Moyle 1999).

The white perch (*Morone americana*) is an invasive species that has steadily increased its distribution throughout inland waters of North America. White perch are native to estuaries in the Atlantic slope but beginning in the late 1880s, white perch have invaded inland waters in north-Atlantic states (Zeurlein 1981), the Great Lakes (Boileau 1985), Nebraska (Hergenrader and Bliss 1971), and mid-Atlantic states (Wong et al. 1999). White perch were introduced to non-native waters by many means including voluntary and incidental agency stockings, migration, and possible angler introductions (Jenkins and Burkhead 1993; Carlander 1997; Fuller et al. 1999). White perch have become the most abundant species in many of these waters as a result of their opportunistic feeding, broadcast spawning with no preference for substrate type, and high fecundity (Wong et al. 1999).

Kerr Reservoir (Buggs Island Lake) is a 19,790-ha hydroelectric and flood control impoundment in south-central Virginia that has a reputation for its largemouth bass (*Micropterus salmoides*) and trophy crappie (*Pomoxis spp.*) fisheries. Kerr also features one of the few self-sustaining landlocked striped bass (*Morone saxatilis*) populations. White perch populations have been established in Kerr Reservoir since 1988 (Wilson 1997), probably through angler introductions. In 2000, the white perch was the most abundant sportfish species collected in Virginia Department of Game and Inland Fisheries's (VDGIF) fall gillnet samples (N =711, catch rate 15.0/net; VDGIF, unpublished). A small panfish fishery has even become established for white perch in Kerr Reservoir (Wilson 1997; DiCenzo 2001), but there is concern that an overabundance of white perch in Kerr Reservoir may produce a stunted population. Many instances of stunting in white perch populations have been observed in other inland waters (Hergenrader and Bliss 1971; Marcy and Richards 1974; Zeurlein 1981; Boileau 1985; Wong et al. 1999).

White perch invasions can have dramatic negative effect on resident fish populations. Drops in abundance of resident fishes have often followed white perch invasions (Hergenrader and Bliss 1971; Zeurlein 1981; Boileau 1985; Gopalan et al. 1998; Wong et al. 1999; Madenjian et al. 2000). Madenjian et al. (2000) found that the most plausible explanations for the reduction of native white bass (*Morone chrysops*) populations in Lake Erie and Oneida Lake, New York were that white perch interfered with the survival of white bass eggs, larvae, and/or juveniles. It is likely that the mechanisms causing the declines in resident fish populations are white perch competition and/or predation.

White perch are opportunistic feeders (Wong et al. 1999). Small white perch (<150 mm TL) primarily feed on zooplankton and benthic invertebrates, the important foods of larval and early stages of most age-0 fishes. Significant trophic overlap (> 0.6 on a 0-1.0 scale) has been reported between age-0 striped bass and age-0 white perch in the lower James River and Potomac Estuary, Virginia (Setzler-Hamilton et al. 1982; Rudershausen and Loesch 2000), age-0 yellow perch (*Perca flavescens*) and age-0 white perch in Oneida Lake, New York (Prout et al. 1990), and age-0 white bass, alewife (*Alosa pseudoharengus*), and yellow perch versus age-0 white perch in western Lake Erie (Gopalan et al. 1998). Larger white perch (>200 mm) have been known to eat a variety of foods, including other fish species (Warner 1974; Elrod et al. 1981; Boileau 1985; Weisberg and Janicki 1990).

White perch are also known to be ovivores (Elrod et al. 1981; Bath and O'Connor 1985). White perch have been documented eating the eggs of white perch and striped bass in the Pamunkey River, Virginia (McGovern and Olney 1988); white perch, white bass, and walleye (*Stzostedion vitreum*) eggs in the Sandusky River tributary of Lake Erie (Schaeffer and Margraf 1987); alewife eggs in Lake Ontario (Danehy et al. 1991); and walleye eggs in the western basin of Lake Erie (Roseman et al. 1996). In addition, white perch have been found to feed on striped bass eggs and larvae even in instances of high turbidity (McGovern and Olney 1988; Monteleone and Houde 1992).

Although white perch can be detrimental to native fish populations, they can also provide a valuable forage base for sportfishes. In their native, estuarine environment, white perch have been important forage for striped bass over 200 mm TL (Gardinier and Hoff 1982), and age-0 bluefish (*Pomatomus saltatrix*) (Juanes et al. 1993). Hartman and Margraf (1992) found that walleye in Lake Erie fed on *Morone* species (primarily white perch) when gizzard shad (*Dorosoma cepedianum*) were not abundant. White perch constituted a seasonally important food source for the white bass in Lake Erie throughout the summer (Hartman 1998). In Lake Ontario, northern pike (*Esox lucius*) had substantial proportions of white perch in their diets two years after white perch had become established (Boileau 1985). Piscivores that eat spiny-rayed prey (such as largemouth bass) have also been shown to target white perch, when white perch was the most abundant prey fish (Ward and Neumann 1998).

State biologists have speculated that white perch may be having a significant effect on resident sport fishes in Kerr Reservoir. Indices of striped bass year-class strength were reduced in the early 1990's directly after the first white perch were found in Kerr Reservoir gillnet samples (Wilson 1997). Since the establishment of white perch in Kerr Reservoir, anglers have suggested that striped bass fishing is not as good as it used to be and requested supplemental stocking of fingerings. Additionally, the adult white bass population has declined dramatically since the establishment of white perch (V. DiCenzo, Virginia Department of Game and Inland Fisheries, personal communication). The trophic significance of white perch on sportfish communities in Kerr Reservoir is unknown, but the white perch's reputation and performance record leads to some concern. To determine the impact of white perch to the overall fishery of Kerr Reservoir, it is imperative to gain an understanding of the trophic relationships between white perch and resident sportfishes.

To assess the impacts of the white perch introduction into Kerr Reservoir, I conducted an analysis of trophic benefits (utilization) and detriments (predation and competition) to resident sportfishes. My research focused on the trophic interactions between white perch and resident sportfishes, in particular striped bass.

White Perch Biology and Ecology

Distribution - The white perch is native to estuaries in the Atlantic Slope of North America as far south as South Carolina (Jenkins and Burkhead 1993), and as far north as the Miramichi River Estuary in New Brunswick (Johnson and Evans 1991). During the period between 1880 and 1950, federal and state hatcheries established inland populations of white perch in Maine, Maryland, Connecticut, New York, and Massachusetts (Zeurlein 1981).

After initial introductions, the white perch extended its western range by means of canals and river systems. In the late 1940s, white perch became established in Lake Ontario from a population in Oneida Lake, New York and in Lake Erie via the Erie Barge Canal (Scott and Christie 1963). By 1983, populations were established in the Detroit River, Lake St. Clair, the St. Clair River, and Lake Huron (Boileau 1985). By 1988, white perch populations had been established in Lake Michigan, the Illinois River (Cochran and Hesse 1994), and more recently have been found in the Upper Mississippi River System (Irons et al. 2002).

Before 1964, the western range of white perch distribution was the Great Lakes. In 1964, white perch were stocked in Nebraska lakes by the Game and Parks Commission to establish suitable fisheries in highly alkaline lakes (Hergenrader and Bliss 1971). From initial stockings, white perch have established populations in the Platte and Missouri River systems (Hergenrader and Bliss 1971). From Nebraska, the white perch has moved south into Oklahoma through the Arkansas River system, and white perch have been recently found in Oklahoma reservoirs (K. Kuklinski, Oklahoma Department of Wildlife Conservation, personal communication).

In Virginia, the white perch is indigenous to all of the coastal drainages below the Fall Line (Jenkins and Burkhead 1993). By means of canal systems and possible stockings, the white perch has colonized waters above the Fall Line in the Potomac, Roanoke, and York drainages (Jenkins and Burkhead 1993). Inland waters of North Carolina have also experienced establishment of white perch populations (Wong et al. 1999).

Food Habits - The white perch has a terminal mouth and a tongue with two narrow tooth patches on the anterolateral margin for grasping prey items (Jenkins and Burkhead 1993). Larval white perch (3-23 mm TL) first feed on micro-zooplankton (rotifers, cladocerns, and copepods) (Setzler-Hamilton et al 1982). Hjorth (1988) found that white perch larvae are efficient predators at a relatively small size, because they shift diets to smaller zooplankton prey when abundances of larger, preferred zooplankton are low.

The diets of young-of-year and older white perch are very diverse, varying with spatial and temporal availability of suitable prey. Young-of-year white perch feed on zooplankton early in life, but soon shift to benthic invertebrates (Gopalan et al. 1998). In the James River, Virginia, the diets of age-0 white perch up to 40 mm TL consisted primarily of copepods and leptodorids, but diets shifted to mysids, insect larvae and pupae in white perch above 40 mm TL (Rudershausen and Loesch 200). A similar diet shift at 40 mm TL (from copepods and daphnids to amphipods and chironomids) was documented in the diets of age-0 white perch in Oneida Lake, New York (Prout et al. 1990). Diets of white perch in the Richibucto Estuary, New Brunswick shifted at 50 mm TL from copepods and amphipods to sand shrimp (Crangon septenspinosa) (St-Hilaire et al. 2002).

Age-1 and older white perch are opportunistic, benthic feeders. Aquatic insects (chironomids, trichopterans, and ephemeropterans), amphipods, isopods, and zooplankton (cladocerns and copepods) all constitute seasonally important prey items for age-1 and older white perch (Alsop and Forney 1962; Moore et al. 1975; Elrod et al. 1981; Zuerlein 1981; Schaeffer and Margraf 1986; Weisberg and Janicki 1990; Danehy et al. 1991; Hurley 1992). White perch also feed on the eggs of fish. White perch have been documented eating the eggs of white perch (McGovern and Olney 1988), white bass (Schaeffer and Margraf 1987), alewife (Danehy et al. 1991), freshwater drum (*Aplodinotus grunniens*), and walleye (Roseman et al. 1996). Schaeffer and Margraf (1987) observed that in the Sandusky River tributary of Lake Erie, fish eggs constituted 100% (by volume) of white perch diets from May-June. In larger white perch (>200 mm TL), fish constitute an important prey item. When the prey was abundant, white perch have eaten gizzard shad (Schaeffer and Margraf 1986), other white perch, yellow perch (Madenjian et al. 2000), shiners (*Notropis spp.*) (Schaeffer and Margraf 1987), and bluegill (*Lepomis macrochirus*) (Zuerlein 1981).

Age and Growth - White perch prolarvae are approximately 3 mm TL, and postlarvae (yolk and oil globule absorbed) are approximately 4 mm TL (Mansueti 1964). Scales develop on white perch between 20 and 25 mm TL, after which most of the adult meristics are attained (Mansueti 1964). White perch growth is greatest during the first two growing seasons and decreases after age 3 (Alsop and Forney 1962; Marcy and Richards 1974; Zuerlein 1981). Growth of white perch varies dependent on water body (Zuerlein 1981). In Nebraska reservoirs (Zuerlein 1981) and in Oneida Lake, New York (Alsop and Forney 1962), white perch reached 230 mm TL by age 3. Comparatively, white perch did not reach 200 mm TL until age 4 in the Lower Connecticut River (Marcy and Richards 1974), age 5 in the Fox River, Wisconsin (Cochran and Hesse 1994), and age 7 in the Delaware River (Wallace 1971). In the tidal James River, Virginia, mean length-at-age for white perch observed was 76 mm TL, age 1; 120 mm TL, age 2; 149 mm TL, age 3; 172 mm TL, age 4; 189 mm TL, age 5; 204 mm TL, age 6; 220 mm TL, age 7; 236 mm TL, age 8; 253 mm TL, age 9; 262 mm TL, age 10 (St. Pierre and Davis 1972). The maximum age of 17 and total length of 483 mm of a white perch was found in Maine (Jenkins and Burkhead 1993).

Growth of white perch can also be density dependent. Stunting of white perch can occur when population densities are high (Boileau 1985; Wong et al. 1999). When abundances increased, mean length-at-age of age-1 white perch declined from 130 mm TL in 1966 to 112 mm TL in 1967 in Wagon Trail Reservoir, Nebraska (Hergenrader and Bliss 1971), and from 96 mm TL in 1959 to 69 in 1965 in the lower Connecticut River (Marcy and Richards 1974).

Spawning and Reproduction - In its native estuarine environment, the white perch is semianadromous and spawns in the spring when water temperatures are between 10 and 16º C (Mansueti 1961; Jenkins and Burkhead 1993). In Kerr Reservoir, this temperature range occurs in May, the same month when the majority of striped bass spawn (Neal 1969). In landlocked waters, white perch spawn in both river and reservoir areas, and migrate from deep to shallow waters to spawn when temperature are between 15 and 20º C (Zuerlein 1981). White perch have no preference for habitat types during spawning and egg deposition (Zuerlein 1981). Spawning occurs in a 1- to 2-week period, with individual females expelling eggs on more than one occasion (Mansueti 1961). Female white perch are oviparous, broadcasting demersal, adhesive eggs to be fertilized externally (Mansueti 1961). White perch fecundity ranges between 20,000 and 150,000 eggs per individual female (Jenkins and Burkhead 1993).

White perch maturation is size-specific with males maturing at smaller sizes than females (Mansueti 1961). In the Patuxent Estuary, Maryland, male white perch began maturing at 80 mm SL (50% mature by 100 mm SL), while females began maturing at 90 mm SL (50% mature by 105 mm SL) (Mansueti 1961). In this same system, all males were mature by age 2 and all females by age 4 (Mansueti 1961). Zuerlein (1981) found that male and female white perch matured earlier (by age 1 with total lengths between 102-127 mm) in Nebraska reservoirs where they exhibit rapid growth.

Goal and Objectives

Scientific evidence reveals that white perch can be detrimental to sportfish populations when introduced to inland waters. Reported negative effects of the white perch are mostly due to some form of predation and/or competition. However, it has also been reported that white perch can add to the forage base for piscivorous fishes in these systems when less than ideal forage is unavailable. My research focused on the trophic impacts, both beneficial and detrimental, of white perch on pre-existing sportfishes (striped bass, largemouth bass, and crappie) in Kerr Reservoir, Virginia. The study particularly focused on the impacts to striped bass. The Kerr Reservoir self-sustaining striped bass population supports a very popular sport fishery, but there is growing concern among striped bass anglers that the fishing success has decline. Anglers have requested supplemental stockings of striped bass to improve the fishery. Specific biological data to support a need for supplemental stockings have not as yet been developed, but the history of the white perch provides many reasons for concern.

Findings from this study may also reveal important information on the effects of white perch introductions to the community of fishery mangers and professionals. The range of the white perch is extending rapidly, and climate warming may accelerate range expansion (Johnson and Evans 1990). Fisheries personnel must recognize the effects on and changes to sportfish communities after white perch invasions to minimize impacts. This study was one of the most comprehensive investigations undertaken to date on the trophic interactions between white perch and other sportfishes. The goal of this two-year study was to describe the trophic relationships and assess impacts of white perch on the Kerr Reservoir sport fish community, especially striped bass: Specific objectives were to:

1. **Describe the intensity and extent of white perch predation on the eggs and larvae of co-occurring sportfishes;**
2. **Evaluate the potential for trophic competition between white perch and age-0 sportfishes;**
3. **Quantify the contribution of white perch to the diets of piscivorous sport fishes; and**
4. **Compare growth and abundance of sportfishes before and after white perch establishment.**

STUDY SITE

Kerr Reservoir is a 19,790-ha impoundment on the Roanoke (Staunton) and Dan Rivers (Figure 1). The reservoir borders Virginia and North Carolina between Clarksville, Virginia and Henderson, North Carolina. Kerr Dam was constructed in 1952 and is operated by the U.S. Army Corps of Engineers for the purposes of flood control, hydroelectric generation, and water supply. The eutrophic reservoir is highly dendritic with 1,287 km of shoreline, and it has an annual water level fluctuation of approximately 5 m (Wilson 1997). The high water level fluctuations limit the establishment of significant aquatic vegetation (DiCenzo 2001) and result in severe shoreline erosion (Wilson 1997). The reservoir has a maximum depth of 32 m, a mean depth of 10 m, a retention time of approximately 98 days, and a drainage area of 2,020,184 ha (DiCenzo 2001).

Kerr Reservoir supports sport fisheries for blue catfish (*Ictalurus furcatus*), channel catfish (*Ictalurus punctatus*), crappie, flathead catfish (*Pylodicyis olivaris*), largemouth bass, striped bass, and walleye (Dicenzo 2001). The Kerr Reservoir crappie fishery is sustained by populations of both black crappie (*Pomoxis nigromaculatus*) and white crappie (*Pomoxis annularis*), but is dominated by black crappie (approximately 95% black crappie; V. DiCenzo, Virginia Department of Game and Inland Fisheries, personal communication). For my study black and white crappie were pooled for analysis, because anglers seldom differentiate between the two species (Mitzner 1981; Maceina and Stimpert 1998; Isermann et al. 2002; Sammons et al. 2002). The reservoir's sportfish assemblage is supported by an abundance of available forage fish populations including threadfin shad (*Dorosoma petenense*), gizzard shad, alewife, and blueback herring (*Alosa aestivalis*). The reservoir is renowned for its largemouth bass and trophy crappie fisheries. It also has one of the few self-sustaining landlocked striped bass stocks

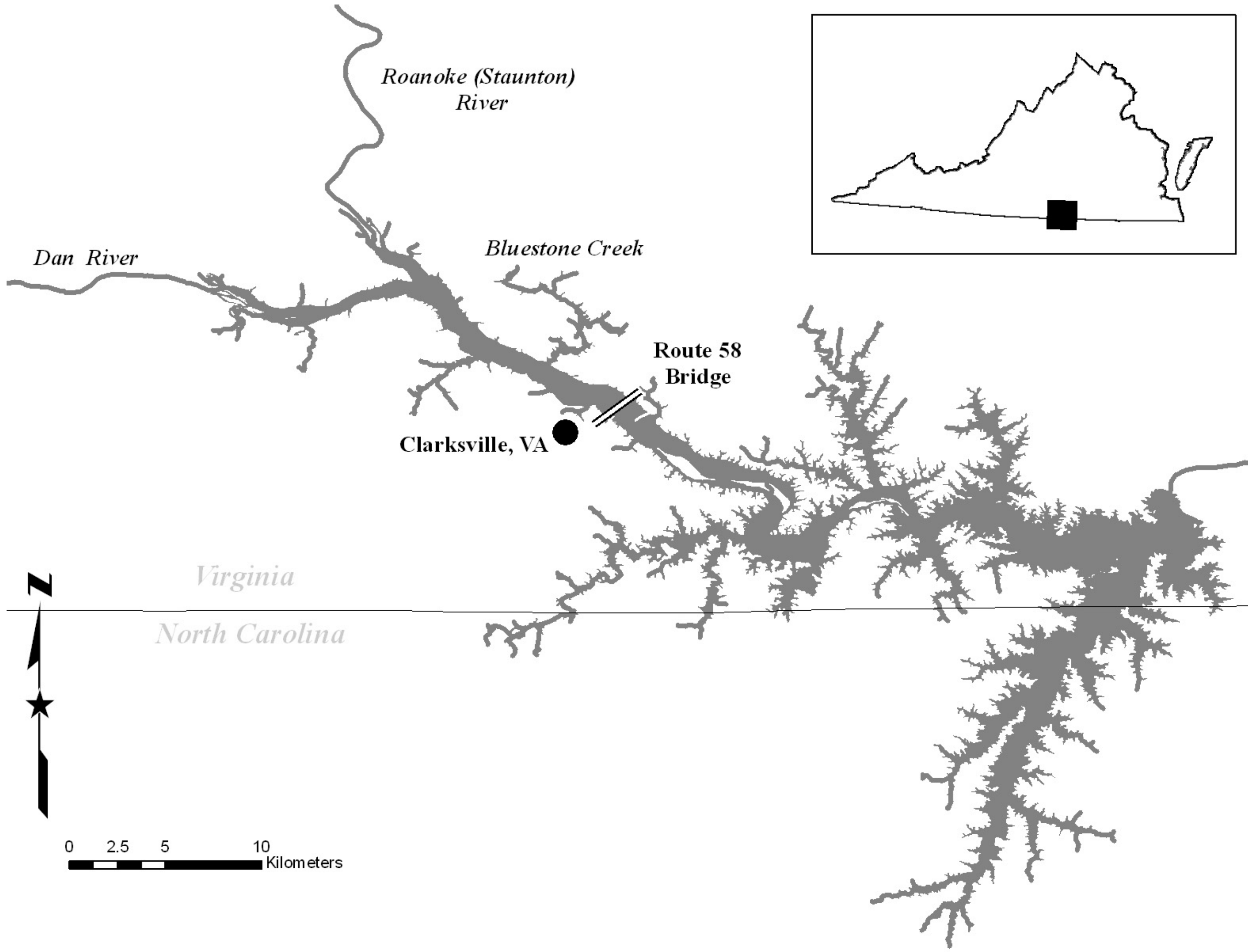

Figure 1. Map of Kerr Reservoir, Virginia/North Carolina.

Table 1. Striped bass stocking history of Kerr Reservoir and the Roanoke River, Virginia from 1975-1997.

Year	Location	Size Class	Number Stocked	Year	Location	Size Class	Number Stocked
1953	Kerr Reservoir	Fry	670,000	1987	Roanoke River	fry	150,000
1954	Kerr Reservoir	Fry	500,000		Roanoke River	Fingerling	5,168
1955	Kerr Reservoir	Fry	1,000,000	1988	Kerr Reservoir	Fry	3,250,000
1975	Kerr Reservoir	Fry	476,548		Kerr Reservoir	Fingerling	15,403
	Kerr Reservoir	Fingerling	76,631		Roanoke River	Fry	100,000
	Roanoke River	Fry	5,375,016	1989	Kerr Reservoir	Fry	3,200,000
1976	Kerr Reservoir	Fry	3,669,255		Kerr Reservoir	Fingerling	9,624
	Kerr Reservoir	Fingerling	239,751		Roanoke River	fry	1,000,000
1979	Kerr Reservoir	Fingerling	45,073	1990	Kerr Reservoir	Fry	5,800,000
	Roanoke River	Fry	13,773,000		Kerr Reservoir	Fingerling	166,284
1980	Roanoke River	Fry	18,700,000		Roanoke River	fry	826,000
1981	Kerr Reservoir	Fry	7,500,000	1991	Roanoke River	Fry	1,600,000
	Kerr Reservoir	Fingerling	77,000	1992	Kerr Reservoir	Fingerling	45,600
	Roanoke River	Fry	10,500,000	1993	Kerr Reservoir	Fingerling	147,660
	Roanoke River	Fingerling	175,000	1994	Kerr Reservoir	Fingerling	161,523
1982	Kerr Reservoir	Fry	3,425,000	1995	Kerr Reservoir	Fingerling	750,000
	Kerr Reservoir	Fingerling	53,300	1997	Kerr Reservoir	Fingerling	14,330
	Roanoke River	fry	13,440,000	1998	Kerr Reservoir	Fingerling	535,323
1983	Kerr Reservoir	Fry	12,350,000		Roanoke River	fry	1,100,000
	Roanoke River	Fry	740,000	1999	Roanoke River	Fingerling	19,437
1984	Kerr Reservoir	Fingerling	233,503	2000	Kerr Reservoir	Fingerling	159,840
	Roanoke River	Fry	1,650,000	2001	Kerr Reservoir	Fingerling	33,721
1985	Kerr Reservoir	Fry	4,200,000	2002	Kerr Reservoir	Fingerling	287,847
	Roanoke River	fry	950,000	2003	Kerr Reservoir	Fingerling	369,945
1986	Kerr Reservoir	Fingerling	67,620	2004	Kerr Reservoir	Fingerling	339,304
	Roanoke River	Fry	1,400,000	2005	Kerr Reservoir	Fingerling	406,935

in North America (Neal 1969). Kerr Reservoir was originally stocked with striped bass fry between 1953 and 1955 (Neal 1969), and it has been subject to periodic surplus fry and fingerling stocking (Table 1). Since the initial stockings, successful striped bass spawns have occurred annually (Neal 1969).

The Roanoke and Dan Rivers are the spawning grounds for Kerr Reservoir striped bass (Whitehurst 1982). Striped bass spawning locations (upstream from Kerr) are 39-66 km in the Roanoke River and 37-68 km in the Dan River (Neal 1969). Average annual flows are similar in both rivers. The Roanoke had an annual average flow of 94 m^3/s into Kerr, while the Dan had an average annual flow of 80 m^3/s into Kerr between the years of 1972 and 1975 (Weiss et al. 1978; Whitehurst 1982). The Roanoke provides 103 km of unobstructed stream flow above Kerr Reservoir, while the Dan provides 68 km of unobstructed flow with respective barriers at Leesville Dam on the Roanoke River and Brantley Steam Plant on the Dan River (Whitehurst 1982).

For this study, all field sampling occurred in the Roanoke River and the upper end of Kerr Reservoir (above the Route 58 Bridge). Sampling sites pursuant to each objective are described in Methods.

METHODS

Extensive field collection and laboratory work were essential to the completion of this two-year study. The first year of this study, 2004, was of value both for the data obtained and refinement of adequate sampling arrangements and laboratory procedures. Because of the knowledge gained in 2004, sampling and laboratory procedures were refined and intensified in 2005.

Age and Growth Analysis

Concerns regarding possible stunting and vulnerability to predation prompted analysis of the length-at-age distribution of the Kerr Reservoir white perch population based on specimens (N = 192) collected pursuant to project objectives. Because collected white perch were sacrificed for diet analysis (described in project objectives), perch were aged using sagittal otoliths to insure aging accuracy and precision (Devries and Frie 1996).

In the laboratory, otoliths were prepared and aged using a quick process. Otoliths were lightly burned using an open flame to enhance annulus contrast in the opaque white perch otoliths (Christensen 1964). After burning, otoliths were broken at the nucleus using a sharp scalpel (Maceina 1988), because otoliths were too thick to age by whole-view methods. Broken edges were polished using wetted, fine-grit sandpaper (600 grit) and dipped in immersion oil. Polished edges of the posterior end of otoliths were viewed and aged under a compound light microscope (40-100 x). Each otolith was read independently by two readers without knowledge of perch total length (TL), and agreement between readers was greater than 95 %. In cases of disagreement of age estimations between readers, otoliths were read a third time and assigned congruent ages between readers.

Length-at-age of white perch was back-calculated using the direct proportion method (Devries and Frie 1996):

$$Ln = Sn/Sc * Lc$$

where Ln is the length-at-age of white perch when a given annulus was formed, Sn is the otolith measurement to the given annulus, Sc is the measurement to the edge of the otolith, and Lc is the white perch total length (TL) at capture. The direct proportional method was used because regressions of white perch body length-at-age versus otolith radius had intercepts at or near the origin.

Additionally, patterns of first–year growth of white perch, crappie, largemouth bass, and striped bass were described as mean TL by month for each species. Age-0 fishes were collected pursuant to Objective 2.

Objective 1: Predation

Field Collection. - White perch were collected in the spring of 2004 and 2005 to quantify the perch's spring-time diet and determine whether they preyed on the eggs and larvae of Kerr Reservoir sportfishes (primarily striped bass). White perch were obtained throughout the day using pulsed-DC boat electrofishing (4-6 A, pulsed at a frequency of 120 pulses per second) in the Roanoke River tributary of Kerr Reservoir. In each sampling day, shorelines and main channels of the Roanoke River were sampled at each location where white perch were collected. The Roanoke River rather than the Dan River was selected because of its numerous access points. Due to controlled flow conditions, the greater numbers of viable striped bass eggs are spawned in the Roanoke River (Whitehurst 1982). In each year, sampling started at the beginning of May when surface water temperatures approached 18ºC, the temperature when striped bass start spawning in the Roanoke River (Neal 1969).

White perch were collected from five locations within the Roanoke River throughout May of 2004 and 2005. The most upstream location (Clarkton Boat Launch) was located approximately 58 km above the backwaters of Kerr Reservoir (Figure 2), which were defined by Whitehurst (1982). By collecting and ageing striped bass eggs from the Roanoke River during the spawning period of striped bass, Neal (1969) and Whitehurst (1982) found that the mean spawning site of striped bass was located just below Clarkton Boat Launch, around Turnip Creek (48-55 km upstream of reservoir backwaters). The four other collection sites were located approximately 39 km (Ridgeway Farms), 26 km (Watkins Bridge), 14 km (Route 360 Bridge), and 0 km (Staunton View Boat Launch) upstream from the backwater of the reservoir (Figure 2). All sites were selected for their proximities to boat launches and were distributed throughout the river.

In the Roanoke River, striped bass spawn throughout May and early June, but the majority of striped bass (approximately 80%; Neal 1969) spawn in a 1 to 2 week period in May which I considered the peak striped bass spawning period. In each year, adult white perch collection was concentrated at the four upriver sites prior to and during the peak striped bass spawning period, to collect fish that had the potential to consume striped bass eggs. Directly after the peak spawn, perch collection was concentrated in the most downriver site (Staunton View Boat Launch), to obtain fish that had the potential to eat striped bass larvae entering the reservoir. Through egg collections in the Roanoke River, Neal (1969) and Whitehurst (1982) determined that the majority of striped bass eggs hatch between 360 Bridge and Staunton View Boat Launch. Collection continued throughout the month of May, or approximately 16 days after the peak spawn. Whitehurst (1982) found that striped bass eggs in the Roanoke River hatch in two to four days, and in lab studies white perch predation on striped bass larvae declines

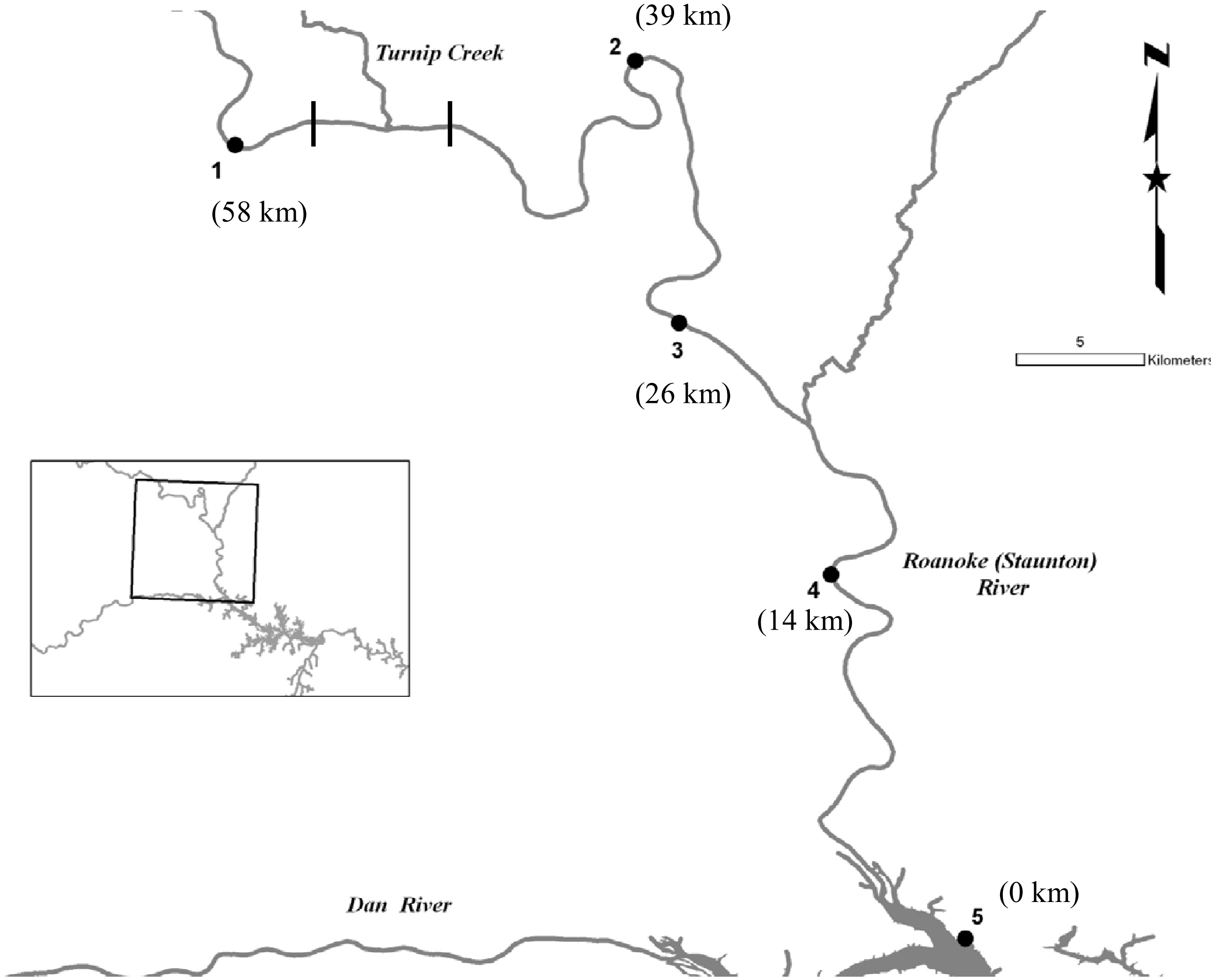

Figure 2. Map of the Roanoke River below Brookneal, Virginia, with locations of white perch sampling sites in May 2004 and 2005. Site numbers correspond to: (1) Clarkton Boat Launch; (2) Ridgeway Farms; (3) Watkins Bridge; (4) Route 360 Bridge; and (5) Staunton View Boat Launch. Kilometers indicate the distance each site is located upstream from the backwaters of the reservoir. The mean spawning waters of striped bass is enclosed by black bars in the area around Turnip creek.

sharply 12 days post hatch (Monteleone and Houde 1992). In 2004, white perch were only collected on weekdays so collections would not interfere with anglers during that period, but white perch collection were expanded to included weekend periods in 2005. A detailed account of sampling in the Roanoke River relating to the peak striped bass spawn for 2004 and 2005 is presented in Tables 2 and 3, respectively. A qualitative assessment of the peak striped bass spawning period was determined through visual observations of striped bass spawning activity, increased abundance of striped bass throughout the river, presence of striped bass eggs in the water column of the river, and from communication with striped bass hatchery officials at Vic Thomas State Fish Hatchery in Brookneal, Virginia who collect striped bass from the Roanoke River during the spawning period.

Collected perch were immediately placed on ice. Due to the observation of partially digested stomach contents in 2004, stomach (visceral) cavities of white perch collected in 2005 were injected with 10% buffered formalin at the time of capture using a 23-gauge hypodermic needle to cease digestion (Emmett et al. 1982). At the end of each sampling day, white perch were measured to the nearest 1 mm, and weighed to the nearest 1 g. Stomachs were removed and preserved in a 10% formalin solution for further laboratory analysis. Additional samples of white perch and their gut contents were collected pursuant to Objective 2 (June through December) and in 2005 VDGIF spring trapnet surveys, during the period when other Kerr Reservoir sportfish spawn. White perch were also collected during this time period to determine their predation on the larvae, juveniles, and adults of Kerr Reservoir sportfish.

Food Habits. - Once in the laboratory, white perch stomach contents were analyzed for the presence of eggs and larvae. Each stomach item was identified to the lowest practical taxon using a dissecting microscope and keys for fish eggs and larvae. Striped bass eggs were

Table 2. White perch sampling record for 2004 from Roanoke River in relation to peak spawning period of striped bass.

			Location				
Date	Surface Water Temp (ºC)	Striped Bass Spawning Activity	Clarkton (58 km)	Ridgeway (39 km)	Watkins (26 km)	Route 360 (14 km)	Staunton View (0 km)
1-May		Low					
2-May		Low					
3-May		Low					
4-May	16.0	Low		X			
5-May		Low	X				
6-May		Low					
7-May		Peak					
8-May		Peak					
9-May		Peak					
10-May	19.5	Peak	X		X	X	
11-May	21.0	Low		X	X	X	
12-May	21.0	Low			X		
13-May	21.0	Low		X	X	X	
14-May	22.0	Low	X				
15-May		Low					
16-May		Low					
17-May	21.0	Low		X			
18-May	25.0	Low					X
19-May	22.0	Low					X
20-May	26.0	Low					X
21-May	24.0	Low					X
22-May		Low					
23-May		Low					
24-May	27.5	Low					X
25-May	28.0	Low					X
26-May	27.0	Low					X
27-May	29.0	Low					X
28-May	26.0	Low					X
29-May		Low					
30-May		Low					
31-May		Low					

Table 3. White perch sampling record for 2005 from Roanoke River in relation to peak spawning period of striped bass.

			Location				
Date	Surface Water Temp (ºC)	Striped Bass Spawning Activity	Clarkton (58 km)	Ridgeway (39 km)	Watkins (26 km)	Route 360 (14 km)	Staunton View (0 km)
1-May		Low					
2-May	17.2	Low		X			
3-May	15.6	Low		X	X	X	
4-May	15.6	Low	X		X		
5-May	17.8	Low		X			
6-May		Low					
7-May		Low					
8-May		Low					
9-May	17.8	Low		X	X		
10-May	17.8	Peak	X		X		
11-May	20.0	Peak		X	X	X	
12-May	20.0	Peak	X		X	X	
13-May	22.2	Peak		X	X	X	
14-May	20.0	Peak		X	X		
15-May		Peak					
16-May	20.0	Low			X	X	
17-May	20.6	Low				X	X
18-May	22.2	Low					X
19-May	21.1	Low					X
20-May		Low					
21-May		Low					
22-May		Low					
23-May	23.3	Low					X
24-May	21.7	Low					X
25-May	21.1	Low					X
26-May	21.1	Low					X
27-May	22.2	Low					X
28-May		Low					
29-May		Low					
30-May		Low					
31-May		Low					

distinguished from other eggs because of their large size and perivitelline space (Mansueti 1964). Stomach items were then blotted dry and weighed to the nearest 0.001 g. To determine the percent of white perch selecting eggs and larvae in their diet, frequency of occurrence (FOO) was calculated (Bowen 1996). FOO was determined using the equation:

$$FOO = N_i/N_t,$$

where FOO is the percent of white perch selecting for food item i, N_i is the number of white perch containing food item i in their stomach, and N_t is the total number of white perch containing food.

To determine the relative importance of fish eggs and larvae in the diet of white perch, percent contribution by weight (Hylsop 1980) of major diet items was calculated using the equation:

$$\%WTP_i = \sum (WTP_i/WT)/N,$$

where $\%WTP_i$ is the mean percent contribution by weight for prey item i, WTP_i is the weight of prey item i eaten by an individual white perch, WT is the total weight of all prey items consumed by that white perch, and N is the total number of white perch sampled containing food (Sutton 1997; Rash 2003). The percent-contribution-by-weight method suggests the relative importance of individual prey items in terms of nourishment by quantifying prey items in directly comparable weight units (Bowen 1996; Sutton 1997).

Estimates of Total Egg Predation. - The occurrence of striped bass egg predation is of little importance without some quantification of how this predation affects the recruitment of this species. It was not possible to estimate total consumption of striped bass eggs by white perch directly, because the total number of white perch in the Roanoke River could not be determined. As an alternate approach, I estimated the population sizes of white perch needed to consume

10%, 50%, and 90% of the annually produced striped bass eggs, and then evaluated whether the resultant white perch abundance estimates were realistic from field collections of white perch. Inputs needed for this approach were annual number of striped bass eggs spawned in the Roanoke River, consumptions rates of white perch, and diet composition of white perch.

Egg estimates were derived from a comprehensive study of striped bass in the Roanoke River from 1976 to 1979, which was the most current study on eggs production of striped bass in the Roanoke River. Whitehurst (1982) estimated striped bass egg production by two methods: (1) egg collections in the Roanoke River; and (2) population estimates of female striped bass and average fecundity in the Roanoke River. Only egg production estimates from the egg collections were used for this study, because the population estimate method often produced much higher estimates of egg production, probably due to the assumption that all ovarian eggs were spawned. Further, egg production estimates using the egg collection method were similar in magnitude to those from previous studies on striped bass egg production in the Roanoke River (Neal 1969; Neal 1976). Throughout the Whitehurst (1982) study, 1976-79, egg estimates ranged from 1,509,533,243 to 5,015,570,772 eggs produced annually, with an average yearly production of 3,068,024,698. To account for annual variability, two scenarios of egg production were modeled: (1) worst-case scenario of egg production (1,509,533,243 eggs); and (2) average annual egg production (3,068,024,698 eggs). Additionally, egg production numbers were adjusted to represent the number of eggs produced during the peak striped bass spawning period, because in this study, instances of egg predation by white perch were only found during this period. Approximately 80% of the total striped bass eggs produced are spawned during the peak spawn in the Roanoke River (Neal 1969).

The white perch total daily ration, C_D, were obtained from a combination of scientific literature and a bioenergetics model. A study by Parrish and Margraf (1990) on Lake Erie was the only reference found that contained consumption values for white perch. During their study, white perch consumption ranged between 0.026 and 0.219 grams of food ingested per gram of fish per day ($g*g^{-1}*d^{-1}$) in two basins of Lake Erie and were some of the highest ever reported for any species. For my model, maximum consumption (0.219 $g*g^{-1}*d^{-1}$) observed was used in the egg predation simulations to represent worst-case (most intense) egg predation. Due to the lack of information on white perch consumption, consumption was alternatively calculated with a bioenergetics model using input parameters of congeneric age-1 striped bass (Hartman and Brandt 1995); no bioenergetics model has been developed for white perch (K. Hartman, West Virginia University, personal communication). In this model, temperature-dependent maximum consumption was calculated from the equation:

$$Cmax = CA * W^{CB} * f(T)$$

where Cmax is maximum daily consumption, CA and CB are species specific constants (Hartman and Brandt 1995), W is fish body weight, and f(T) is an algorithm of temperature dependency for consumption (Thornton and Lessem 1978; Hartman and Brandt 1995). Average weight of white perch collected in May 2005 (65.4 g) and mean water temperatures during the peak striped bass spawn during 2005 (18º C) were used in the bioenergetics equation. This model predicted a maximum consumption value of 0.104 $g*g^{-1}*d^{-1}$, which was comparable to the mean consumption value but was less than the maximum consumption values reported by Parris and Margraf (1990). Since bioenergetic estimates were close to the mean value observed by Parris and Margraf (1990) and were modeled at specific spring temperatures of the Roanoke River, consumption rates of age-1 striped bass (0.104 $g*g^{-1}*d^{-1}$) were used in the egg predation models to represent realistic temperature-based egg consumption rates of white perch. Lastly, all consumption rates were converted to grams of food ingested daily by the average-sized white perch.

White perch diet composition was obtained from stomach contents of white perch collected in May of 2005, the year when considerable striped bass egg predation was apparent. For my simulations, percent contribution by weight of striped bass eggs to diets of white perch was averaged in days during the peak striped bass spawn. Additionally, only food habits of white perch collected from locations where significant instances of striped bass egg predation occurred (Ridgeway Farms and Watkins Bridge) were used to calculate means. This mean value of eggs was 58% of white perch stomach contents by weight.

Total weight of striped bass eggs consumed daily by one white perch was calculated by multiplying daily grams of food ingested by one white perch versus percent contribution by weight of eggs in diets of white perch. Consumed egg weights were then converted to the number of striped bass eggs need to represent those weights. The average weight of one striped bass egg (0.0076 g) was determined by calculating the mean weight of 30 randomly selected eggs collected from Vic Thomas State Fish Hatchery.

Once all variables were established, population sizes of white perch needed to consume different quantities of eggs were calculated using the following equation:

$$\text{Population Size of White Perch} = \frac{(\text{Total \# of Striped Bass Eggs/Days in the River})}{\text{\# of Eggs Consumed Daily by One White Perch}}$$

In 2005, peak striped bass spawning occurred during a six-day period, and all egg predation observed occurred during this period. Further, Neal (1969) determined that striped bass eggs hatch within 2 days after they were spawned with springtime Roanoke River water temperatures. For both these reasons, eggs were estimated to be in the river for 8 days during the peak striped bass spawn in 2005.

<u>Objective 2: Trophic Competition</u>

Field Collection. - The collection of age-0 sportfishes (crappie, largemouth bass, striped bass and white perch) and adult white perch was necessary to quantify diets and determine the potential for trophic competition. Age-0 sportfishes and white perch of all sizes were collected in 2004 and 2005 from June through November. Collection began during the second week of June of both 2004 and 2005 in the upper end of Kerr Reservoir, near Staunton View State Park (see Figure 2). Because of the great size of Kerr Reservoir and to increase the collection of naturally reproduced (versus stocked) striped bass, fish collection was concentrated at the upper end of the reservoir. In historical trawl surveys of Kerr Reservoir during 1978-1979, age-0 striped bass spawned in the Roanoke and Dan Rivers were mostly collected in the upper portions of the reservoir (Whitehurst 1982). Sampling locations were derived from traditional VDGIF striped bass seining sites (Tables 4 and 5; Figure 3). In each sampling session, a variety of collection sites were sampled depending on sampling gear used (Table 6).

Age-0 fish were collected throughout the growing season using a variety of gear types. Initially, age-0 fishes were collected two to four times per month by seining shallow, unvegetated shorelines with a 10-m-long x 1-m-deep seine (bar mesh size of 3.2 mm). By mid-July age-0 fish were large enough to capture with electrofishing gear, so from July through November, age-0 fish were collected two to four times per month via shoreline pulsed-DC boat electrofishing (4-6 A, pulsed at a frequency of 120 pulses per second).

To collect larger age-0 fish in deeper water, late in the growing season, three bi-panel monofilament gillnets (30.5 m long and 2.0 m deep consisting of two 15.2-m-long panels with

Table 4. Detailed descriptions of 2004 and 2005 seining and electrofishing locations from the Roanoke River side of Kerr Reservoir, Virginia.

Site #	Site Description	Latitude	Longitude
1	Big point at confluence of Roanoke and Dan Rivers	36.6955	-78.6519
2	Beach just above Staunton View Boat Launch	36.6993	-78.6427
5	Red shoreline on right 3/4 mile above Staunton View Landing (small island of trees out from bank)	36.7082	-78.6530
6	Beach across cove from Staunton view landing	36.6980	-78.6384
7	Next beach down from site 6 (big rock at upper end of beach)	36.6862	-78.6304
8	Beach on Roanoke River side in front of red and white houses	36.6768	-78.6217
9	Beach below red and white houses	36.6743	-78.6204
10	2nd beach uplake from mouth of Bluestone Creek	36.6650	-78.6069
11	Beach at uplake end of the mouth of Bluestone Creek	36.6585	-78.5923
12	Beach next to old boat ramp at the mouth of Bluestone Creek	36.6573	-78.5863
13	Red bank on the right as you go into Bluestone (major point)	36.6616	-78.5830
14	Beach adjacent to Corps of Engineers boat ramp in Bluestone Creek	36.6642	-78.5706
15	1st beach below the mouth of Bluestone	36.6537	-78.5821
16	Beach below site 15 (2nd major cove uplake from powerline)	36.6474	-78.5600
17	Beach 3/4 mile below site 16 (1st cove uplake from powerline)	36.6438	-78.5530
18	Beach 1/4 mile below site 17 (beach between railroad trestle and powerline)	36.6404	-78.5499
19	Beach 200 yards uplake of site 20	36.6409	-78.5468
20	Beach in front of trailer park between railroad trestle and bridge	36.6383	-78.5456
32	Large boat launch at Occoneechee State Park	36.6336	-78.5356
33	Small boat launch on the back side of Occoneechee State Park	36.6240	-78.5251
35	Large gravel hill across lake from Buffalo Creek	36.6689	-78.6149

Table 5. Detailed descriptions of 2004 and 2005 seining and electrofishing locations from the Dan River side of Kerr Reservoir, Virginia.

Site #	Site Description	Latitude	Longitude
3	Beach up Dan River Arm on the right	36.6959	-78.6615
4	Beach across lake from Staunton River State Park	36.6878	-78.6626
21	Beach slightly upstream of Prestwood Plantation (1st major point uplake from trestle)	36.6381	-78.5680
22	Beach 1/2 mile below mouth of Bluestone Creek	36.6394	-78.5825
23	Point below site 25	36.6521	-78.5981
25	Above mouth of Bluestone (4th major point downstream of Buffalo adjacent to small point with rip-rap)	36.6529	-78.6021
26	Uplake from site 25 but before Buffalo (3rd major point, Flag Point, downlake of Buffalo)	36.6558	-78.6088
27	Beach across mouth from Buffalo Creek point	36.6585	-78.6226
28	1st beach on right in Buffalo (Army Corps. recreational beach)	36.6606	-78.6266
29	Beach next to Buffalo Creek fish shelter	36.6627	-78.6269
30	1/4-1/2 mile uplake from site 28 (adjacent to creek and brown house on hill)	36.6669	-78.6304
31	Uplake of site 29 at cedar tree (large cove across lake from Staunton View)	36.6849	-78.6442
34	Large point at the mouth of Buffalo Creek	36.6609	-78.6239

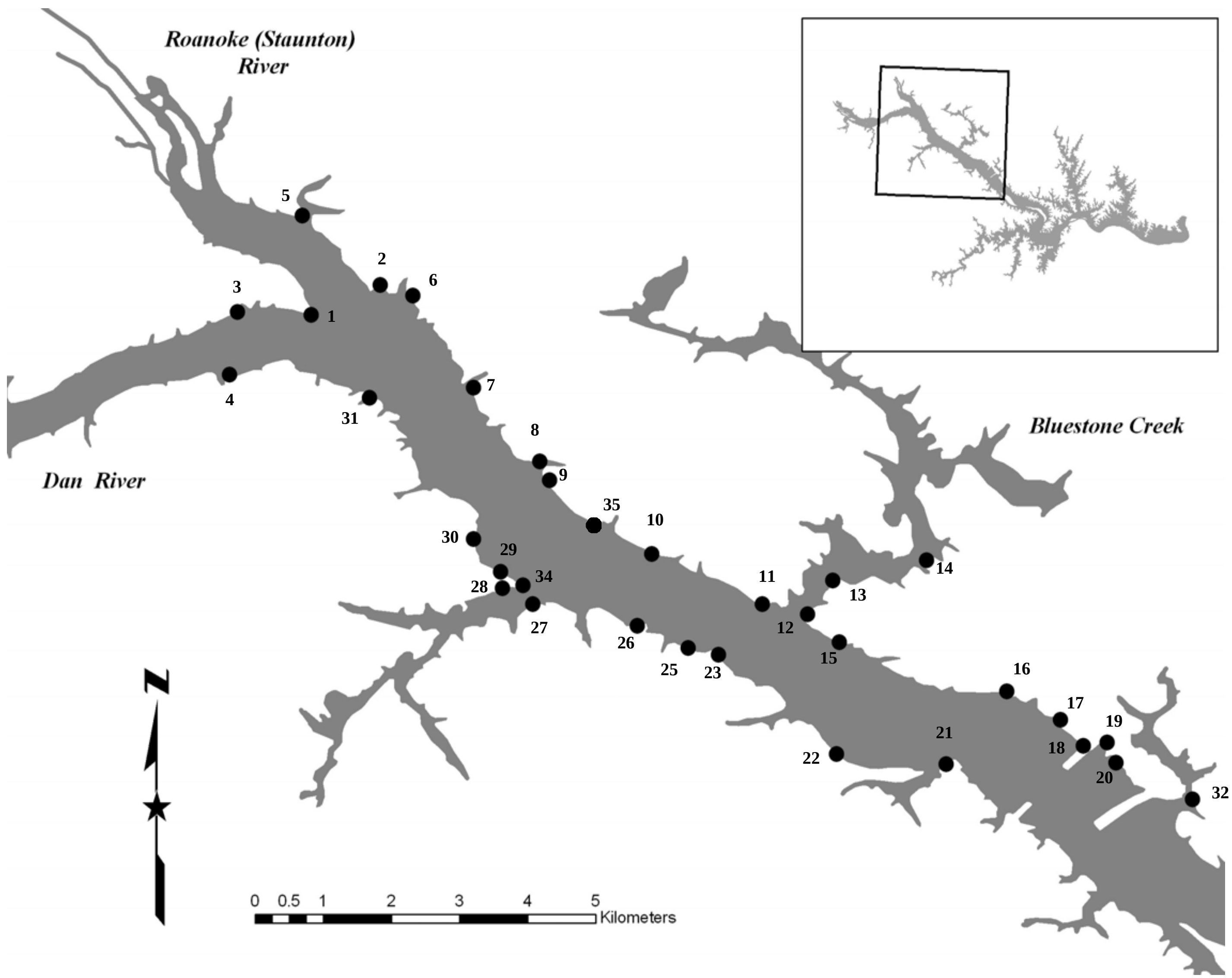

Figure 3. Map of the upper end of Kerr Reservoir, Virginia. 2004 and 2005 seining and electrofishing locations for age-0 sportfishes and adult white perch are indicated by black dots.

Table 6. Distribution of sampling for age-0 fish over time and sites (see Tables 4 and 5).

2004			2005		
Sampling Period	Seine	Electrofishing	Sampling Period	Seine	Electrofishing
Jun 15-17	All Sites	----	Jun 7-8	All Sites	----
Jun 22-24	All Sites	----	Jun 15-16	All Sites	----
Jun 28-29	All Sites	----	Jun 21-22	All Sites	----
Jul 6-7	All Sites	----	Jun 29-30	All Sites	----
Jul 20-22	1, 2, 3, 5, 6, 7, 8, 9, 10	14, 5, 25, 28, 34	Jul 8-9	All Sites	----
Jul 26-27	----	1, 2, 3, 5, 6, 28, 34	Jul 18-19	All Sites	----
Aug 4-5	----	1, 4, 5, 7, 11, 28, 29, 34	Jul 26-27	----	1, 3, 5, 6, 9, 10, 11, 14, 28, 34
Aug 10-11	----	1, 5, 28, 29, 34	Aug 2-3	----	1, 5, 11, 28, 34, 35
Sept 1-2	----	1, 5, 11, 28, 34	Aug 11-12	----	5, 10, 11, 13, 28, 34, 35
Sept 15-16	----	1, 5, 11, 25, 29, 34	Aug 23-24	----	5, 11, 13, 28, 34, 35
Sept 22-23	----	1, 4, 5, 34	Sept 19-20	----	5, 6, 11, 34
Oct 6-7	----	11, 14, 28, 29, 34	Sept 29-30	----	11, 15, 25, 35, 34
Oct 13-14	----	5, 11, 23, 29, 28, 34	Oct 12-13	----	11, 13, 15, 28, 34, 35
Oct 20-21	----	5, 11, 23, 25, 28, 34	Oct 18-19	----	11, 13, 15, 28, 34, 35
Oct 27-28	----	5, 11, 13, 23, 25, 34	Oct 25-26	----	13, 14
Nov 3-4	----	11, 28, 34	Nov 27-28	----	11, 13, 14, 32
Nov 8-9	----	11, 15, 28, 34			
Dec 16-17	----	11, 13, 14, 15, 28, 34			

bar mesh sizes of 25 and 19 mm, 19 and 13 mm, and 25 and 13 mm) were set perpendicular to the shoreline from mid-September through November, concurrent with electrofishing sampling. Additionally, in 2005 trapnets were set one night per week during June to supplement age-0 crappie collections. To increase capture efficiency, all age-0 collection took place after dark, the period when most age-0 fish migrate to shallow areas. On each sampling trip, I attempted to collect at least 30 fish from each species for diet analysis. Fish captured were immediately put on ice and returned to the laboratory for analysis.

Food Habits. - In the laboratory, fish were measured to the nearest 1mm, weighed to the nearest 1 g, and had their stomachs removed. Stomachs were preserved in a 10% formalin solution pending later analysis. After initial preservation, stomach contents were examined with a dissecting microscope, identified to the lowest practical taxon (using keys for aquatic invertebrates, zooplankton and larval fish), and weighed to the nearest 0.001g. Partially digested clupeid species were differentiated from other fish species by the presence of a gizzard-like stomach (Jenkins and Burkhead 1993). Diet composition of different species of age-0 fishes and adult white perch was quantified for each month in 2004 and 2005 and each 10 mm-length interval as percent of each diet item by total diet weight using the same equation as in Objective 1 (page 23).

Diet Overlap. - To assess interspecific trophic competition between white perch and age-0 sportfishes, diet overlap was calculated for adult and age-0 white perch versus each species of age-0 sportfish (crappie, largemouth bass, and striped bass) for every month and for each 10-mm length interval during the 2004 and 2005 growing seasons (Sutton and Ney 2002). Overlap was evaluated using Schoener's (1970) overlap index, which is defined as:

$$C_{xy} = 1.0 - 0.5 \sum_{i=1}^{n} |p_{xi} - p_{yi}|,$$

where C_{xy} is the overlap index, p_{xi} is the percentage of food type i eaten by species x, p_{yi} is the percentage of food type i eaten by species y, and n is the total number of prey item categories (Sutton 1997 and Rash 2003). Schoener's index values range from 0.0 to 1.0 with values greater than 0.6 indicating significant trophic overlap for the resource (Zaret and Rand 1971). Wallace (1981) determined that when resource availability is unknown, Schoener's index, using weight percentages, is the best method available to calculate diet overlap.

Overlap estimates can often lead to inaccurate results and unreliable interpretations when sample sizes are small (Smith 1985). To avoid misleading results, cumulative prey species curves were used to determine adequate samples sizes needed to accurately describe diets of each species for each month and 10-mm length interval (Brodeur and Pearcy 1984; Sutton 1997). Only samples large enough to properly quantify diets were used in overlap analysis. Due to low collection numbers of age-0 white perch in 2005, diet overlap was additionally calculated between age-0 white perch collected in 2004 versus age-0 crappie, largemouth bass, and striped bass collected in 2005.

To determine the potential for trophic competition between white perch and adult sportfishes, diet overlap was computed between adult white perch versus adult sportfish species collected in both 2004 and 2005. Adult sportfish were collected pursuant to Objective 3.

<u>Objective 3: Sportfish Utilization of White Perch</u>

Field Collection. - Stomach contents of adult (age 1 and older) sportfishes were obtained from a variety of sources beginning in the summer of 2004. Adult largemouth bass were collected throughout the growing season (July-December) of 2004 and 2005 using pulsed-DC boat electrofishing (4-6 A, pulsed at a frequency of 120 pulses per second). Largemouth bass collection took place in the upper end of Kerr Reservoir pursuant to Objective 2. Once collected, largemouth bass were measured to the nearest 1 mm and had their stomachs evacuated. Stomachs were evacuated by inserting an acrylic tube into the fish's esophagus and stomach (Van Den Avyle and Roussel 1980). Stomach contents were then preserved in a 10% formalin solution for laboratory analysis.

All other adult sportfish species were obtained through VDGIF annual gillnet surveys. These species included striped bass, walleye, catfish species, white bass and crappie species. A total of six gillnets (60.96 m long and 2.44 m deep containing bar mesh sizes of 50.8 mm, 31.8 mm, and 19.1 mm) were set once per month October through December of 2004 and 2005. Upon retrieving gillnets, fish were immediately placed on ice. Subsequently, fish were measured to the nearest 1 mm and had their stomachs removed within three hours of capture. Excised stomachs were preserved in a 10% formalin solution pending laboratory analysis. Additional crappies were collected in April 2005 from VDGIF annual trapnet surveys. Trapnetted fish were processed in the same manner as gillnetted fish.

Food Habits. - In the laboratory, individual stomach contents were examined with a dissecting microscope, identified to the lowest practical taxon and weighed to the nearest 0.001g. Partially digested clupeid species were differentiated from other fish species by the presence of a gizzard-like stomach (Jenkins and Burkhead 1993).

Frequency of Occurrence (FOO) of white perch consumed was calculated for each species-group of sportfish to determine the percentage with white perch in their diet. Diet composition was quantified as percent by weight of white perch and other major prey items consumed by each species-group of sportfish.

Total length, eye diameter, and caudal peduncle depth of consumed white perch were measured and converted to total lengths using the regressions developed by Scharf et al. (1997). The regressions were defined as:

Total Length of white perch = 14.911* Eye Diameter – 2.923, and

Total Length of white perch = 9.991 * Caudal Peduncle Depth + 2.427.

Total lengths of white perch consumed were calculated to determine sizes of white perch vulnerable to predation by adult sportfish in Kerr Reservoir.

Objective 4: Sportfish Performance

VDGIF Historical Data Sets. - Annual sampling by VDGIF personnel provided yearly data on key resident fishes of Kerr Reservoir used for comparison of performance (before versus after white perch establishment) in this study. Data sets provided relative abundance and length information on fish collected in annual electrofishing and gillnet samples.

Annual electrofishing surveys provided catch-per-unit-effort (CPUE) and length data on largemouth bass for the years of 1982-1994, 1996, 1997, 1999, 2001, 2002, and 2004. Beginning in 1999, electrofishing samples were collected only in the spring of each year, so for comparative reasons, only fish collected from March through June in years prior to 1999 were used in this analysis. Annual largemouth bass relative abundance (CPUE = N/hour) in years prior to white perch introductions (before 1988) were compared to yearly abundance after white perch were establish in Kerr Reservoir (1996 to the present). Although white perch were first found in 1988 VDIF samples, they were not collected in high abundance until 1996 (Wilson 1997). Total lengths of largemouth bass were used to calculate proportional stock density (PSD) and relative stock density of preferred fish (RSD-P) (Anderson and Neumann 1996). Stock density estimates (PSD and RSD-P) were compared in years pre- versus post-white perch to determine whether proportions of quality- (≥ 300 mm TL) and preferred- (≥ 380 mm TL) (Gabelhouse 1984) sized largemouth bass declined. Largemouth bass length-at-age data were obtained for the years of 1974-1980, 1982, 1985, 1993, 1997, and 2004. Lengths of age-3 largemouth bass were compared pre-white perch (1974 to 1987) versus post-white perch (1997-2004), to evaluate growth of largemouth before versus after white perch. Age-3 was chosen for comparison because at age-3 all largemouth bass are recruited to electrofishing gear and usually comprise the most abundant age group in the sample.

Yearly VDGIF gillnet samples provided abundance data for pelagic species (clupeid species, striped bass, and white bass) of Kerr Reservoir. In each year, gillnet samples were collected only in the fall (September-December), but the number of nets set and mesh sizes differed among years. From 1980 through 1994, gillnets with mesh sizes of 51 mm, 32 mm, and 19 mm (traditional gillnets) were fished in two fixed area of Kerr Reservoir. After 1994, additional gillnets with added mesh sizes (76, 64, 38, 16, and 13 mm) were used in other reservoir locations. To ensure comparability among years, only data collected from fish obtained in traditional gillnet locations and mesh sizes were used in temporal comparisons. Relative abundance (CPUE = N/100 m^2 of net) was calculated for striped bass in the years of 1974-2004, for clupeid species in 1980-1997, and 1999-2004, and for white bass in 1980-1999, and 2001-2004. For each pelagic species, annual CPUEs were compared pre versus post-white perch establishment. Length-at-age data were also provided for striped bass in 1979-1985, 1987, 1988, 1995-1997, and 1999-2004. As with largemouth bass, lengths of age-3 striped bass were compared before and after white perch introductions. Age-3 striped bass were used to ensure that all striped bass in this age class were recruited to gillnet gear.

Data on other key species of Kerr Reservoir sportfish (e.g. crappie species) were also obtained from VDGIF data sets, but sampling effort and gear were inconsistent among years and/or fish were not collected in enough years for comparison. For these reasons, comparison of growth and abundance pre- versus post-white perch establishment for crappie, catfishes, and walleye was not undertaken.

Statistical Analysis

A variety of parametric and non-parametric statistics were used to analyze data sets. Because parametric tests have strict assumptions of normality and equal variance (Townend 2002), each data set was tested for normality using the Kolmogorov-Smirnov Test and equal variance using the "F" or Bartlett's Tests. Normality and variance tests were passed at levels greater than $\alpha = 0.05$. The CPUEs of white perch collected from the Roanoke River in 2004 were used to compare relative abundances of white perch collected among sites with one-way Analysis of Variance (ANOVA). The CPUEs of fish collected in 2005 were compared over sites using a Kruskal-Wallis Test (non-parametric equivalent of the parametric ANOVA) because the test for normality failed. In the case that a significant difference in relative abundance among sites was found in either year, Tukey-Kramer's HSD range test was used to determine site differences (Zarr 1999).

Annual relative abundances (CPUE) of largemouth bass, striped bass, and white bass pre- versus post-white perch were compared using the parametric Student's "T" test. Clupeid CPUEs before versus after white perch were compared using a Mann-Whitney "U" test (non-parametric counterpart to the parametric Student's "T" test), because the test of normality failed.

Additionally, pooled lengths of age-3 largemouth bass and striped bass were compared pre versus post-white perch using the Mann-Whitney “U” test, because data failed the tests for normal distribution.

All tests were two sided and were considered significant at the $\alpha = 0.05$ level, to account for type-I error. All statistical procedures used in this study are shown in Table 7.

Table 7. Statistical procedures used to analyze Kerr Reservoir data sets.

Data Set	Normality Test	Equal Variance Test	Staistical Tests Used
Relative abundance of White Perch collected at sites in the Roanoke River 2004	Passed (P = 0.066)	Passed (P = 0.146)	ANOVA, Tukeys Kramer's HSD
Relative abundance of White Perch collected at sites in the Roanoke River 2005	**Failed (P < 0.05)**	Passed (P = 0.123)	Kruskal-Wallis, Tukey's Kramer's HSD
Relative abundance of largemouth bass pre vs. post-white perch establishment	Passed (P = 0.474)	Passed (P = 0.147)	Student's "T" test
PSD of largemouth bass pre vs. post-white perch establishment	Passed (P = 0.609)	Passed (P = 0.329)	Student's "T" test
RSD-P of largemouth bass pre vs. post-white perch establishment	Passed (P = 0.553)	Passed (P = 0.228)	Student's "T" test
Length at age-3 of largemouth bass pre vs. post-white perch establishment	**Failed (P < 0.05)**	**Failed (P < 0.05)**	Mann-Whitney "U" test
Relative abundance of striped bass pre vs. post-white perch establishment	Passed (P = 0.081)	Passed (P = 0.354)	Student's "T" test
Length at age-3 of striped bass pre vs. post-white perch establishment	**Failed (P < 0.05)**	Passed (P = .996)	Mann-Whitney "U" test
Relative abundance of clupeid species pre vs. post-white perch establishment	**Failed (P < 0.05)**	Passed (P = 0.624)	Mann-Whitney "U" test
Relative abundance of white bass pre vs. post-white perch establishment	Passed (P = 0.536)	Passed (P = 0.384)	Student's "T" test

RESULTS

<u>Age and Growth Analysis</u>

A total of 192 white perch collected from Kerr Reservoir were aged using sagittal otoliths. Collected white perch ranged in age from one to nine years, with the majority of white perch (94%) in the 1- to 4-year age groups. Mean calculated total lengths of ages one through nine white perch were 104, 149, 175, 208, 239, 254, 264, 281, and 303 mm, respectively (Table 8). White perch experienced the most growth (49%) in their first two years of life. Continued growth in length was still displayed after perch reached age two, but declined to less than 35 mm per year.

In 2004, all age-0 species averaged lengths less than 55 mm TL during the first month of the growing season (June). Both white perch and largemouth bass reached 100 mm TL by September and 110 mm by December (see Figure 4). Crappie achieved 100 mm in October and reached 130 mm TL by December. Striped bass grew to 100 mm by August and 170 mm TL by December. In June 2005, all age-0 species had average lengths less than 44 mm TL (see Figure 5). Both white perch and largemouth bass grew to 100 mm TL by September, and largemouth bass reached total lengths of 140 mm TL by November. Crappie reached 60 mm TL by September. Striped bass achieved total lengths of 100 mm by August, 240 mm by November, and 250 mm by December.

<u>Objective 1: Predation</u>

Collection Results. - To obtain white perch that had the potential to consume striped bass eggs and larvae, juveniles and adults were collected in the Roanoke River in May of 2004 and 2005, during the peak of the Roanoke River striped bass spawn. Striped bass egg densities were

Table 8. Calculated lengths of white perch at successive ages from Kerr Reservoir, Virginia.

		Mean Length Age (mm)								
Year Class	N	1	2	3	4	5	6	7	8	9
2004	44	101	--	--	--	--	--	--	--	--
2003	3	99	142	--	--	--	--	--	--	--
2002	97	105	145	170	--	--	--	--	--	--
2001	36	107	155	186	206	--	--	--	--	--
1999	4	119	170	205	228	248	--	--	--	--
1998	4	99	148	189	222	248	264	--	--	--
1997	0	--	--	--	--	--	--	--	--	--
1996	3	107	146	170	195	219	240	262	280	--
1995	1	124	158	183	213	236	260	270	287	303
Weighted Mean		104	149	175	208	239	254	264	281	303
Increments (mm)		104	45	26	33	31	15	10	17	22
% growth to the 9th year		34	15	9	11	10	5	3	6	7
Number		192	148	145	48	12	8	4	4	1

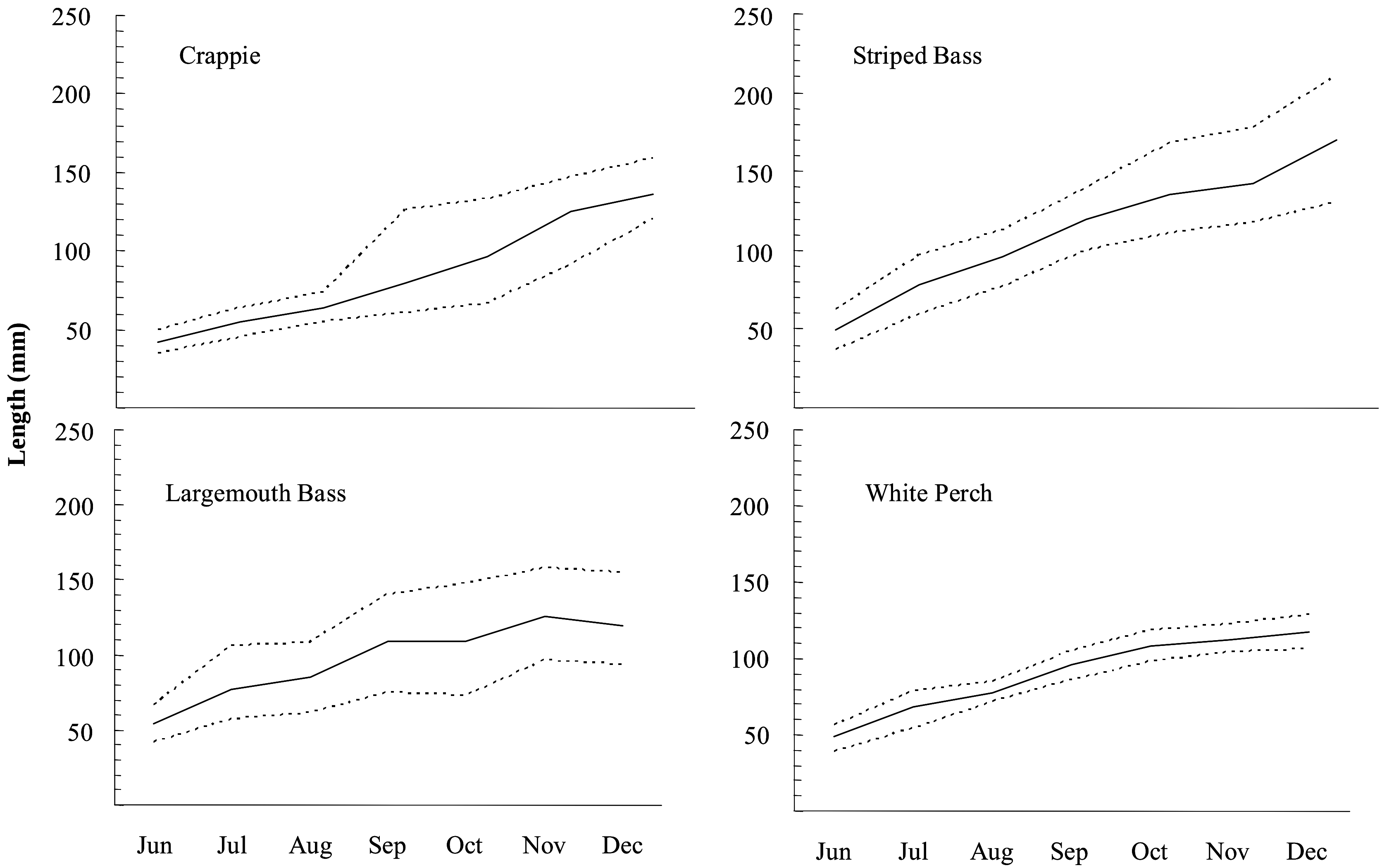

Figure 4. Monthly mean lengths of age-0 sportfish collected in 2004 from Kerr Reservoir, Virginia. Dotted lines indicate 10th and 90th percentiles.

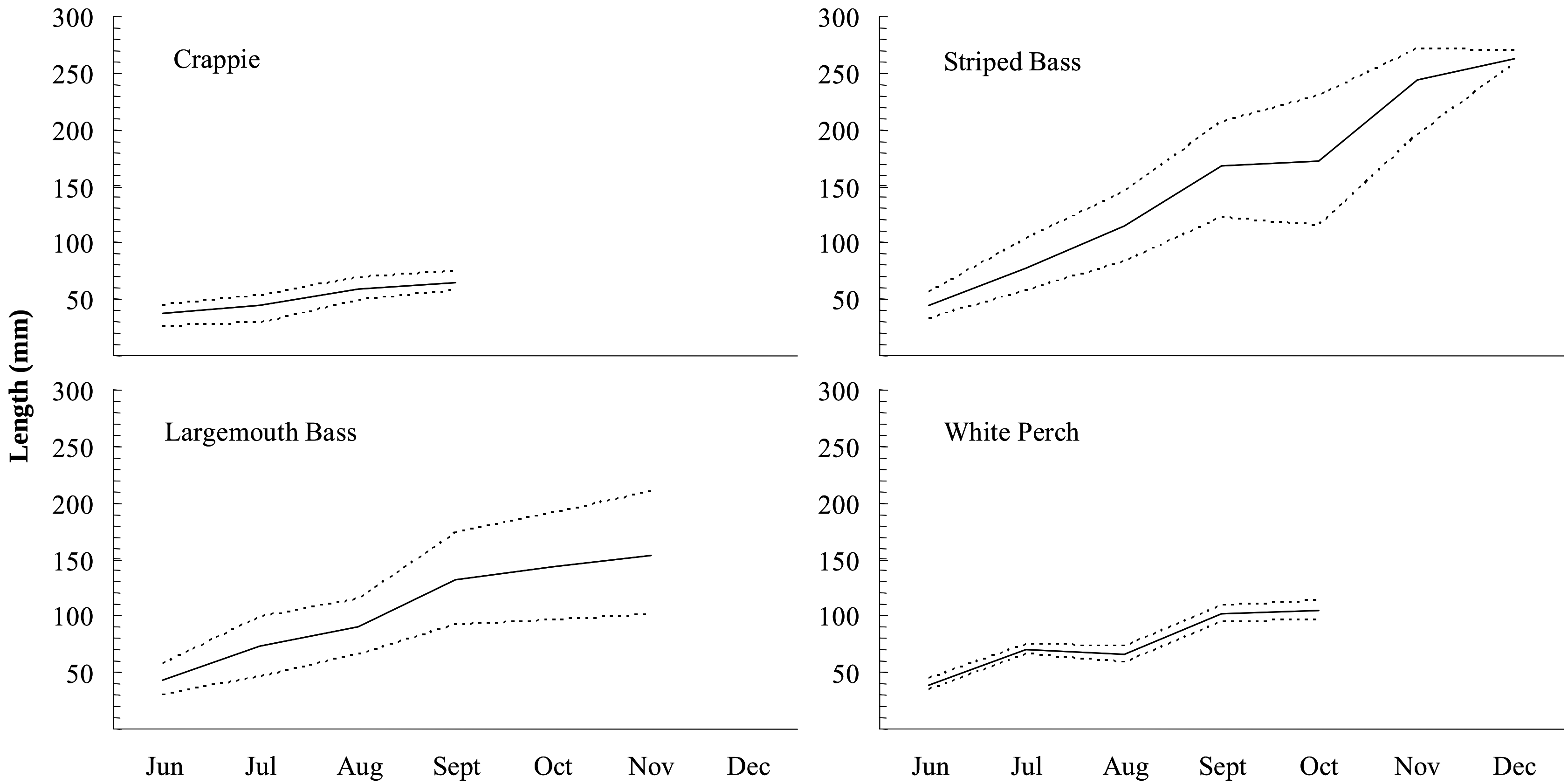

Figure 5. Monthly mean lengths of age-0 sportfish collected in 2005 from Kerr Reservoir, Virginia. Dotted lines indicate 10th and 90th percentiles.

not directly measured in the Roanoke River, so the peak spawn was determined qualitatively by visual observation of striped bass spawning activity and the presence of striped bass eggs in the water column of the river. In 2004, peak striped bass spawning occurred in a five-day period beginning on the 6th of May, when water temperatures reached approximately 18ºC, and concluded on the 10th of May. During this period, the majority of observed spawning activity was concentrated in a 33-km stretch of river between Clarkton Bridge and Watkins Bridge (Figure 2). From May 4th until May 28th, 733 adult white perch were collected throughout the Roanoke River. Daily site collection and relative abundances are shown in Table 9. Mean relative abundances (CPUE) of white perch were not significantly different among all sites except between 360 Bridge (60.5 fish/hour) and Staunton View (17.3 fish/hour) (ANOVA, Tukey-Kramer's HSD, df = 4, P = 0.04). White perch collected in May 2004 ranged in size from 72 to 330 mm TL (see Figure 6) with an average total length of 146 mm, and ranged in weight from 4 to 400 g with a mean weight of 47 g.

In 2005, the observed peak striped bass spawn was 7 days versus 5 days in 2004. The peak spawn began on the night of May 9th and continued through May 15th. Surface water temperatures during this period ranged from 17ºC to 22ºC. In 2005, white perch sampling began on May 2nd and concluded on May 27th. A total of 986 white perch were collected during this period. Table 10 details daily collection records and relative abundances of white perch collected throughout the Roanoke River. During May of 2005, mean CPUEs of white perch were higher at 360 Bridge (43 fish/hour) and Staunton View (44 fish/hour) versus Watkins Bridge (14 fish/hour) (ANOVA, Tukey-Kramer's HSD, df = 4, P < 0.05), but CPUEs were not statistically different versus any other site. In May 2005, white perch averaged (means for May)

Table 9. Electrofishing collection numbers and relative abundances (CPUE) of white perch obtained from the Roanoke River, Virginia during May of 2004.

	Clarkton		Ridgeway		Watkins		360 Bridge		Staunton View	
Date	N	CPUE (catch/hr.)	N	CPUE (catch/hr.)	N	CPUE (catch/hr.)	N	CPUE (catch/hr.)	N	CPUE (catch/hr.)
4-May-04			20	9.0						
5-May-04	34	21.1								
10-May-04	35	60.0			22	30.5	79	114.5		
11-May-04			19	27.4	32	41.0	25	31.9		
12-May-04					27	31.5				
13-May-04			31	27.6	58	67.6	27	35.0		
14-May-04	29	31.9								
17-May-04			9	9.1						
18-May-04									22	8.8
19-May-04									13	12.9
20-May-04									51	24.7
21-May-04									56	28.7
25-May-04									28	10.2
26-May-04									34	12.8
27-May-04									34	12.1
28-May-04									48	28.7
Total	98	31.6	79	15.7	139	43.2	131	58.4	286	16
Mean	33	37.7	20	18.3	35	42.7	44	60.5	36	17.3

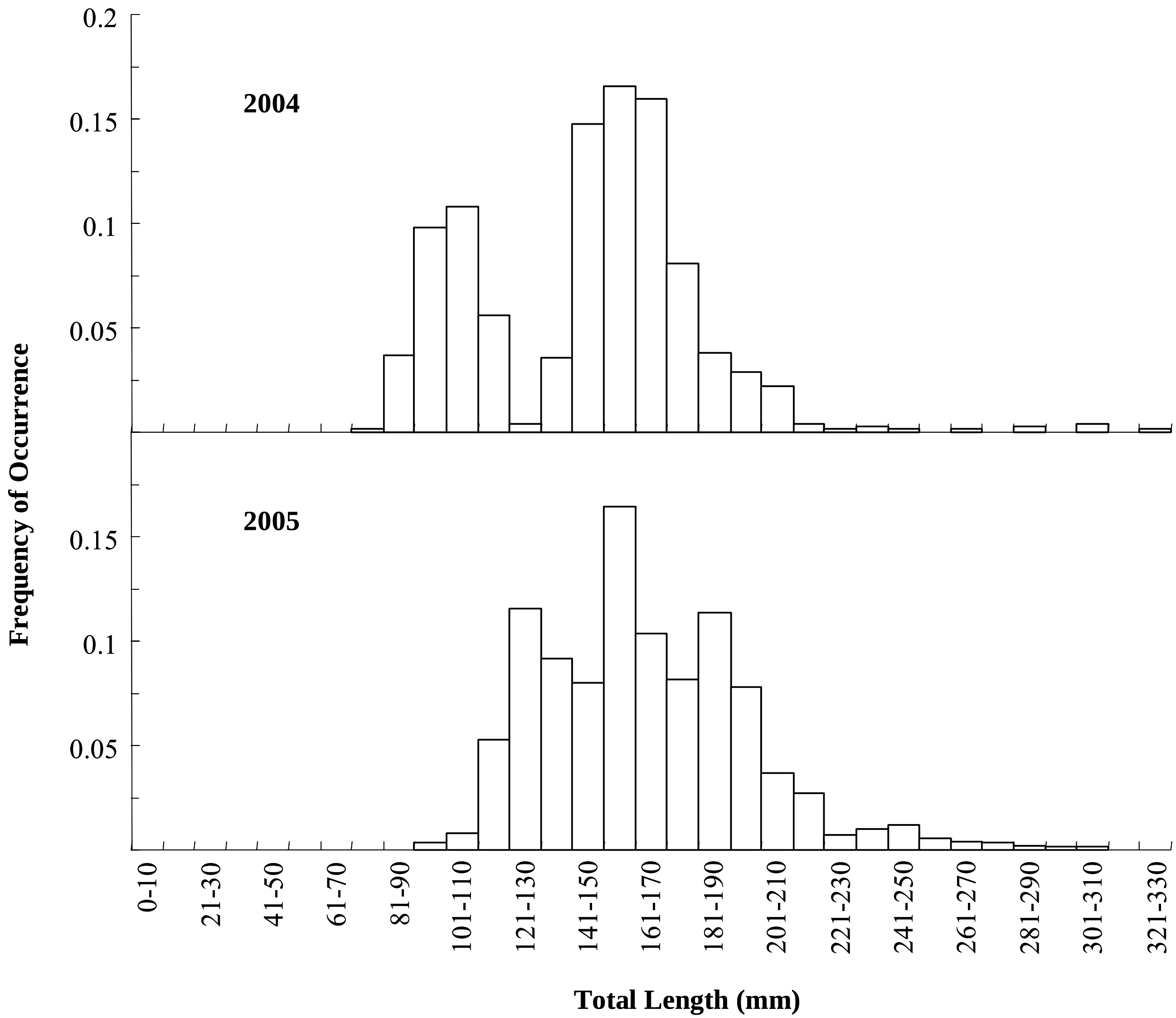

Figure 6. Length distribution of white perch collected throughout the Roanoke River, Virginia during May of 2004 and 2005.

Table 10. Electrofishing collection numbers and relative abundances (CPUE) of white perch obtained from the Roanoke River, Virginia during May of 2005.

	Clarkton		Ridgeway		Watkins		360 Bridge		Staunton View	
Date	N	CPUE (catch/hr.)	N	CPUE (catch/hr.)	N	CPUE (catch/hr.)	N	CPUE (catch/hr.)	N	CPUE (catch/hr.)
2-May-05			0	0.0						
3-May-05			19	19.6	16	7.3	40	91.2		
4-May-05	36	61.7			12	20.6				
5-May-05			26	23.4						
9-May-05			32	22.5	10	9.7				
10-May-05	14	16.7			12	6.9				
11-May-05			24	13.8	17	12.5	74	195.6		
12-May-05	39	26.3			26	19.1	73	190.4		
13-May-05			22	12.3	28	22.0	27	45.5		
14-May-05			31	34.8	18	14.0				
16-May-05					20	17.9	21	35.3		
17-May-05							23	19.2	36	42.0
18-May-05									36	34.6
19-May-05									40	43.7
23-May-05									34	25.4
24-May-05									32	34.2
25-May-05									67	114.7
26-May-05									39	29.5
27-May-05									43	28.4
Total	89	30.7	154	18.8	159	13.3	258	72.0	327	38.4
Mean	30	34.9	22	18	18	14.4	43	96.2	41	44.1

163 mm TL and 65 g, with respective ranges of 92 to 303 mm TL (Figure 6) and 12 to 410 g. In both years of the study, white perch obtained from the Roanoke River were primarily captured in slack, back-water areas near structure. Other habitats were sampled, but capture efficiency was decreased considerably in these areas due to high spring-time flows of the Roanoke River.

Additionally in 2004 and 2005, age-1 and older white perch were captured from June until December, during age-0 fish collection for Objective 2 (Competition) and adult sportfish collection for Objective 4 (Sportfish Utilization). A majority (86%) of adult white perch obtained in both years were collected by electrofishing along unvegetated, sandy shorelines and points in the upper end of Kerr Reservoir (above the Route 58 Bridge). The rest were collected from VDGIF fall gillnet samples. A total of 668 and 497 white perch of potentially piscivorous (> 80 mm TL) size were collected in 2004 and 2005, respectively in Kerr Reservoir (see Table 11). A small sample (N = 11) of white perch also was obtained in April of 2005 from VDGIF trapnet surveys. Stomach contents of white perch captured in the Roanoke River and Kerr Reservoir were analyzed for incidence and intensity of predation on sportfish eggs, larvae, and juveniles.

2004 Food Habits. - In May 2004, 77% of the 733 white perch stomachs collected contained prey items. White perch consumed primarily aquatic insects throughout the Roanoke River (Figure 7). Aquatic insects comprised greater than 89% by weight of perch stomach contents at all sites. Ephemeropterans (between 20% and 55% of diet by weight at all sites) and chironomids (between 21% and 70% of diet by weight at all sites) were the principal insect prey. A variety of other aquatic invertebrates (insects, crayfish, Asiatic clams, and zooplankton) were consumed but not in high percentages (< 11% of diet by weight for any taxon). Fish predation

Table 11. Number, size, and method of capture for white perch collected from the upper end of Kerr Reservoir, Virginia during the growing seasons of 2005 and 2005.

Year	Month	Number Collected	Mean Length (mm)	Range (mm)	Mean Weight (g)	Range (g)	Capture Method
2004	June	116	169	89-211	73.6	9-150	Seining
	July	155	147	85-230	51.2	9-205	Seining, Electrofishing
	August	67	147	117-191	44.7	20-112	Electrofishing
	September	111	148	120-213	45.8	22-146	Electrofishing
	October	153	172	121-227	53.5	21-159	Electrofishing, VDGIF Gillnets
	November	66	158	133-221	51.2	27-147	Electrofishing
	December	None	--	--	--	--	--
	2004 Total	668	154	85-230	54.3	9-205	--
2005	June	None	--	--	--	--	--
	July	55	157	100-203	60.9	17.8-122.5	Electrofishing
	August	101	168	119-248	72	21.9-235	Electrofishing
	September	69	157	129-226	54.3	25.1-176	Electrofishing
	October	237	161	120-255	59.5	20.3-264	Electrofishing, VDGIF Gillnets
	November	28	235	198-312	209	117.5-480	VDGIF Gillnets
	December	7	219	195-292	175.2	87-410	VDGIF Gillnets
	2005 Total	497	167	100-312	71.5	17.8-480	--

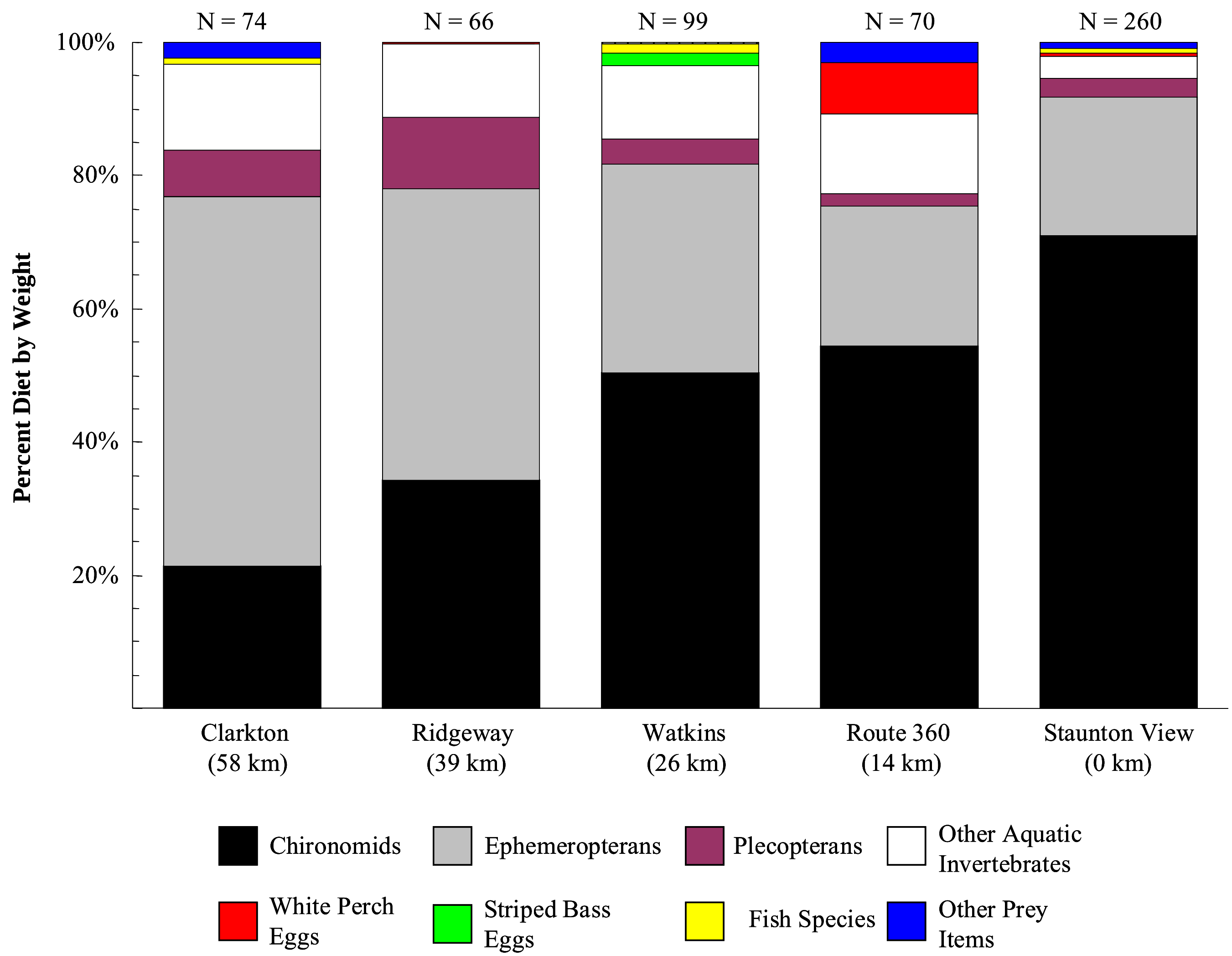

Figure 7. Diet composition of white perch collected throughout the Roanoke River, Virginia during May of 2004. N = number of perch that contained food and were used in diet analysis.

(cyprinid and percid species) was also observed but never exceeded 2% of diets by weight at any site. Larval fish were not observed in white perch diets.

Eggs of striped bass and white perch were found in white perch stomachs during May 2004. Egg predation occurred at all sites where white perch were collected, but the majority of eggs eaten were of white perch (Figure 7). Striped bass eggs were only observed in a total of 6 white perch stomachs collected throughout May. Striped bass egg predation was only observed at two locations, Ridgeway Farms and Watkins Bridge, and at very low frequency of occurrence (1.5% and 5%, respectively) (Figure 8). Observed frequency of occurrence of eggs in the diets of white perch at these sites was highest during May 10^{th} - 17^{th}, coinciding with the peak of striped bass spawning (Table 12). Striped bass and white perch eggs represented small proportions of white perch diets (< 2% and < 8% by weight, respectively, for any site) during May 2004 (Figure 7).

From June through November 2004, white perch fed primarily on aquatic invertebrates in Kerr Reservoir (Figure 9). Ephemeropterans, chaoborids, and chironomids were the predominant prey items (between 87% and 97% by weight) found in stomachs of white perch until October, after which greater than 70% of stomach contents by weight were comprised of ephemeropterans and zooplankton (copepods and cladocerans). Fish (clupeid, centrarchid, cyprinid and percid species) were infrequently found (FOO < 14% in all months) in the stomachs of white perch and never exceeded 12% of stomach contents by weight for any month (Figure 9). Other than age-0 centrarchids (*Lepomis* species), no juvenile sportfish were observed in the diets of white perch. White perch were piscivorous at all sizes greater than 80 mm, and fish predation was relatively consistent among all size classes of white perch greater than 80 mm (Figure 10).

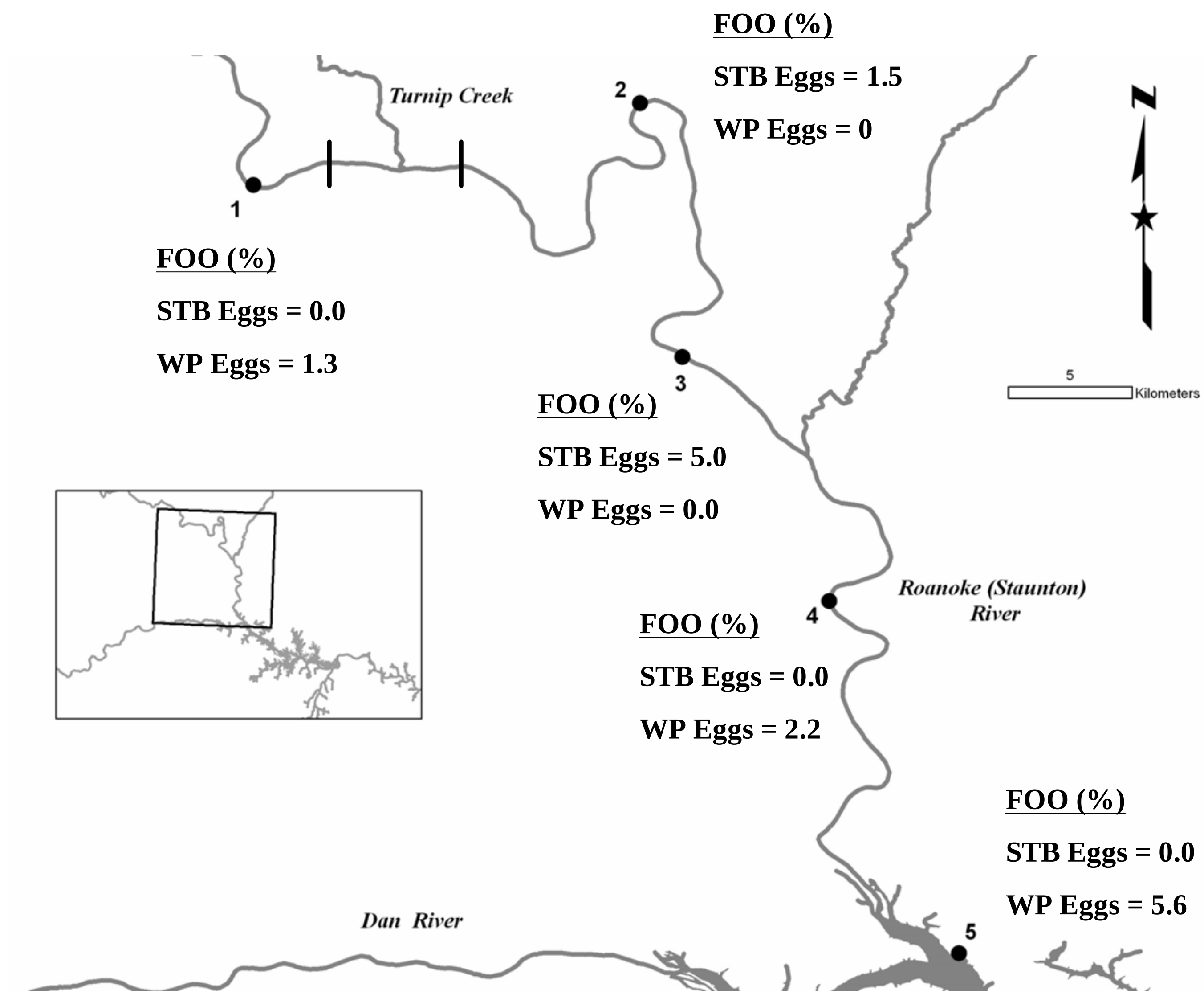

Figure 8. Spatial occurrence of egg predation by white perch throughout the Roanoke River, Virginia during May of 2004. FOO represents frequency of occurrence in diets of white perch, STB represents striped bass, and WP represents white perch.

Table 12. Frequency of occurrence (FOO) of striped bass eggs in the diets of white perch collected from two locations within the Roanoke River, Virginia during the peak of striped bass spawning activity in 2004.

	Ridgeway Farms		Watkins Bridge	
Date	N	FOO (%)	N	FOO (%)
4-May-04	12	0	-	-
10-May-04	-	-	15	0
11-May-04	16	0	28	3.6
12-May-04	-	-	22	9.1
13-May-04	31	3.2	36	5.6
17-May-04	8	0	-	-

- no white perch collected from site on specified date

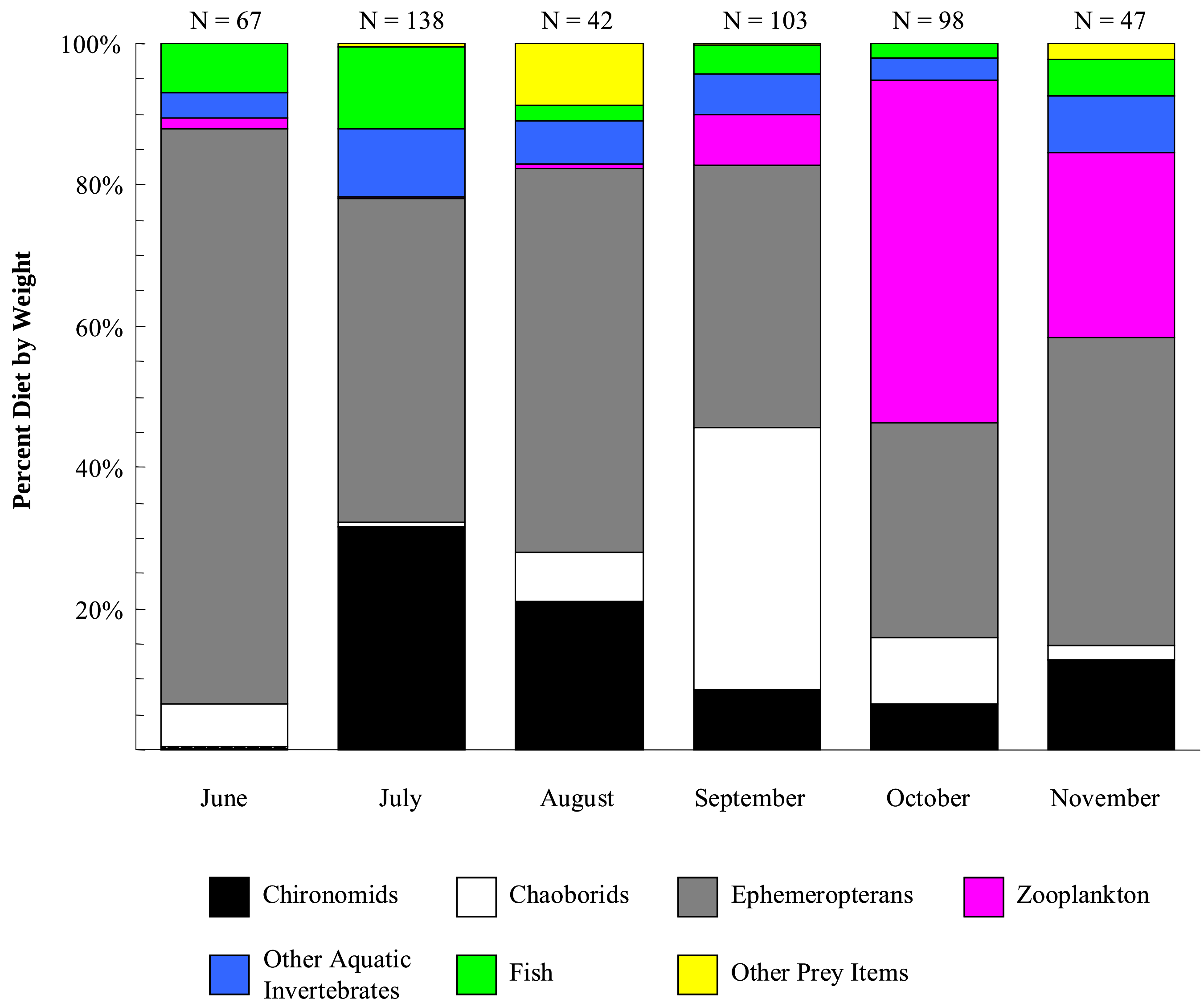

Figure 9. Temporal food habits of adult white perch collected from Kerr Reservoir, Virginia during 2004. N = number of perch that contained food and were used in diet analysis.

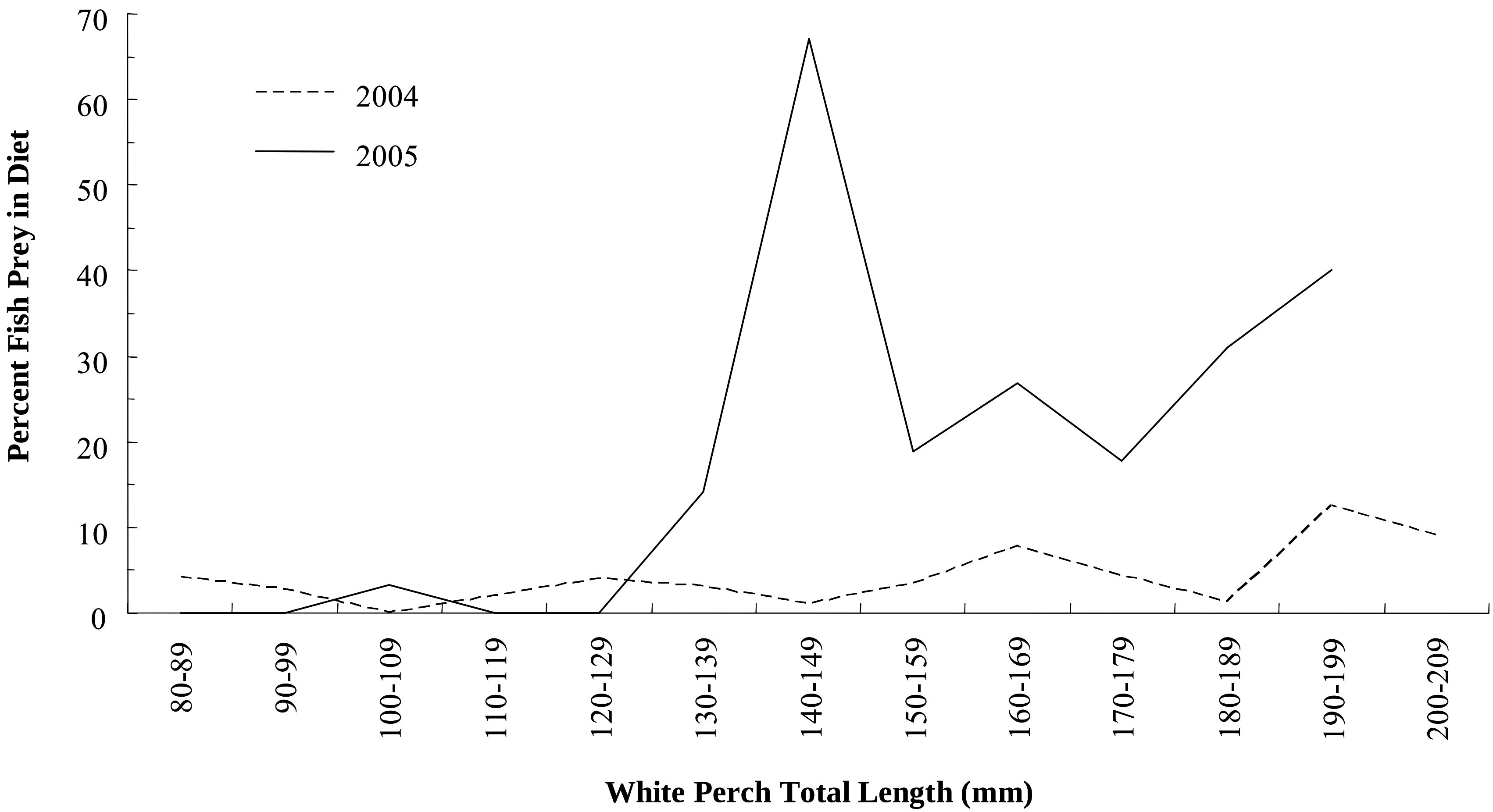

Figure 10. Percentage of fish by weight in diets of age-1 and older white perch collected from Kerr Reservoir, Virginia.

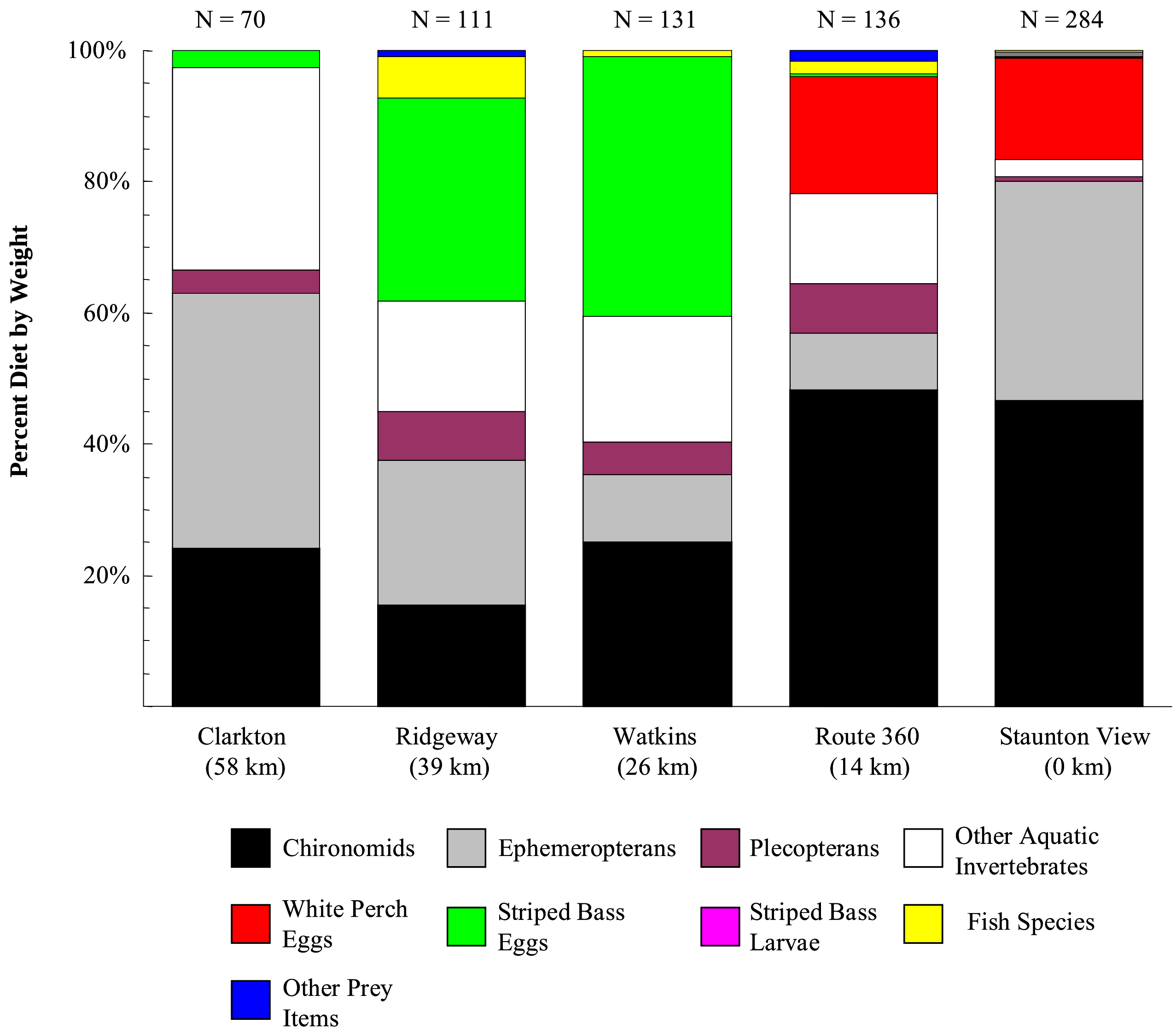

Figure 11. Diet composition of white perch collected throughout the Roanoke River, Virginia during May of 2005. N = number of perch that contained food and were used in diet analysis.

2005 Food Habits. - Of the 986 white perch collected in May of 2005, 74% had food in their stomachs. As in 2004, white perch collected in 2005 preyed predominately on aquatic insects, principally chironomids and ephemeropterans (Figure 11). Aquatic insects represented between 59% and 98% (by weight) of white perch diets at all sites. Percid, cyprinid, and clupeid species were found infrequently (FOO < 3% at any site) in the stomachs of white perch throughout May 2005, and were never a large portion of diet (< 2% by weight) at any site. Unlike 2004, larval fish predation by white perch was observed during May 2005. All larval predation found was of newly hatched striped bass, but it was only observed in the stomachs of white perch collected at three locations (Ridgeway Farms, Watkins Bridge, and Staunton View). Observed predation on striped bass larvae was low, and larvae never exceeded 1% of white perch diets by weight (Figure 11). Additionally, larvae were rarely found in stomachs of white perch (frequency of occurrence < 2% at all sites) (Figure 12).

The only other prey items regularly found in the diets of white perch collected in May of 2005 were striped bass and white perch eggs. Striped bass eggs were found in white perch stomach contents at all collection sites except Staunton View, but they were a relatively small proportion of perch diets at Clarkton Bridge (2% by weight) and 360 Bridge (< 1% by weight). However, striped bass eggs were a much larger proportion of white perch stomach contents at Ridgeway Farms (31% by weight) and Watkins Bridge (40% by weight), with approximately 40% (Ridgeway Farms) and 52% (Watkins Bridge) of the non-empty white perch stomachs containing striped bass eggs (Figure 12). Striped bass eggs were comprised larger proportions of white perch diets (up to 93% by weight) on days during the peak striped bass spawn (see Table 13), indicating that much of the egg predation occurred during this period. Additionally, striped bass eggs were eaten by a large percentage (frequency of occurrence as high as 100%) of white

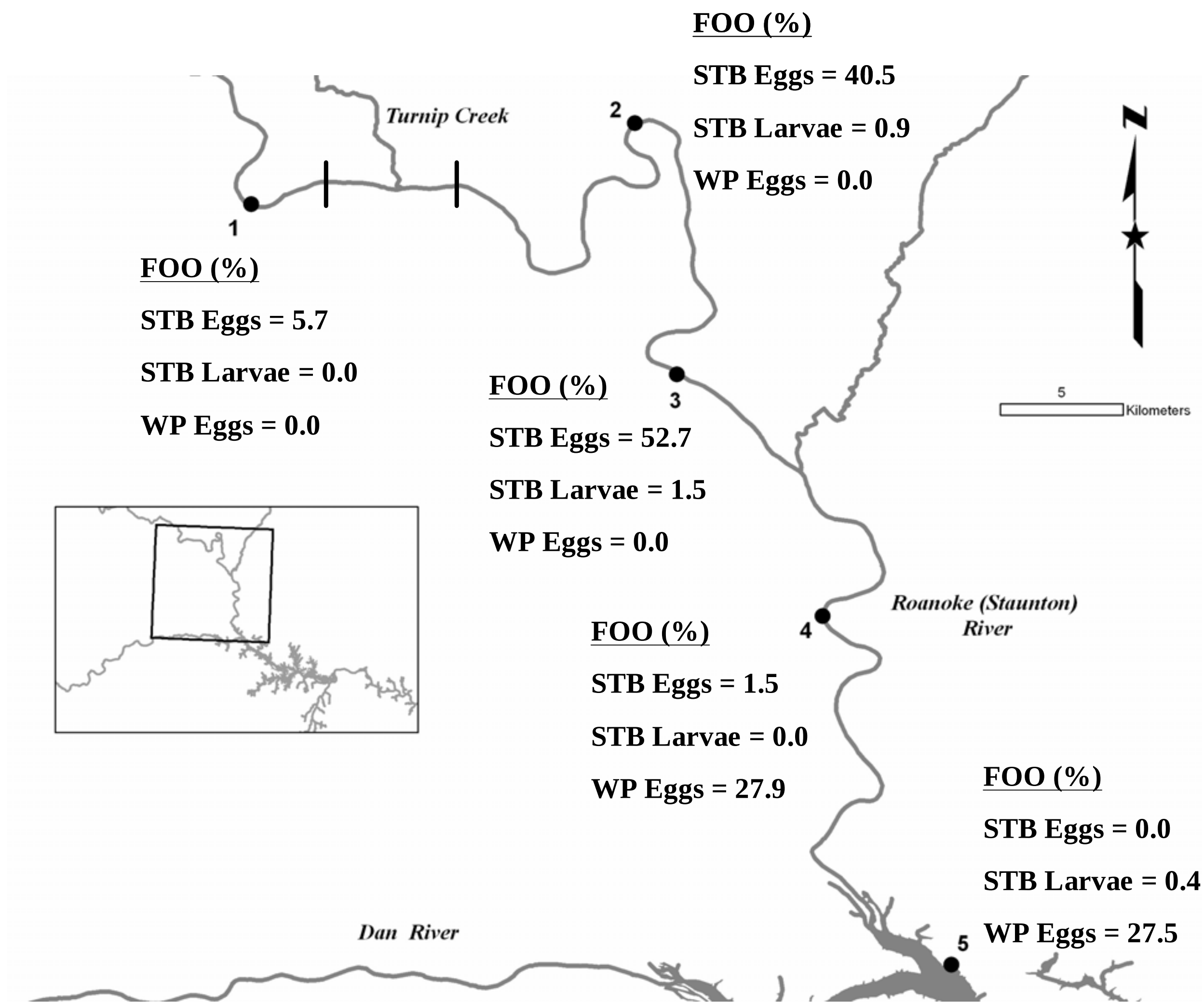

Figure 12. Spatial occurrence of egg and larval predation by white perch throughout the Roanoke River, Virginia during the entire month of May, 2005. FOO represents frequency of occurrence in diets of white perch, STB represents striped bass, and WP represents white perch.

Table 13. Daily accounts of striped bass egg predation by white perch collected from four locations within the Roanoke River, Virginia during the peak of striped bass spawning activity in 2005.

Site	Distance Upstream from Reservoir	Date	Striped Bass Spawning Activity	N	Striped Bass Eggs	
					FOO (%)	Percent Diet by Weight
Clarkton Bridge	58 (km)	4-May-05	Low	25	0	0
		10-May-05	Peak	12	17	2
		12-May-05	Peak	33	6	5
Ridgeway Farms	39 (km)	3-May-05	Low	16	0	0
		5-May-05	Low	8	0	0
		9-May-05	Low	22	0	0
		11-May-05	Peak	24	67	39
		13-May-05	Peak	21	100	91
		14-May-05	Peak	20	40	29
Watkins Bridge	26 (km)	3-May-05	Low	9	0	0
		4-May-05	Low	9	0	0
		9-May-05	Low	4	0	0
		10-May-05	Peak	10	50	50
		11-May-05	Peak	17	88	45
		12-May-05	Peak	25	88	60
		13-May-05	Peak	26	100	93
		14-May-05	Peak	13	8	1
		16-May-05	Low	18	0	0
360 Bridge Bridge	14 (km)	3-May-05	Low	13	0	0
		11-May-05	Peak	26	4	< 1
		12-May-05	Peak	35	3	2
		13-May-05	Peak	22	0	0
		16-May-05	Low	18	0	0
		17-May-05	Low	21	0	0

perch collected at Ridgeway Farms and Watkins Bridge on days during the peak spawn (Table 13). During the entire month of May, 10% of non-empty white perch stomachs (pooled from all sites) contained striped bass eggs (12% of stomach contents by weight), while during the peak striped bass spawn, 42% of all non-empty white perch contained eggs of striped bass (31% of stomach contents by weight). The differences in consumption of eggs during these two periods is further indication that striped bass egg predation by white perch was primarily concentrated during the peak spawning period. White perch eggs were found in white perch diets only at the two most downstream sites (360 Bridge and Staunton View), and were between 15% and 18% of stomach contents by weight.

White perch collected in the summer and fall months of 2005 fed on a variety of prey items (Figure 13). In June and July, ephemeropterans, fish (clupeids, centrarchids, and cyprinids), and chironomids constituted approximately 90% of white perch diets by weight, with ephemeropterans being the dominant prey item (40% by weight). During these months, fish (primarily clupeid species) represented 29% (July) and 35% (August) of white perch stomach contents by weight. From September through October, white perch fed mainly on chironomids, ephemeropterans, and cladocerans (Figure 13), with chironomids representing at least 52% of stomach contents by weight in both months. In September and October, fish comprised less than 12% of white perch stomach contents by weight. By November, fish (primarily clupeids) were the principal prey for adult white perch, constituting greater than 90% of stomach contents by weight for the months of November and December. As in 2004, the only species of juvenile sportfish found in stomach contents of adult white perch were age-0 lepomid species, but sunfishes were never more than 7% of stomach contents by weight in any month. In 2005, fish prey was found in the stomachs of white perch greater than 90 mm TL, but fish prey only

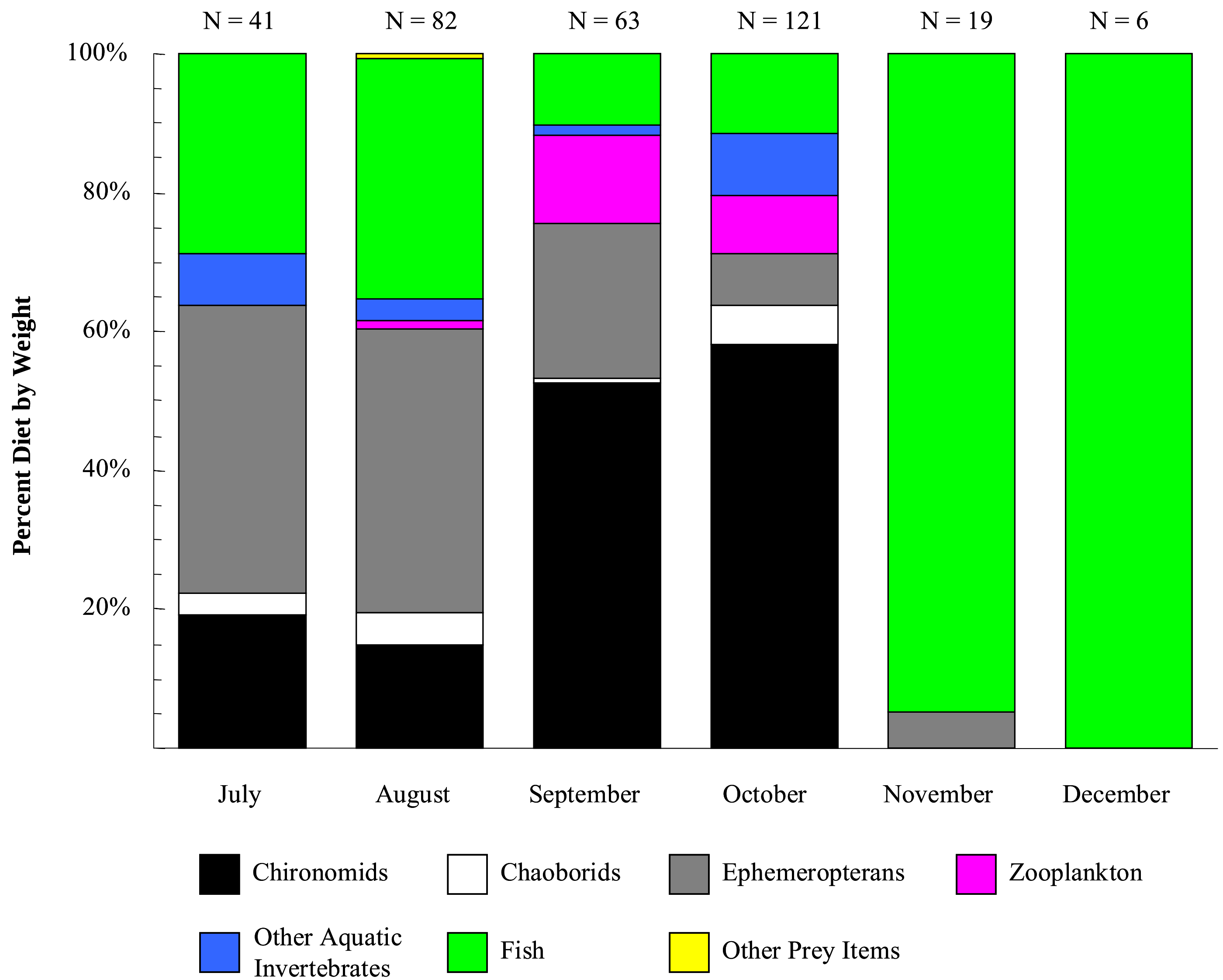

Figure 13. Temporal distribution of food habits of adult white perch collected from Kerr Reservoir, Virginia during 2005. N = number of perch that contained food and were used in diet analysis.

constituted considerable proportions of white perch diets (>20% by weight) in fish greater than 140 mm TL (see Figure 10).

Stomachs of white perch collected in April 2005 trapnet surveys contained crappie eggs. Of the 11 perch collected during this time, five had prey items in their stomach, and two of thesecontained the eggs of *Pomoxis* species. A total of 46 crappie eggs were found in the stomachs of the two white perch.

Estimates of Total Egg Predation. - Projected population sizes of white perch required to consume given percentages of striped bass eggs spawned during the peak spawn of 2005 varied with egg production estimates and white perch consumption rates (Table 14). In my analysis, the average (64.5 g) white perch ate 520 striped bass eggs/day (58% diet by weight) for eight days. In the worst-case scenario (lowest egg production and highest consumption), large numbers of white perch (> 68,724 perch) would be needed throughout the Roanoke River to consume at least 50% of the striped bass eggs. Egg predation was only observed in a 44-km stretch of river from Clarkston Bridge (just above the mean striped bass spawning location) to 360 Bridge, so these populations would have to be concentrated in this section of River. This translates to totals of greater than 1,561 white perch needed per kilometer in this section of the Roanoke River to consume at least 50% of the striped bass eggs.

In average circumstances (egg production and consumption), predicted population sizes of white perch were approximately five times larger than the worst-case scenarios (Table 14). At least 295,344 (6,713 perch/km) white perch would be required to consume at least 50% of the total number of striped bass eggs spawned during the peak spawning period.

Table 14. Projected population sizes of white perch required to consume various percentages of striped bass (STB) eggs spawned in the Roanoke River, Virginia during the peak spawning period of May, 2005. Eggs were assumed to be in the river for eight consecutive days. Two consumption rates were used.

Total # of STB Eggs Produced	# STB Eggs Spawned During Peak	Percentage of Eggs	White Perch Daily Consumption ($g*g^{-1}*d^{-1}$)	# of STB Eggs Consumed Daily	# of White Perch Needed to Consume Percentage of Eggs	# of White Perch Needed per River km
1,509,533,243	1,207,626,594	10%	0.104	520	29,064	661
(low estimate)			0.219	1099	13,745	313
		50%	0.104	520	145,316	3,303
			0.219	1099	68,725	1,562
		90%	0.104	520	261,568	5,945
			0.219	1099	123,706	2,812
3,068,024,698	2,454,419,758	10%	0.104	520	59,069	1,343
(mean estimate)			0.219	1099	27,936	635
		50%	0.104	520	295,344	6,713
			0.219	1099	138,680	3,152
		90%	0.104	520	531,619	12,083
			0.219	1099	251,424	5,715

Objective 2: Trophic Competition

Collection Results. - Age-0 specimens of crappies, largemouth bass, and striped bass as well as white perch of all sizes were collected in the growing seasons of two successive years to describe food habits and determine the potential for trophic competition. In both years, fish were collected by seining and electrofishing unvegetated shorelines in the upper end of Kerr Reservoir. Experimental gillnets and trapnets were unproductive for age-0 sportfish; no fishwere collected with these methods. However, additional samples of age-0 striped bass and adult white perch were obtained from VDGIF fall gillnet samples.

In 2004, collection began on June 15th and concluded on December 17th. During this period, a total of 2107 age-0 fish and 668 adult white perch were collected (Table 15). Of the age-0 fish collected, 43% were white perch, 25% were largemouth bass, 23% were striped bass, and the remaining 9% were crappie.

As in 2004, fish collection in 2005 began in June (7th) and concluded by December (8th). A total of 1646 age-0 fish were collected, with the majority (94%) being striped bass and largemouth bass (Table 15). Additionally, 497 adult white perch were collected during this period.

Age-0 Crappie Food Habits. - In 2004, adequate samples to quantify diets (determined from cumulative prey species curves) of age-0 crappies were collected for all months of the growing season except August. Throughout the 2004 growing season, juvenile crappies fed heavily on aquatic insects (chironomids, ephemeropterans, and chaoborids) and zooplankton (copepods and cladocerans), with these prey items representing greater than 93% of crappie stomach contents by weight for every month (Figure 14). Composition of aquatic insects in the diet varied from month to month, dependent on available prey items. From June through

Table 15. Collection numbers of juvenile sportfish obtained from Kerr Reservoir, Virginia. Fish were collected by seining (S) boat electrofishing (E) and from VDGIF fall gillnet samples (V).

Year	Month	Collection Method	Age-0 Crappie	Age-0 Largemouth Bass	Age-0 Striped Bass	Age-0 White Perch
2004	Jun	S	43	116	56	42
	Jul	S, E	15	109	71	136
	Aug	E	4	73	67	177
	Sept	E	19	68	71	119
	Oct	E,V	50	81	138	241
	Nov	E,V	40	59	62	157
	Dec	E,V	31	14	15	33
	Total		202	520	480	905
2005	Jun	S	16	177	177	2
	Jul	S, E	28	155	172	4
	Aug	E	14	188	185	3
	Sept	E	4	116	102	16
	Oct	E, V	----	93	78	20
	Nov	E, V	----	19	74	----
	Dec	E, V	----	----	3	----
	Total		62	748	791	45

---- no fish captured in respective month

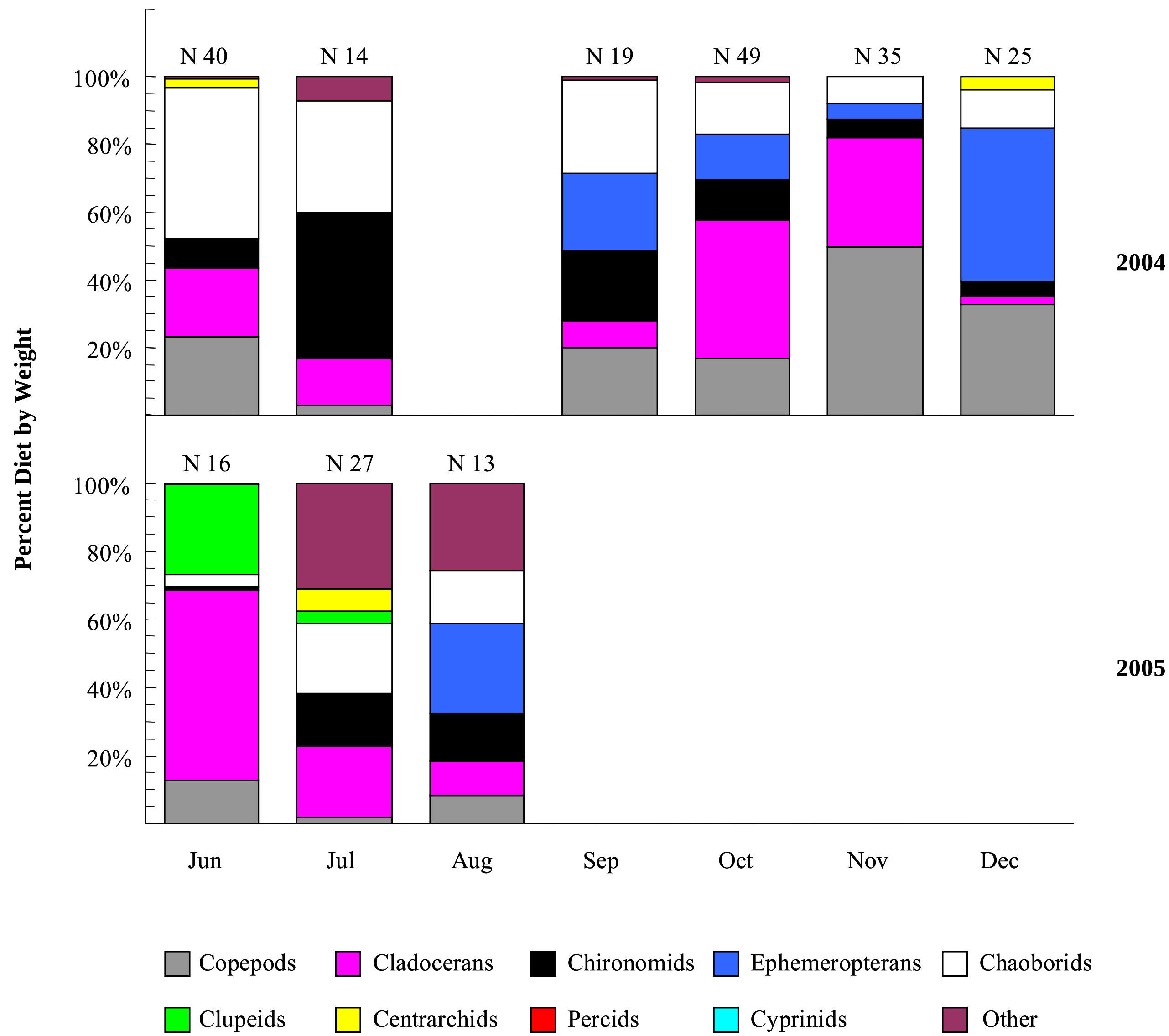

Figure 14. Temporal patterns in food habits of age-0 crappie collected in 2004 and 2005 from Kerr Reservoir, Virginia. N = number of crappie that contained food and were used in diet analysis.

September, chaoborids were the principal aquatic insect consumed (between 27% and 45% of stomach contents by weight), after which all insect groups were equally represented in crappie diets (Figure 14). Zooplankton consumption also varied from month to month (Figure 14), but was a larger percentage (between 58% and 82% by weight) of crappie diets in the months of October and November. Fish prey (lepomid species) also were found in the stomach contents of age-0 crappies, but only in the months of June and December. During these months *Lepomis* prey represented small proportions of crappie diets (< 5% by weight).

In 2005, food habits of age-0 crappies were only described in the summer months of the growing season (June through August). During this time period, juvenile crappies preyed primarily on zooplankton (copepods and cladocerans) and aquatic insects (amphipods, dipterans, corixids, ephemeropterans, chaoborids, and trichopterans), with both categories combined comprising greater than 74% of stomach contents by weight (Figure 14). Unlike 2004, fish species (primarily age-0 clupeids) were found in the stomach contents of age-0 crappies collected in 2005, but were only a considerable proportion (26% by weight) in the month of June (Figure 14). The smallest piscivorous crappie was 31 mm TL.

Age-0 Largemouth Bass Food Habits. - Food habits of age-0 largemouth bass were quantified throughout the growing seasons of 2004 and 2005. In 2004, juvenile largemouth bass fed on a mixture of aquatic invertebrates (insects and zooplankton) and fish (centrarchids, clupeids, cyprinids, and percids) during the growing season (Figure 15). Zooplankton (copepods and cladocerans) was the largest proportion of juvenile diets in the months of June (43% of stomach contents by weight) and October (33% of stomach contents by weight). During June, all largemouth collected were less than 60 mm. In all other months, age-0 fishes (primarily centrarchids and clupeids) were the dominant prey consumed by juvenile largemouth bass

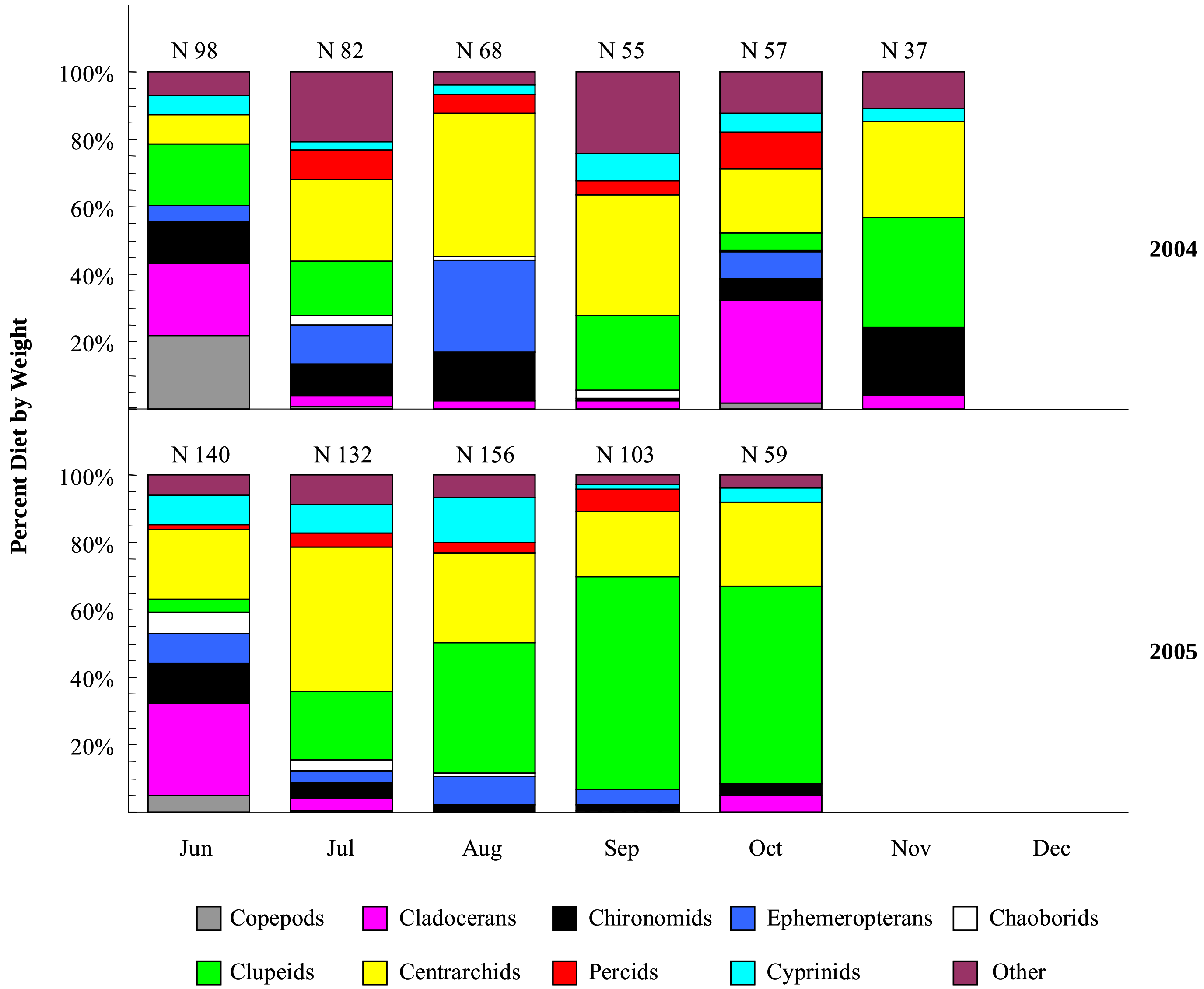

Figure 15. Temporal patterns in food habits of age-0 largemouth bass collected in 2004 and 2005 from Kerr Reservoir, Virginia. N = number of largemouth bass that contained food and were used in diet analysis.

(Figure 15), representing at least 41% of diets by weight. Fish consumption remained relatively consistent for the remaining months of the growing season, except for September and November when fish prey represented greater than 65% of stomach contents by weight. Percids and cyprinids were the only other fish prey found in stomachs of age-0 largemouth bass.

In 2005, food habits of age-0 largemouth bass displayed temporal shifts in prey types. Although juveniles were piscivorous in all months, largemouth bass stomach contents contained an assortment of fish (35% of stomach contents by weight), aquatic insects (33% of stomach contents by weight), and zooplankton (32% of stomach contents by weight) in June of 2005 (Figure 15). In July, juvenile largemouth bass fed almost exclusively on age-0 fish species (centrarchids, clupeids, cyprinids, percids), which represented approximately 75% of juvenile stomach contents by weight (Figure 15). In this period when largemouth diets shifted to fish, the majority of juveniles were approaching 80 mm in length (see Figure 5). From August through October, greater than 82% of largemouth stomach contents by weight were composed of fish, with fish consumption reaching its height (approximately 90% of stomach contents by weight) in September. Composition of fish consumed by age-0 largemouth bass also changed during the 2005 growing season. In the early months of the growing season, age-0 centrarchids were the dominant fish prey consumed (Figure 15), but by September approximately 63% (by weight) of largemouth bass diets were composed of age-0 clupeids.

In both years of this study, age-0 largemouth bass displayed a size-dependent shift in food habits during the growing season (Figure 16). In 2004, stomach contents of juvenile largemouth <100 mm were composed of large proportions (greater than 40% by weight) of aquatic invertebrates (aquatic insects and zooplankton). However, aquatic insects were considerably lower proportions of stomach contents of juveniles greater than 100 mm and were

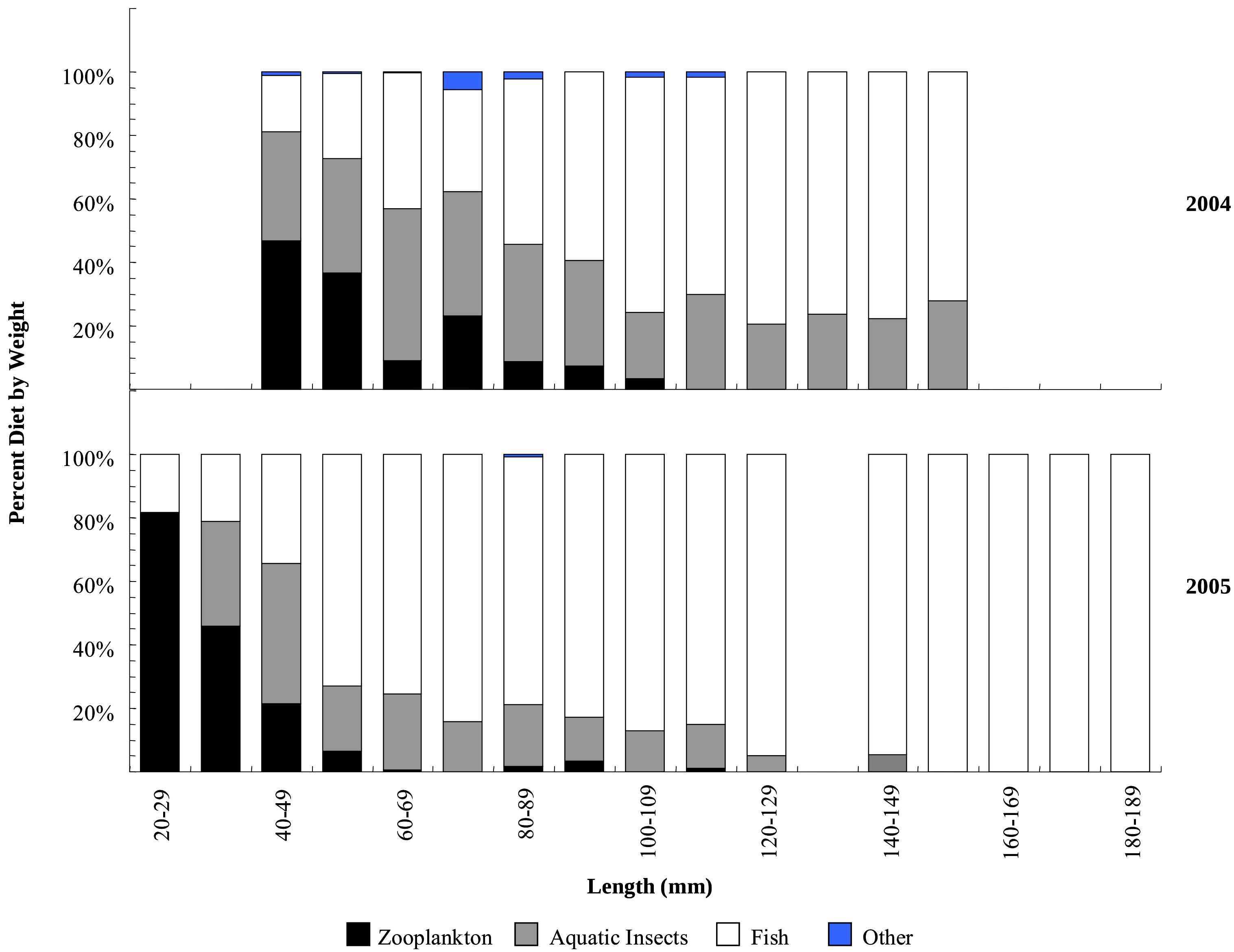

Figure 16. Size-dependent food habits of age-0 largemouth bass collected in 2004 and 2005 from Kerr Reservoir, Virginia.

replaced by fish prey (Figure 16). In 2005, this same shift occurred in age-0 largemouth bass food habits, but at a much smaller size (approximately 50 mm; Figure 16).

Age-0 Striped Bass Food Habits. - In both 2004 and 2005, age-0 striped bass displayed temporal shifts in consumed prey items during the growing seasons (Figure 17). In June of 2004, striped bass (mean length of 50 mm) fed on a variety of diet items, including fish (clupeids and centrarchids), zooplankton (copepods and cladocerans), and aquatic insects (chaoborids and chironomids) (Figure 17). Age-0 fishes represented the largest proportion of striped bass stomach contents in June (approximately 52% by weight), while 46% of stomach contents by weight were comprised of zooplankton and aquatic insects. Fish and aquatic insects, but not zooplankton, continued to be significant proportions of striped bass diets until the end of August (Figure 17). After August, striped bass fed primarily on age-0 fishes, which represented between 62% and 75% of juvenile stomach contents by weight for the rest of the growing season. This diet shift to fish prey after August occurred when striped bass were approaching 120 mm (see Figure 4). Of the fish consumed by striped bass, age-0 clupeids were the dominant prey type (Figure 17), representing greater than 62% of stomach contents by weight for all months after August.

A similar trend in food habits of age-0 striped bass was exhibited during 2005, but it occurred much earlier in the growing season (Figure 17). In June of 2005, striped bass ate an assortment of prey types, distributed rather evenly amounts of zooplankton, aquatic insects, and fish. By July, age-0 fishes (mainly clupeids) became the principal prey item, representing greater than 80% of striped bass diets by weight for each month after June (Figure 17).

Size-dependent shifts in food habits of age-0 striped bass were exhibited in both 2004 and 2005. In 2004, age-0 striped bass fed on a mixture of aquatic insects, zooplankton, and fish

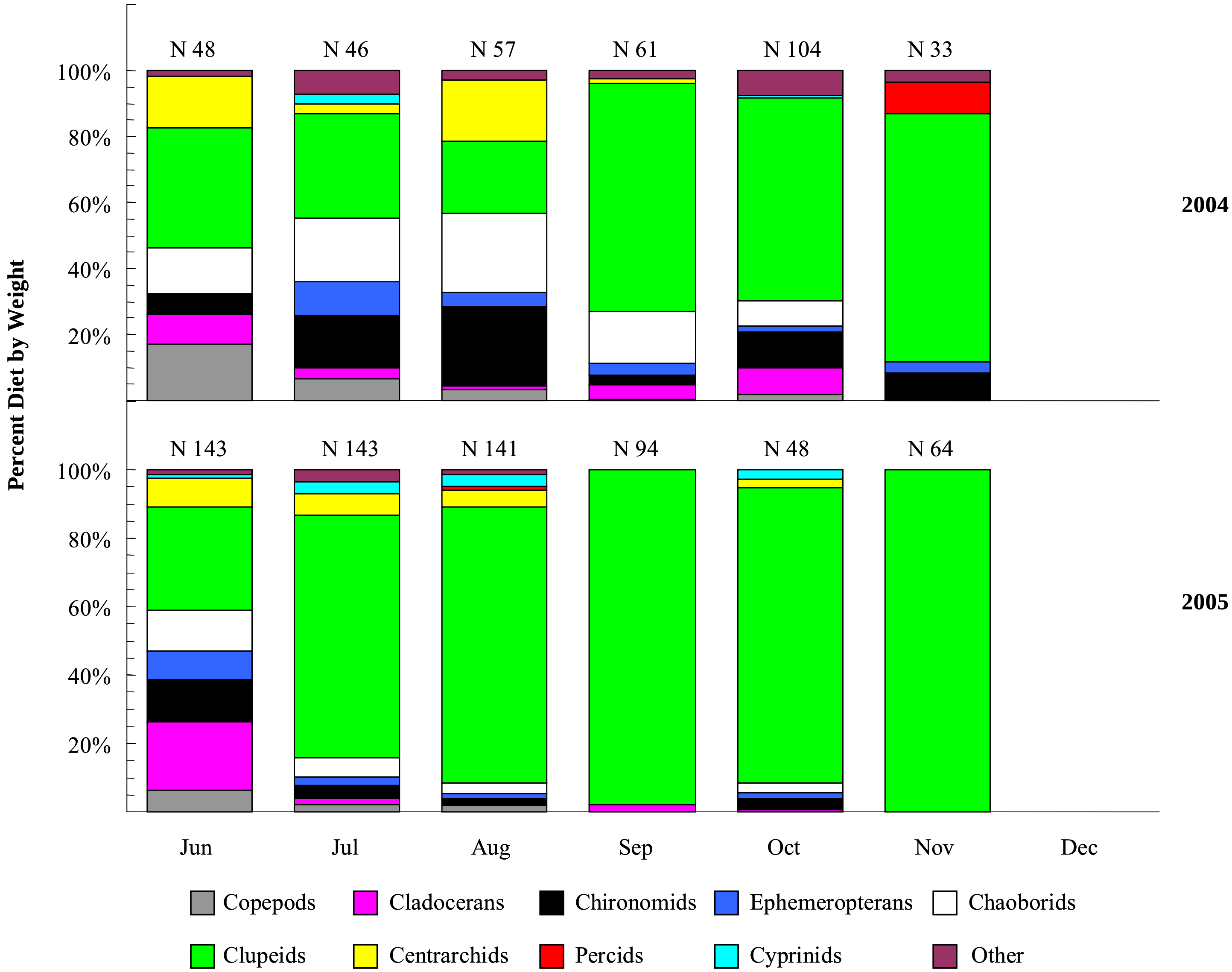

Figure 17. Temporal patterns in food habits of age-0 striped bass collected in 2004 and 2005 from Kerr Reservoir, Virginia. N = number of striped bass that contained food and were used in diet analysis.

species at sizes less than 130 mm (Figure 18). Juvenile striped bass >130 mm preyed primarily (greater the 80% of stomach contents by weight) on fishes (mostly age-0 clupeids). In 2005, the same shift occurred, but at a much smaller size than in 2004 (Figure 18). Greater than 83% of stomach contents by weight were composed of fish in striped bass larger than 70 mm, while fish smaller than 70 mm consumed mixtures of fish and aquatic invertebrates (Figure 18). In 2005, striped bass were able to become piscivorous at smaller sizes because of the high abundance of the smaller clupeid species (threadfin shad) as opposed to the larger, faster growing clupeid species (gizzard shad) in 2004. Additionally, juvenile striped bass collected in 2005 became completely piscivorous at a length of 160 mm and grew to larger average sizes than striped bass collected in 2004 (see Figures 4 and 5).

Age-0 White Perch Food Habits. - Diets of age-0 white perch were quantified for all months of the growing season in 2004 but, due to low sample sizes, only the months of September and October in 2005. In both years, aquatic invertebrates were the only prey items consumed by age-0 white perch (Figure 19). In 2004, composition of invertebrates found in perch stomachs varied from month to month (Figure 19). Cladocerans were the primary prey item consumed in the months of June, October, and November, representing 43%, 50%, and 61% of stomach contents by weight in respective months. In every other month, chaoborids, chironomids, and ephemeropterans were the principal prey items found in diets of age-0 white perch (Figure 19).

White perch collected in September and October of 2005 fed primarily on chironomids (greater than 62% of stomach contents by weight in each month) (Figure 19). In September but not October, considerable portions (approximately 31%) of cladocerans also were found in the stomach contents of age-0 white perch. The only other prey items consumed by white perch

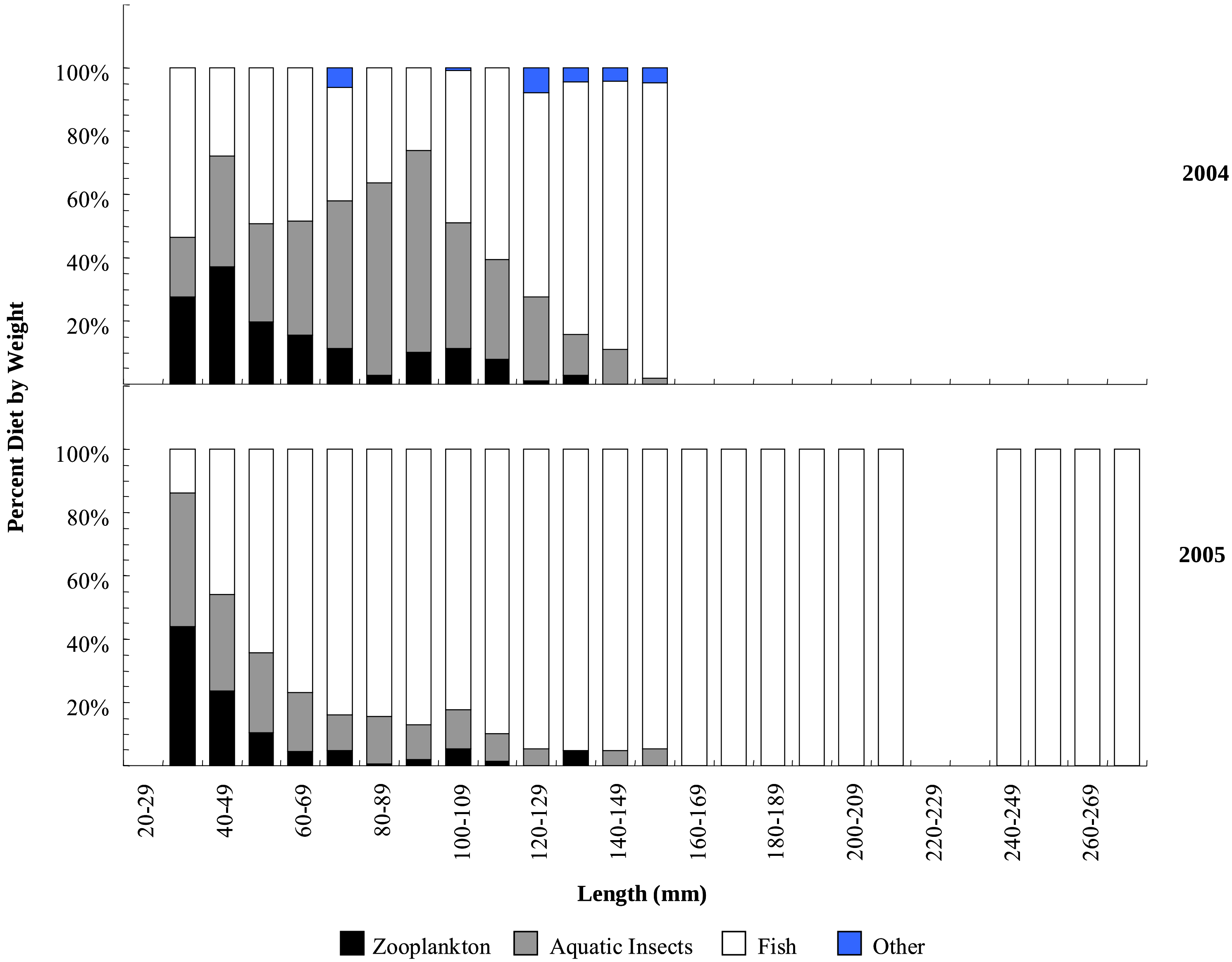

Figure 18. Size-dependent food habits of age-0 striped bass collected in 2004 and 2005 from Kerr Reservoir, Virginia.

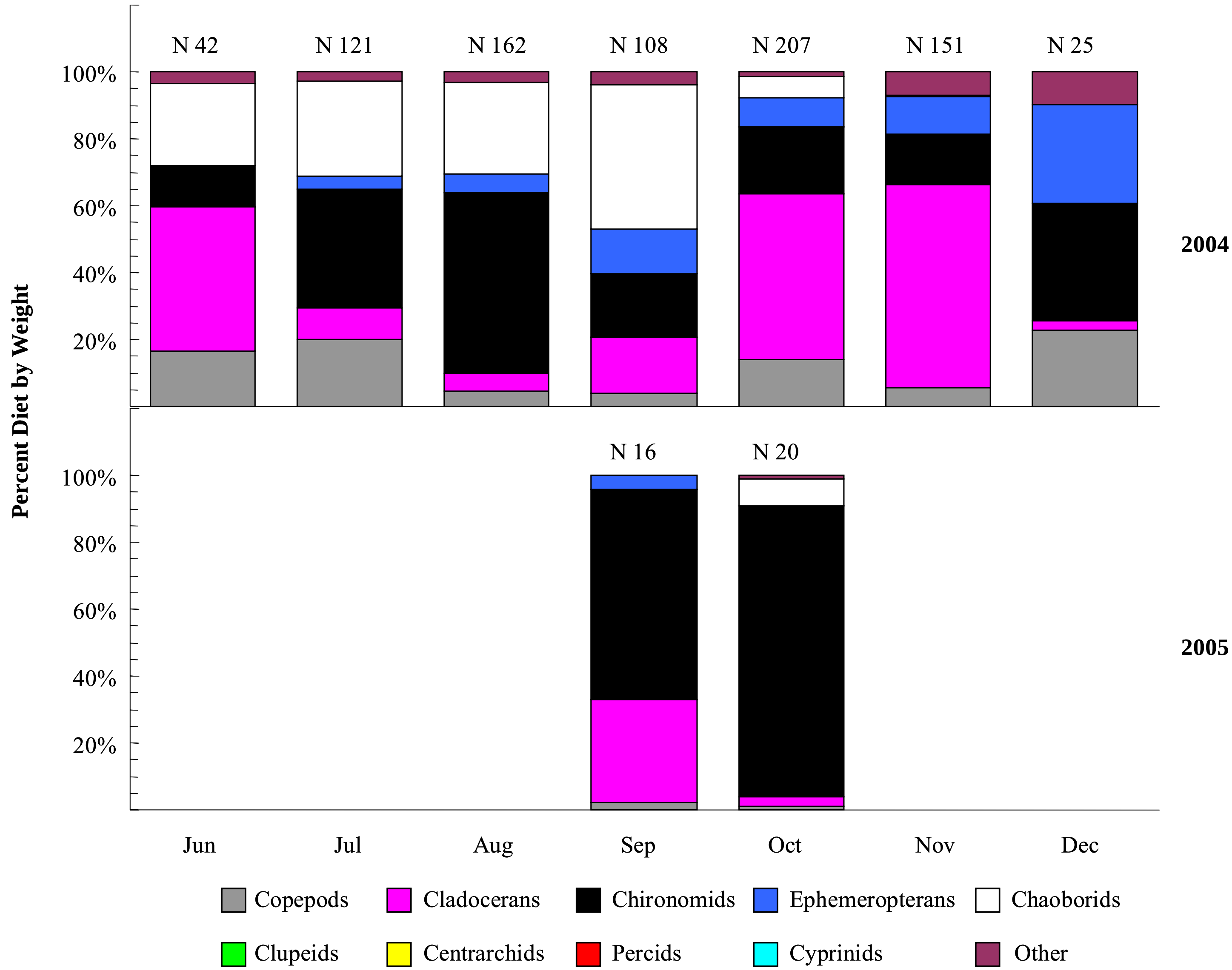

Figure 19. Temporal patterns in food habits of age-0 white perch collected in 2004 and 2005 from Kerr Reservoir, Virginia. N = number of perch that contained food and were used in diet analysis.

collected in 2005 were copepods, chaoborids, ephemeropterans, and odonates, but these were never large percentages of diets (Figure 19). White perch grew relatively slow compared to striped bass (see Figures 4 and 5), and by fall (end of the growing season) of both years white perch were only approaching 100 mm.

Diet Overlap. - Diet composition of age-0 sportfishes versus both juvenile and adult white perch were compared monthly and by length intervals in both years of this study to determine potential for trophic competition. Additionally, adult white perch diets were compared annually to diets of adult sportfish for both 2004 and 2005. To make overlap estimates realistic in terms of potential competition, a variety of prey categories were used in comparison between white perch and sportfish (Table 16). A prey category was included in overlap analysis if that category represented at least 5% (by weight) of the stomach contents of one or more species in at least one month during collections.

In 2004, trophic overlap values between age-0 sportfishes versus age-0 white perch were the highest in early months of the growing season (Table 17). During this time, all age-0 species were dependent on aquatic insects and zooplankton for much of their nutrition. Although overlap values were highest for all species in the summer months, significant overlap (>0.6) with white perch was only found for age-0 crappies in the months of June, July, and September. In these months, the diets of crappie and white perch were almost completely composed of aquatic invertebrates, while largemouth bass and striped bass had considerable proportions of fish in their diets. Overlap between crappies and age-0 white perch declined somewhat for the remainder of the growing season (Table 17). During this time, age-0 crappies consumed small cladocerans species (e.g. *Bosmina*), whereas age-0 white perch fed primarily on larger cladocerans species (e.g. *Daphnia*). Diets of adult white perch displayed significant overlap with

Table 16. Prey categories used in all Schoener's Overlap comparisions between white perch x age-0 and adult sportfish from Kerr Reservoir, Virginia. Prey categories are listed by prey type.

Fish	Zooplankton	Aquatic Insects	Other Aquatic Invertebrates	Other
Alosa species	Bosmina	Ceratopogonidae	Amphipoda	Organic debris
Centrarchid species	Calanoid Copepods	Chaoboridae	Corbicula	Terrestrail Insect
Dorosoma species	Daphnia	Chironomidae	Decapoda	
Gambusia	Ostracods	Corixidae	Hirudinea	
Ictalurid species	Parasitic Copepods	Culicidae	Hydracarina	
Notropis species		Dytiscidae		
Percid species		Elmidae		
		Ephemeroptera		
		Hemiptera		
		Hymenoptera		
		Odonata		
		Plecoptera		
		Tabanidae		
		Tipulidae		
		Trichoptera		

Table 17. Diet overlap for age-0 sportfishes versus white perch collected in 2004 from Kerr Reservoir, Virginia.

	Age-0 White Perch			Adult White Perch		
Month	Crappie	Largemouth Bass	Striped Bass	Crappie	Largemouth Bass	Striped Bass
Jun	**0.71**	0.52	0.46	0.08	0.10	0.09
Jul	**0.77**	0.22	0.48	0.31	0.32	0.38
Aug	----	0.24	0.57	0.43	0.28	0.31
Sep	**0.71**	0.15	0.27	**0.68**	0.23	0.29
Oct	0.46	0.48	0.30	0.46	0.49	0.28
Nov	0.15	0.16	0.13	0.17	0.17	0.13
Dec	0.57	----	----	----	----	----

---- Minimum number of stomachs to adequately characterizes food habits not acquired age-0 crappies, but only in September. Overlap was the highest in this month due to large proportions of ephemeropterans and chaoborids present in the diets of each species. Overlap between adult white perch and all other species was relatively low throughout the growing season (Table 17).

In 2005, I was unable to capture age-0 white perch consistently throughout the growing season, and adequate numbers of perch stomachs to describe diets were only collected in September and October. For this reason, food habits of age-0 sportfishes collected in 2005 were compared separately to diets of white perch collected in both years of this study. Overlap values between age-0 sportfishes collected in 2005 and age-0 white perch collected in 2004 were highest in the June (Table 18), the month when all juveniles fed heavily on aquatic invertebrates. Significant overlap was only observed between age-0 crappies and age-0 white perch, and only for the diets described in the months of June. Overlap values between all age-0 sportfish collected in 2005 and adult white perch collected in 2004 were relatively low in months when diets were described (Table 18). From the white perch collected in 2005, significant diet overlap (0.79) was only observed with age-0 striped bass and adult white perch during the month of November. At this time both species heavily fed on age-0 clupeid species.

In both 2004 and 2005, trophic overlap values between adult white perch versus each species of adult sportfish, with the exception of crappies, were low (Table 19). Trophic overlap between adult crappies and white perch was high in both years but was only significant (0.73) in 2005. Both adult crappies and white perch consumed considerable portions of aquatic invertebrates in both 2004 and 2005 leading to similarities in diets for these species. The only other sportfish species that consumed large proportions of invertebrates was white catfish (*Ameiurus catus*), but the majority of the invertebrates consumed were Asiatic clams (*Corbicula*

Table 18. Diet overlap for age-0 sportfishes collected in 2005 versus white perch collected in 2004 and 2005 from Kerr Reservoir, Virginia.

	2004 Age-0 White Perch			2004 Adult White Perch		
Month	Crappie	Largemouth Bass	Striped Bass	Crappie	Largemouth Bass	Striped Bass
Jun	**0.61**	0.48	0.49	0.07	0.18	0.19
Jul	0.48	0.15	0.11	0.25	0.23	0.18
Aug	0.44	0.14	0.07	0.48	0.13	0.09
Sept	----	0.07	0.02	----	0.11	0.04
Oct	----	0.11	0.08	----	0.13	0.10
Nov	----	----	0.00	----	----	0.01
Dec	----	----	----	----	----	----
	2005 Age-0 White Perch			**2005 Adult White Perch**		
	Crappie	Largemouth Bass	Striped Bass	Crappie	Largemouth Bass	Striped Bass
Jun	----	----	----	----	----	----
Jul	----	----	----	0.25	0.36	0.30
Aug	----	----	----	0.48	0.28	0.42
Sept	----	0.06	0.02	----	0.16	0.08
Oct	----	0.05	0.05	----	0.20	0.18
Nov	----	----	----	----	----	**0.79**
Dec	----	----	----	----	----	----

---- Minimum number of stomachs to adequately characterizes food habits not acquired

Table 19. Diet overlap for adult sportfishes versus adult white perch collected in 2004 and 2005 from Kerr Reservoir, Virginia.

	Year	
Species	2004	2005
Blue Catfish	0.18	0.37
Channel Catfish	0.31	0.18
Crappie	0.50	**0.73**
Largemouth Bass	0.08	0.22
Striped Bass	0.05	0.20
Walleye	0.02	0.21
White Bass	0.02	0.21
White Cat	0.03	0.28

fluminea), which were low percentages of white perch diets. All other sportfish species preyed predominantly on fish prey, whereas white perch consumed primarily aquatic invertebrates.

Objective 3: Sportfish Utilization of White Perch

Collection Results. - Adult sportfish from Kerr Reservoir were collected in two consecutive years to determine the degree to which they utilized white perch for forage. In 2004, a total of 387 piscivorous fish were collected, including three species of catfish (blue, channel, and white), crappie (white and black), largemouth bass, striped bass, walleye, and white bass (see Table 20). The majority (66%) of the fish were collected from VDGIF fall gillnet samples, the rest were collected by boat electrofishing gear during May through November.

In 2005, an increased number of adult sportfish were collected, partially due to collections of crappie species via VDGIF trapnet surveys. From April through December, 785 piscivores were collected (see Table 20). Of the fish obtained for diet analysis, 60% were collected from VGDIF gillnet samples, 29% from VDGIF trapnet surveys, and 11% from boat electrofishing during age-0 fish collection.

Food Habits of Adult Sportfish. - In both years of the study, a variety of diet items were consumed by adult sportfish (Figures 20 and 21). Adult catfishes (blue, channel, and white) ate primarily aquatic insects (between 30% and 87% of diet by weight), clupeid species (between 6% and 63% of diet by weight), and organic matter (between 2% and 42% of diet by weight) in 2004 and 2005 (Figures 20 and 21). Aquatic invertebrates consumed were mainly Asiatic clams (*Corbicula fluminea*) and ephemeropterans, while filamentous algae represented the largest proportion of vegetative matter found in catfish diets. Although each of the catfish species consumed similar prey items, the larger blue catfish species relied more on clupeid fish (63% and

Table 20. Adult sportfish collected from Kerr Reservoir, Virginia in 2004 and 2005.

	Number Collected	Mean Length (mm)	Length Range (mm)	Collection Method	Month Collected
2004					
Blue catfish	64	437	167-776	VDGIF Gillnets	Oct., Nov., Dec.
Channel Catfish	16	413	185-545	VDGIF Gillnets	Oct., Nov., Dec.
Crappie	48	255	125-370	Electrofishing, VDGIF Gillnets	May, Oct., Nov., Dec.
Largemouth Bass	111	281	123-535	Electrofishing	Jul. through Nov.
Striped Bass	107	546	357-810	VDGIF Gillnets	Oct., Nov., Dec.
Walleye	12	461	393-635	VDGIF Gillnets	Oct., Nov., Dec.
White Bass	5	301	257-362	VDGIF Gillnets	Oct., Nov., Dec.
White Catfish	24	279	202-332	VDGIF Gillnets	Oct., Nov., Dec.
2005					
Blue catfish	112	406	197-1020	VDGIF Gillnets	Oct., Nov., Dec.
Channel Catfish	33	426	255-512	VDGIF Gillnets	Oct., Nov., Dec.
Crappie	302	203	101-420	VDGIF Trapnets, VDGIF Gillnets	Apr., Oct, Nov, Dec.
Largemouth Bass	89	278	170-474	Electrofishing	Jul. through Nov.
Striped Bass	202	512	249-780	VDGIF Gillnets	Oct., Nov., Dec.
Walleye	5	545	500-586	VDGIF Gillnets	Oct., Nov., Dec.
White Bass	16	357	323-410	VDGIF Gillnets	Oct., Nov., Dec.
White Catfish	26	238	191-273	VDGIF Gillnets	Oct., Nov., Dec.

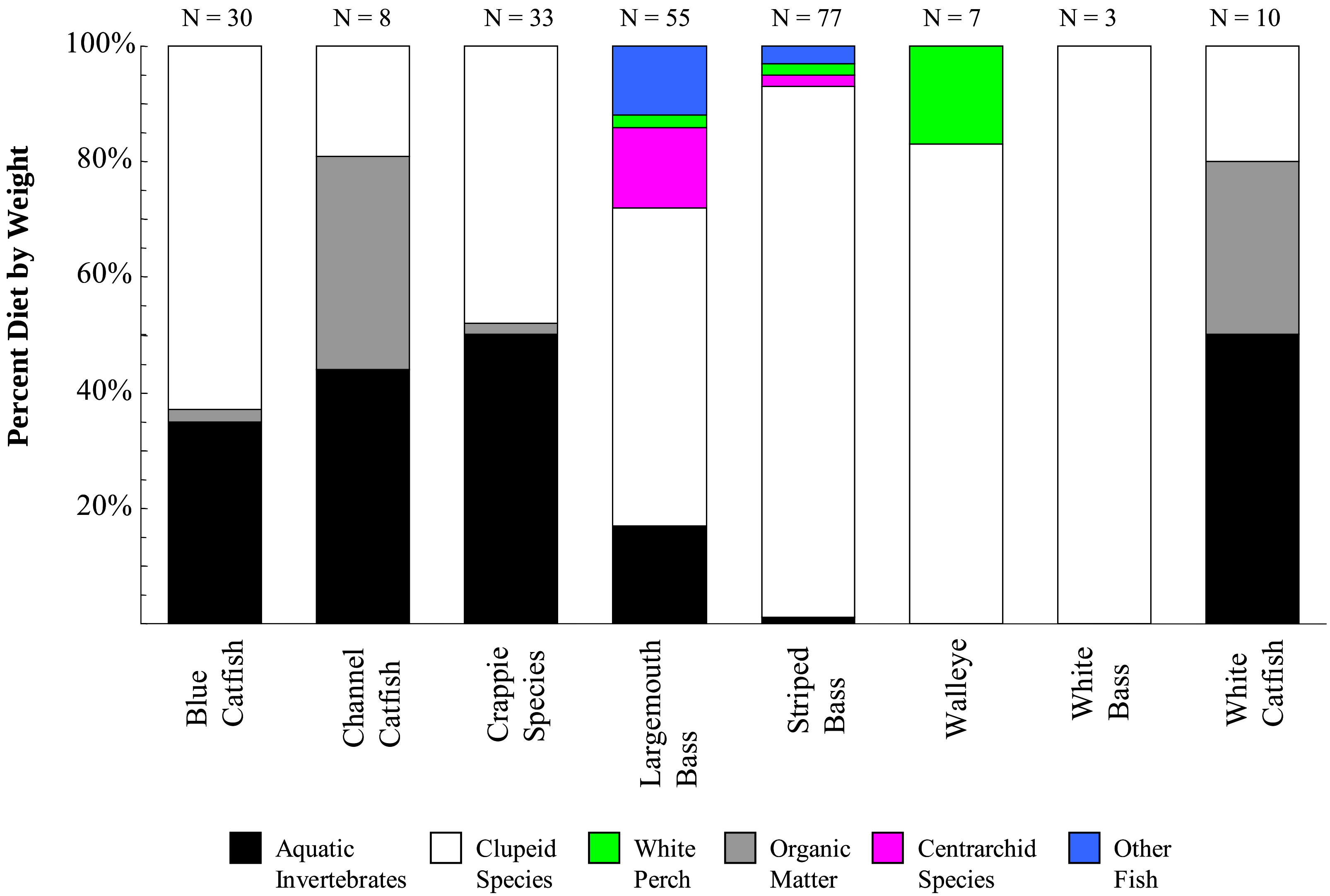

Figure 20. Food habits of adult sportfish collected in Kerr Reservoir during 2004. N = number of fish that contained food and were used in diet analysis.

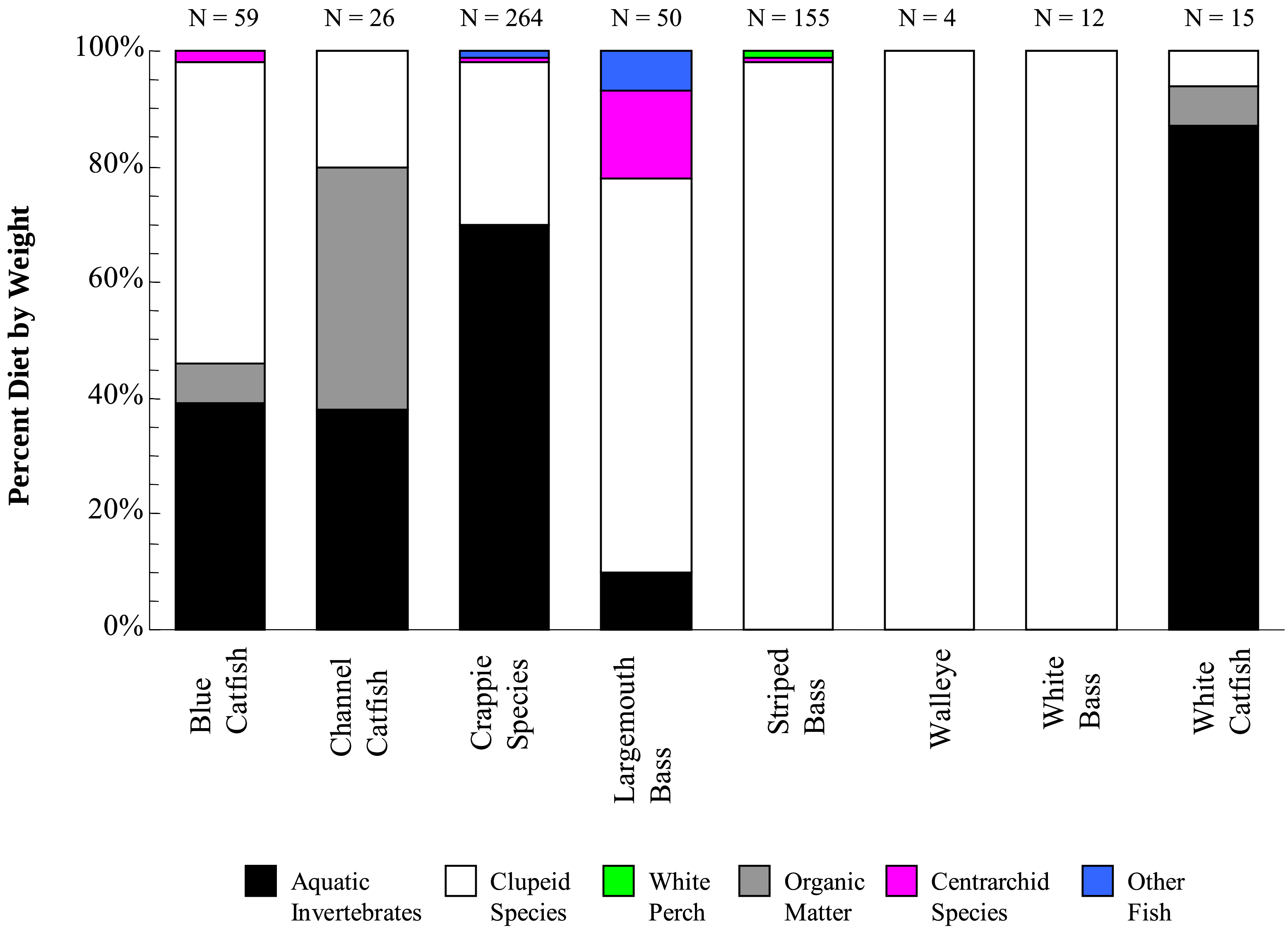

Figure 21. Food habits of adult sportfish collected in Kerr Reservoir during 2005. N = number of fish that contained food and were used in diet analysis.

54% of diet by weight for 2004 and 2005, respectively) for nutrition whereas the smaller channel and white catfishes ate more aquatic invertebrates and plant matter (Figures 20 and 21).

Crappie species were chiefly dependent on aquatic invertebrates (ephemeropterans, chironomids, and zooplankton) in both 2004 and 2005 (Figure 20 and 21). Aquatic invertebrates comprised 50% and 70% of crappie stomach contents by weight for 2004 and 2005, respectively. Clupeid fishes were the only other prey item consistently eaten by crappie species (48% of diet by weight for 2004 and 29% of diet by weight for 2005).

Unlike crappies, largemouth bass were almost completely piscivorous (Figures 20 and 21). In 2004, fish were 83% (by weight) of largemouth bass stomach contents, with clupeids (55% of diet by weight) and centrarchids (14% of diet by weight) being the primary forage fishes. As in 2004, clupeids (68% weight) and centrarchids (15% weight) were the primary prey items found in largemouth bass stomachs during 2005. Other fishes consumed by largemouth bass were ictalurids, cyprinids, and white perch, but never were more than 6% of diet by weight for any species in either year.

Similar to largemouth bass, adult striped bass preyed predominantly on fish (> 98% of stomach contents by weight for 2004 and 2005; Figures 20 and 21). Soft-rayed clupeids were the dominant fish consumed by striped bass at percentages of 92 and 98 of their overall stomach contents by weight in 2004 and 2005, respectively. Centrarchid, darter, and ictalurid species, as well as white perch were also found in the diets of striped bass, but never individually exceeded 2% by weight.

The diets of walleye and white bass were also examined, but low collection numbers made diet interpretation questionable. In both years, clupeids were the only prey found in the stomachs of white bass and all but one walleye (Figure 20 and 21). A single white perch was the only other diet item found in the stomach of a walleye captured in 2004, which represented 17% of walleye stomach contents by weight. Considering the lack of white perch observed in the diets of walleye collected the following year, this percentage may be an overestimation, and needs to be viewed with caution.

In both years of the study, soft-rayed clupeids were the only prey item found in the stomachs contents of all species of sportfishes, and were usually the highest percentage of the diet (Figures 20 and 21). In contrast, white perch never exceeded 2% of diet by weight for any sportfish species in either year, excluding walleye in 2004. White perch were only found in the stomachs of 3 fish (1 largemouth bass, 1 striped bass, and 1 walleye) in 2004 and in the stomach of 1 striped bass in 2005. Consequently, frequency of white perch predation was low to non-existent for all species during both years (Table 21), except walleye collected in 2004 (approximately 14%).

White perch consumed by largemouth bass, striped bass, and walleye ranged in size from 82 mm to 152 mm total length (TL), with a mean length total length of 110 mm. The largest white perch (152 mm TL) was found in the stomach contents of an adult walleye (635 mm TL). The two striped bass (687 mm and 765 mm TL) ate white perch that were less than 125 mm TL. Total lengths of white perch consumed by striped bass were 12% and 16% of the total lengths of the predator that consumed them. The smallest white perch consumed (TL 88 mm) was found in the stomach contents of a 324 mm (TL) largemouth bass.

<u>Objective 4: Sportfish Performance</u>

Comparative statistics were used to determine whether relative abundance and growth of resident fish of Kerr Reservoir differed during the years prior to versus post-white perch

Table 21. Frequency of occurrence (FOO) of white perch found in diets of adult sportfishes collected in Kerr Reservoir, Virginia.

	2004		2005	
Species	N	FOO (%) of White Perch	N	FOO (%) of White Perch
Blue catfish	30	0	59	0
Channel Catfish	8	0	26	0
Crappie	33	0	264	0
Largemouth Bass	55	1.6	50	0
Striped Bass	77	1.3	155	0.7
Walleye	7	14.3	4	0
White Bass	3	0	12	0
White Catfish	10	0	15	0

establishment in the reservoir. Annual data sets of electrofishing and gillnet sampling provided CPUE, length, and length-at-age data on largemouth bass and striped bass, and CPUE data on clupeid species and white bass. Reliable data on Kerr Reservoir crappie species were lacking, so comparisons of abundance and growth of this species was not undertaken.

Electrofishing CPUEs of largemouth bass collected in spring electrofishing surveys were significantly higher (Student's t-test, df = 10, $P < 0.001$) in years after white perch establishment (mean CPUE of 55 fish/hour, N = 6) than in years before white perch introduction (mean CPUE of 25 fish/hour, N = 6). Annual proportional stock density and relative stock densities of preferred length largemouth bass were not statistically different in years pre- versus post-white perch (Table 22) with respective P-values of 0.768 (Student's t-test, df = 11) and 0.473 (Student's t-test, df = 11). Lengths of age-3 largemouth bass had a higher mean value (350 mm) in years before white perch compared to lengths after white perch (343 mm), but median differences were not significant (Mann Whitney "U" test, df = 226; P = 0.053).

Gillnet data revealed that relative abundances of striped bass and clupeid species were not significantly different, with respective p-values of 0.240 (Student's t-test, df = 21) and 0.075 (Mann Whitney "U" test, df = 14), between periods before versus after white perch establishment. Conversely, white bass relative abundance was significantly lower (Student's t-test, df = 13, P = 0.012) in years after white perch introduction (mean CPUE of 0.22 fish/929 m^2 of net, N = 8) compared to years before white perch (mean CPUE of 0.32 fish/929 m^2 of net, N = 8). Striped bass growth was not statistically different in years before versus after white perch (Mann Whitney "U" test, df = 181, P = 0.543) with age-3 fish averaging 628 mm (before perch) and 632 mm (after perch).

Table 22. Comparison results of Kerr Reservoir data sets in years prior to white perch introduction (1979-1986) versus years after white perch establishment (1996-2004).

Data Set	Before White Perch N	Before White Perch Mean	Before White Perch Standard Deviation	After White Perch N	After White Perch Mean	After White Perch Standard Deviation	P-Value
Annual relative abundances of largemouth bass (N/hour)	6	25.03	3.43	6	55.14	14.64	**$P < 0.001$**
Annual PSDs of largemouth bass	7	71	14	6	74	10	$P = 0.768$
Annual RSD-Ps of largemouth bass	7	44	15	6	38	11	$P = 0.473$
Annual lengths of age-3 largemouth bass (mm)	183	350	58	45	343	27	$P = 0.053$
Annual relative abundances of striped bass (N/929 m^2)	14	5.38	2.29	9	4.14	2.52	$P = 0.240$
Annual lengths of age-3 striped bass (mm)	57	628	32.1	126	632	44	$P = 0.543$
Annual relative abundances of clupeid species (N/929 m^2)	8	24.2	15.89	8	20.09	26.28	$P = 0.705$
Annual relative abundances of white bass (N/929 m^2)	7	0.66	0.32	8	0.25	0.22	**$P = 0.012$**

DISCUSSION

The focus of this study was to evaluate the trophic relationships between white perch and sportfishes (striped bass, crappie, and largemouth bass) of Kerr Reservoir to identify interactions that may affect the recruitment and performance of the latter. Specific trophic interactions examined were predation on sportfish eggs, larvae, and juveniles by white perch, competition for food resources between white perch and sportfish species, and contribution of white perch to diets of adult sportfish. Additionally, trends in sportfish performance (abundance and growth) before versus after white perch establishment were evaluated and related to trophic interactions with white perch.

White Perch Age and Growth

In Kerr Reservoir, white perch reached 100 mm TL by age 1, 200 mm TL by age 4, 250 mm TL by age 6, and 300 mm TL by age 9. Similar patterns in white perch growth have been reported in North Carolina reservoirs (Tatum 1961; Carlander 1997) and in Lake Ontario (Sheri and Power 1969). Higher growth of white perch has been documented in Nebraska reservoirs, with perch attaining 230 mm TL by age 3. In their native estuaries, white perch growth is typically slower than exhibited in Kerr Reservoir, with perch not achieving 100 mm TL until age 2, and 200 mm until age 6 (Mansueti 1961; Wallace 1971; St. Pierre and Davis 1972; Marcy and Richards 1974; Cochran and Hesse 1994).

Indications that density-dependent factors are affecting white perch growth were apparent in Kerr Reservoir due to the observance of declining growth of white perch in years after they became abundant. Mean length of age-1 white perch declined from 124 mm TL in 1995 to 101 mm TL in 2005, and mean length of age-2 perch was reduced to 142 mm TL in 2004 compared to 159 mm in 1995. Density-dependent growth of white perch is common in waters where white perch are abundant (Hergenrader and Bliss 1971; Marcy and Richards 1974; Boileau 1985; Wong et al. 1999).

Density-dependent reduction in growth of white perch can often lead to severe stunting of white perch populations (Grice 1958). In Kerr Reservoir, the high abundance of white perch does not appear to dramatically affect growth to the point that the population has become severely stunted. In contrast, stunted populations of white perch in Indian Lake, Massachusetts did not approach 150 mm TL until age 8 and no white perch 200 mm TL or greater were collected (Grice 1958). In this lake, white perch grew less than 10 mm per year after age 2. Kerr Reservoir white perch were approaching 150 mm TL by age 2 and reached 200 mm by age 4. In Kerr Reservoir, anglers start to harvest white perch when they reach sizes of 150 mm and regularly harvest fish that are greater 200 mm (DiCenzo 2001). Kerr Reservoir white perch reached harvestable lengths by age 2 and preferred lengths by age 4.

Predation

Egg and Larval Predation by White Perch. - White perch collected in the Roanoke River were ovivorous in May of both years, consuming the eggs of striped bass and white perch. Predation on eggs of moronid species by white perch has also been observed in the Sandusky River tributary of Lake Erie (Schaeffer and Margraf 1987), and in the Pamunkey River, Virginia (McGovern and Olney 1988). Throughout the Roanoke River, striped bass eggs were low proportions of the diets of the white perch I collected during May of 2004 (< 1 % by weight) and 2005 (12 % by weight), and were eaten in low frequency (FOO < 11 % in both years). In contrast, Schaeffer and Margraf (1987) reported that nearly 100 % of white perch stomach contents by weight were moronid and walleye eggs from May to June in the Sandusky River.

Although egg predation by white perch was observed in both 2004 and 2005, consumption of striped bass eggs by white perch that I collected was much greater in 2005. Difference in intensity and distribution of sampling effort and a longer peak spawning period in 2005 were the likely causes for the observed increased egg predation. In 2004, white perch were only sampled during weekdays (Monday-Friday) and the majority of striped bass spawning occurred during a weekend period (May 7-9). To avoid missing the peak spawning period in 2005, white perch were collected on both weekday and weekend periods during May of 2005. Additionally, the peak spawning period of striped bass in 2005 was two days longer than in 2004, and the river had eggs in the water column for a longer period of time.

White perch consumption of striped bass eggs varied temporally and spatially during May of both years. Based on sampling results, white perch primarily fed on striped bass eggs during the peak period of striped bass spawning, and eggs were considerable proportions of the diet during this period especially in 2005 (31% by weight for all sites combined). Eggs were also eaten by a large percentage (FOO > 42% for all sites combined) of white perch collected during this period in 2005. During this peak striped bass spawning period, greater than 80% of the Roanoke River striped bass eggs produced are spawned (Neal 1969). It appears that Roanoke River white perch are not specifically targeting striped bass eggs, but are only consuming eggs at times when large quantities are present in the water column. Similarly, Roseman et al. (1996) observed that a large proportion of white perch (approximately 86%) collected in western Lake Erie contained walleye eggs when walleye incubation periods were prolonged, because these eggs were then abundant when the reproductive periods of the two species overlapped. Further evidence of opportunistic consumption of eggs by white perch is the egg cannibalism evidenced by white perch collected from the Roanoke River.

Striped bass eggs were primarily consumed at only two of the five locations that I sampled, Ridgeway Farms and Watkins Bridge. In 2004, striped bass eggs were only found in the stomachs of white perch collected at these two sampling sites. In 2005, 41% (Ridgeway Farms) and 52% (Watkins Bridge) of non-empty white perch stomachs collected during May contained striped bass eggs. At all other locations, frequency of occurrence of eggs in white perch diets never exceeded 6%. Striped bass eggs also constituted larger proportions of white perch diets at Ridgeway Farms and Watkins Bridge (> 30% by weight at both sites in 2005) versus all other locations where perch were collected (< 3% by weight at all locations in 2005). Egg predation by white perch was especially high on specific days during the peak spawn with up to 100% of the white perch collected on these days contained striped bass eggs. The increased instances of predation observed at these locations likely were due to the abundance of striped bass spawning within and in close proximity to these locations. Both Ridgeway Farms and Watkins Bridge sites are located within the mean spawning grounds of striped bass determined by Neal (1969) and Whitehurst (1982). I observed large numbers of striped bass spawning directly upstream and within this section of river in both 2004 and 2005, but not in other sections of the river. For this reason, large quantities of eggs were only available for white perch to consume in this section of river and directly downstream. By the time eggs reached the 360 Bridge site (14 km upriver from Kerr Reservoir), the majority of eggs appeared to have hatched because eggs were no longer observed in the water column.

The impact of egg predation on the recruitment of striped bass in 2005 is unknown, but it is possible that predation by white perch had some effect. Projected population sizes of white perch in the Roanoke River needed to consume between 50% and 90% of striped bass eggs produced during the peak spawn ranged from 138,680 to 531,619, depending on inputs of consumption and egg production. These estimates would only require recruitment rates of white perch to be between 8 and 27 perch/ha from the 19,790-ha Kerr Reservoir. White perch densities in Kerr Reservoir are likely higher than this, as indicated by VDGIF gillnet CPUE data with average catch rates of 15 perch/net in 2000 samples. Although a sufficient reservoir population of white perch was probably present, it is unlikely that they ascended the Roanoke River in high densities. At least 5,715 white perch/river km would have been needed in the 44 km section of river (between Clarkston and Watkins Bridges) to consume at least 50% of striped bass eggs spawned during the peak. Population estimates could not be calculated for white perch in the Roanoke River, but high densities were never observed during electrofishing collections in May of 2005. On the most efficient collection days, I was only able to collect between 20 and 40 perch/km from both sides of the river. Although capture efficiency was probably lowered due to turbidity and high flows, it is unlikely that population densities of white perch were more than one hundred times greater than catch rates. In Tennessee tailwaters, capture efficiency with boat electrofishers ranged from 5% to 54% dependent on the fish species collected (Ruhr 1957; Jacobs and Swink 1982). If capture efficiency of white perch was as low as 5% in the Roanoke River, collections numbers of 40 white perch per kilometer would only translate to 800 white perch in that river kilometer which is still well below projected estimates of white perch needed to have a substantial effect on striped bass recruitment.

In Kerr Reservoir, it appears that the occurrence of a peak striped bass spawning period is an evolutionary advantage because potential predators (e.g. white perch) are swamped with a large abundance of eggs during this peak spawning period. During the peak spawn, predators likely become satiated on eggs allowing for a large percentage of eggs to pass downriver and hatch. If eggs were spawned evenly over the entire spawning period of striped bass as opposed to a one-week period, white perch would have the able to consume much greater proportions of striped bass eggs produced annually. Reductions in percentage of predation mortality have been documented for salmon (*Oncorhynchus* spp.) fry when fry numbers increased and predators were swamped with the abundance of fry (Neave 1953; Hunter 1959; Peterman and Gatto 1978). Predator swamping has been observed to be an important ecological strategy for prey survival in many other organisms including mayflies (ephemeropterans), cichlids, Japanese flounder (*Paralichthys olivaceus*), greater snow geese (*Chen caerulescens atlantica*), common tern (*Sterna hirundo*), mule deer (*Odocoileus hemionus*), and bison (*Bison bison*) (Green and Rothstein 1993; Becker 1995; Whittaker and Lindzey 1999; Kellison et al. 2002; Gauthier et al. 2004; Matter and Mannan 2005)

Without estimates of current striped bass egg production and white perch population size in the Roanoke River, the true impact of egg predation is unknown. Projected number of white perch needed to consume given percentages of eggs were calculated with particular assumptions and uncertainties. Egg production estimates were gathered from historical studies on striped bass in the Roanoke River, and these estimates could be substantially different from current production numbers. Secondly, I assumed that these eggs were spawned evenly throughout the peak spawning period. If larger percentages of eggs were spawned on specific days, then greater densities of white perch would be need to consume eggs on that day. Additionally, sparse information on white perch daily feeding rates was available, so data for striped bass were substituted. Finally, the contribution of eggs to the diets of white perch could be higher than what was observed in this study, if the digestion rate for eggs was faster than for other foods (principally aquatic invertebrates). I could find no published study that compared digestion rates of fish eggs versus other food items for any species of fish. However, if striped bass eggs were underrepresented in the stomach contents that I examined, then the true number of white perch required to eat a set percentage of eggs would be lowered. The Roanoke River would require only 3,895 perch/km to consume 50% of striped bass eggs produced annually if white perch diets were completely (100%) composed of eggs. Even this lower white perch density was unlikely, given my much lower electrofishing catch rates. Additionally, the overall impact of egg predation on Kerr Reservoir striped bass recruitment is unknown, because the intensity of egg predation in the Dan River (the other important tributary of Kerr Reservoir for striped bass spawning; Whitehurst 1982) was not examined.

Predation by white perch on striped bass larvae was observed in 2005, but not 2004. Striped bass larvae were found in the stomachs of white perch at multiple sites in the Roanoke River (Ridgeway Farms, Watkins Bridge, and Staunton View), indicating that larval predation occurred throughout the river. Although predation occurred in more than one location, striped bass larvae were infrequently found in the stomachs of white perch (FOO < 2 % at any site), and never exceeded 1% of white perch diets by weight. The occurrence of larval predation may have been underestimated due to the increased digestion rate of larval prey (Dowd 1986; Rogers and Barley 1991), but it did not seem to be rampant enough in the river to have any substantial effect on striped bass recruitment. Although successful hatches of striped bass eggs occur in the lower reaches of the Roanoke River (Whitehurst 1982), striped bass larvae quickly descend to the upper part of Kerr Reservoir (between 2 to 3 days depending on river flows). Because the majority of my white perch collection was concentrated in the Roanoke River, food habits of white perch should be examined in the upper end of Kerr Reservoir after the peak spawn to fully assess the intensity of striped bass larval predation.

Crappie eggs were found in the diets of a small sample (N = 11) of white perch collected during April of 2005 in Kerr Reservoir. The small sample size did not allow quantification of white perch food habits during spring months (March-May) in Kerr Reservoir, so the intensity of eggs or larval predation on early spring spawners (crappie and largemouth bass) in Kerr Reservoir is unknown. Future research should focus on examining food habits of white perch in Kerr Reservoir during the March-through-May period.

Juvenile Fish Predation by White Perch. - From June through December, age-1 and older white perch (> 80 mm TL) fed on a variety of fish species in Kerr Reservoir during both 2004 and 2005. From June through December, *Lepomis* species were the only sportfish species found in the diets of white perch, occurring in low proportions (< 7% by weight in any month) in both years. Consumption of centrarchid species by white perch has been observed in Nebraska reservoirs (Zuerlein 1981). In Kerr Reservoir, all *Lepomis* specimens consumed by white perch were small (< 30 mm TL) age-0 fish. Because other sportfish (crappie, largemouth bass, and striped bass) are spawned early in the spring compared to continuous summer spawning of *Lepomis* species, it is possible that they have outgrown vulnerability to predation by white perch before the summer months (June-August), when I was collecting white perch in Kerr Reservoir. To determine the predation potential of white perch on the juveniles of other sportfish, white perch food habits in Kerr Reservoir need to be examined in spring when age-0 sportfish are newly hatched and relatively small in size.

Predation on fish prey by white perch in Kerr Reservoir differed between 2004 and 2005. In 2004, fish were relatively low proportions of white perch diets from June through December (< 12% by weight for any month), while fish prey averaged 47% of white perch stomach contents by weight during these same months in 2005. During both years, the majority of fish consumed by white perch in Kerr Reservoir were small (< 50 mm) clupeids. Predation on other fish species (cyprinids, percids, and centrarchids) was also observed, but was infrequent. In 2005, temporal shifts in clupeid consumption by white perch were observed. From June through October, clupeids were smaller proportions of white perch diets compared to months of November and December (> 90% by weight). A strong year-class of threadfin shad was produced in 2005, and small age-0 clupeids were very abundant in fall months compared to other prey items. Temporal shifts in clupeid consumption by white perch have also been observed in Lake Ontario when alewives were abundant (Danehy et al. 1991) and in Lake Erie when gizzard shad were abundant (Schaeffer and Margraf 1986).

In Kerr Reservoir, white perch were piscivorous at relatively small sizes (by 80 mm in 2004 and by 150 mm in 2005), and fish were consumed consistently by all sizes classes of perch. This is contrary to the reported food habits of white perch in other waters where size-dependent shifts in fish consumption by white perch were observed. Fish were not regularly consumed by white perch until the perch reached sizes of 200 mm in Nebraska Reservoirs (Zuerlein 1981), Maine lakes (Warner 1974), and in the Susquehanna River, Maryland (Weisburg and Janicki 1990).

Trophic Competition

Food Habits of Age-0 Fishes. - Food habits of age-0 sportfishes varied between species and temporally with each species. Age-0 crappies displayed primarily invertivorous food habits, consuming mixtures of zooplankton and aquatic insects throughout the growing season; however age-0 crappie also ate small amounts of fish prey. The observed occurrence of fish in the diets of age-0 crappies was unusual compared to other studies. In other reservoirs, age-0 crappies have been documented consuming only zooplankton prey (Ewers and Boesel 1935; Schael et al. 1991;

Devries et al. 1998; Pope and Willis 1998; Pine and Allen 2001; Dubuc and Devries 2002), or combinations of zooplankton and aquatic insects (Mathur and Robbins 1971; Ellison 1984; O'Brien et al. 1984). Generally, crappies do not regularly consume fish until they reach lengths greater than 150 mm (TL), typically reached in their second growing season (Marthur and Robbins 1971; Ellison 1984; O'Briean et al. 1984; Pine and Allen 2001). In Kerr Reservoir, age-0 crappie consumed fish prey at much smaller sizes (by 30 mm TL). In each year of the study, clupeids had very strong year classes (alewife in 2004 and threadfin shad in 2005), and all fish consumed by juvenile crappie were small age-0 clupeids. The occurrence of fish in the diets of age-0 crappies in Kerr Reservoir can be attributed to the abundance of small age-0 clupeids present in the reservoir.

Food habits of age-0 white perch were described for June through December 2004 but only for September and October in 2005, due to low collections of juveniles in 2005. It appeared that white perch experienced low reproductive success in 2005, as opposed to 2004 when age-0 white perch were very abundant. High interannual variability in year-class strength of white perch has been reported in other waters (Cacela 1989; Pace et al. 1993; Gopalan et al. 1998; O'Gorman and Burnett 2001); variability in year-class strength of white perch is thought to be a function of spring temperatures (O'Gorman and Burnett 2001). In both years when diets were quantified, age-0 white perch fed only on aquatic invertebrates (mostly copepods, daphnia, dipterans, and ephemeropterans). Food habits of age-0 white perch in Kerr Reservoir were similar to diet data collected on white perch in coastal waters, where key diets items were copepods, insect larvae and pupae, isopods, and mysids (Bath and O'Conner 1985; Rudershausen and Loesch 2000; St-Hilaire 2002), and in other inland systems where primary diet items were amphipods, copepods, daphnia, chironomids, and trichopterans (Leach 1962; Elrod et al. 1981; Prout et al. 1990; Hurley 1992; Gopalan et al. 1998).

Both age-0 largemouth bass and striped bass fed on a mixture of aquatic invertebrates and fish in June of both 2004 and 2005, but they consumed mostly fish prey from July through December of both years. Similar temporal shifts in food habits of age-0 largemouth bass have been documented in other systems (Pasch 1975; Shelton et al. 1979; Timmons et al. 1980; Keast and Eadie 1985; Mathews et al. 1992; Olsen 1996; Sutton 1997; Garvey et al. 1998; Olsen and Young 2003), and for striped bass in coastal waters (Merriman 1941; Heubach et al. 1963; Markle and Grant 1970; Schaefer 1970; Boynton et al. 1981; Rudershausen and Loesch 2000), and in other inland reservoirs (Stevens 1958; Gomez 1970; Ware 1970; Weaver 1975; Axon 1979; Higginbotham 1979; Saul 1981; Richardson 1982; Humphreys 1983; Van Den Avyle et al. 1983; Mathews et al. 1992; Sutton 1997; Rash 2003). Shifts in diets from invertebrates to fish for age-0 piscivores are dependent on predator size and the availability of ingestible prey (Pasch 1975; Shelton et al. 1979; Timmons et al. 1980; Keast and Eadie 1985; Garvey et al. 1998; Sutton 1997; Rash 2003). Previous studies in other Virginia reservoirs showed that this shift usually occurs at sizes between 120 mm and 130 mm for both largemouth bass and striped bass (Sutton 1997; Rash 2000). In this study, shifts occurred at similar or smaller sizes. Ontogenetic shifts to piscivory of age-0 largemouth were exhibited in fish at sizes of approximately 100 mm in 2004 and at 50 mm in 2005; age-0 striped bass exhibited shifts to piscivory when fish reached approximately 130 mm in 2004 but only 70 mm in 2005. These earlier ontogenetic shifts in diets of largemouth and striped bass were most likely a function of the abundance of age-0 threadfin shad present in Kerr Reservoir in 2005 as opposed to 2004 when the larger age-0 gizzard shad were more abundant.

Potential for Trophic Competition. - High similarities (Schoener's Overlap >0.5) in diets between age-0 white perch and the three species of age-0 sportfish occurred in early June when all were largely invertivorous, but only overlap between age-0 crappie and white perch exceeded 0.6. Additionally, high diet similarities between white perch and sportfish were displayed in small largemouth bass (< 60 mm, Schoener's Overlap > 0.53) and striped bass (< 100 mm, Schoener's Overlap between 0.45 and 0.64). At these small sizes largemouth and striped bass consume large amounts of invertebrates similar to age-0 white perch, and have not made the ontogenetic shift to fish prey. Previous studies have found high trophic overlap between age-0 white perch and striped bass in their native estuaries when both species relied heavily on invertebrate prey (Setzler-Hamilton 1982; Rudershausen and Loesh 2000; St-Hilaire et al. 2002). Diet overlap of white perch versus crappie, largemouth bass, and striped bass has not been reported in inland waters, but white perch have been reported to have high trophic overlap with other age-0 species (alewife; yellow perch, and white bass) that have highly invertivorous diets in inland waters (Elrod et al. 1981; Emmons 1986; Parrish and Margraf 1990; Prout et al. 1990; Gopalan et al. 1998).

High trophic overlap values were also found between age-1 and older white perch versus adult crappie, with overlap values of 0.50 in 2004 and 0.73 in 2005. Both of these species fed on mixtures of zooplankton, aquatic insects, and fish in both years, causing high similarities in diets between these species. Catfish species were the only other species that regularly consumed aquatic invertebrates, but ictalurids fed more heavily on Asiatic clams and organic matter than on the zooplankton and insects consumed by white perch. All other adult sportfish (largemouth bass, striped bass, walleye, and white bass) were primarily piscivorous, and their diets had low overlap (< 0.38) with the diets of the primarily invertivorous white perch.

Similarities in diets indicated that competitive trophic interactions could occur between white perch and all age-0 species of sportfish, especially early in the growing season, and between adult white perch and crappie throughout the year. Determination of the degree and intensity to which trophic competition actually occurs depends on knowledge of the abundance of food resources (Wiens 1977), which was beyond the scope of this study.

The results of trophic competition are manifested in the performance of the competing species. Competitive interactions between fish have often been found to lead to reduced growth and increased mortality (Werner and Hall 1977; Hanson and Leggett 1985, 1986; Osenberg et al. 1988; Frank and Leggett 1994; Cushing 1988; Dong and DeAngelis 1998). Comparisons in temporal trends of sportfish growth and abundance (before vs. after white perch establishment) conclude this discussion.

<u>Sportfish Utilization of White Perch</u>

An analysis of the food habits of Kerr Reservoir sportfishes revealed that white perch were not utilized as a prey source by any species. In all instances, when sportfish preyed on fish they consumed primarily clupeids. Between 2000 and 2004, the mean catch rate of clupeids from fall gillnet samples was 23 fish/929 m^2 of net, which was nearly 2.5 times greater than catch rates of white perch (9 fish/929 m^2 of net). In Kerr Reservoir, clupeids are the most abundant forage fish and are readily available for consumption by piscivorous predators.

Kerr Reservoir catfishes were omnivores, feeding on mixtures of aquatic invertebrates, fish, and filamentous algae. This generalist feeding behavior has been previously reported in other waters for blue catfish (Brown and Deny 1961; Minckly 1962; Perry 1969), channel catfish (Menzel 1943; Bailey and Harrison 1948; Armstrong and Brown 1983; Weisberg and Janicki 1990), and white catfish (Stevens 1959; Crumpton 1999). Although each catfish species was omnivorous, blue catfish consumed primarily clupeids (>52% by weight in both 2004 and 2005), whereas channel and white catfish diets were comprised large mixtures of invertebrates and filamentous algae. The difference in degree of fish consumption among the ictalurids was most likely a function of habitat preference and species-specific behavior. In reservoir systems, blue catfish prefer deep pelagic areas (Graham 1999) where clupeids may be abundant, while channel and white catfish prefer the shallower littoral areas (Klaassen and Marzolf 1971; Hubert and O'Shea 1992).

Kerr Reservoir crappies consumed mainly clupeids and aquatic invertebrates in both 2004 and 2005, with these prey categories representing approximately 98% of stomach contents by weight in both years. Crappie diets consisting of aquatic invertebrates and fish have also been reported in Florida Lakes (Reid 1949), Nebraska reservoirs (Ellison 1984), and Illinois reservoirs (Heidinger 1977, Heidinger et al. 1985). Although crappies consumed fish in the present study, they did not prey on white perch. The absence of white perch in crappie diets was most likely due to prey size, habitat differences, and alternative prey (clupeid) abundance. Gape-limited piscivores often consume deep-bodied prey much smaller than their maximum potential (Hoogland et al. 1956; Lawrence 1958; Kerby 1979; Gillen et al. 1981; Ott and Malvestuto 1981; Humphreys 1983; Hoyle and Keast 1987; Dennerline 1990; Hambright 1991; Juanes 1994; Dettmers et al. 1996; Sutton 1997). In Kerr Reservoir, adult crappies only ate small (< 80 mm) age-0 clupieds, and Kerr Reservoir white perch are only in this size range during summer months of their first growing season (June through September, see Figures 4 and 5). In reservoir systems, crappies primarily suspend in deep offshore areas near submerged structure during summer months (Grinstead 1969; O'Brien et al. 1984; Durfey 1986; Markham et al. 1991; Johnson and Lynch 1992; Guy et al. 1994). During my summer collections, small (< 100 mm) white perch were only collected in unvegetated, littoral areas where adult crappies were not present. Crappies appeared to rely on the more abundant, soft-rayed clupeid species that were available in offshore areas.

Kerr Reservoir largemouth bass were almost completely piscivorous, with clupeids (mostly threadfin and gizzard shad) being the primary prey fish consumed by adult and juvenile bass in both years. When abundant, soft-rayed clupeids have been shown to be the preferred prey of largemouth bass (Storck 1986), and their importance to diets of adult largemouth has been reported in many other waters (Aggus 1973; Lewis et al. 1974; Pasch 1975; Michaletz 1997; Carline et al. 1984; Moore 1988; Timmons et al. 1981; and Yako et al. 2000).
Over the two years of this study, only one captured largemouth bass contained a white perch (FOO < 2%). In contrast, Ward and Neumann (1998) reported that white perch were the most important and seasonally consistent prey item consumed by largemouth bass in Lake Lillinonoh, Connecticut, which lacked a clupeid prey base.

Striped bass fed almost exclusively on clupeids in both years. The high importance of clupeids to the diets of adult striped bass has previously been documented in their native estuarine environment (Gardinier and Hoff 1982; Walter and Austin 2003) and in inland waters (Stevens 1958; Combs 1978; Deppert 1979; Morris and Follis 1978; Kohler and Ney 1981; Persons and Bulkley 1982; Filipek and Tommey 1984; Moore et al. 1985; Bonds 2000). As opposed to shad, white perch were rarely found in diets of striped bass (FOO <2%), and were of low importance (<2% by weight) in both years. Gardinier and Hoff (1982) reported low occurrences (FOO approximately 11%) of white perch consumption by mature striped bass in the Hudson River Estuary in the presence of an alternative clupeid prey base. Additionally, Manooch (1973) found that striped bass preferred soft-rayed fish over spiny-rayed fish (e.g., white perch).

Food-habits analysis for walleye and white bass were questionable due to low sample sizes for each species. In other southern reservoirs, reliance on clupeid prey has been documented for both walleye (Dendy 1946; Momot et al. 1977; Fitz and Holbrook 1978; Moore 1988; Bonds 2002) and white bass (Olmstead and Kilambi 1971; Ruelle 1971). Only one white perch was found in stomachs of Kerr Reservoir walleye (FOO approximately 17%) and none were found in white bass. In Kerr Reservoir, walleye and white bass seem to prefer and depend on the more-abundant clupeids; however it has been documented that both species will prey on white perch when less desirable prey is not abundant (Forney 1974; Hartman and Margraf 1992; Hartman 1998).

Reservoir systems can be highly variable due to rapid fluctuations in water quality and levels (Summerfelt 1999), and shortages in clupeid prey can occur due to these changing conditions (Jenkins and Morais 1978; Jenkins 1979; Michaletz 1997). In times of low clupeid abundance, competition between sportfish species could intensify and white perch could add an alternative forage base for these predators (Forney 1974; Gardinier and Hoff 1982; Hartman and Margraf 1992; Ward and Neumann 1998). Additionally, white perch could be larger proportions of piscivores' diets at different times of year. Piscivores were only collected in the fall for all species except largemouth bass, which were collected June through December. Hartman (1998) found that white perch were a seasonally important food resource for white bass during summer months (June-August) in Lake Erie. It is possible that piscivores fed on white perch at other times of the year, but it seems unlikely due to the high year-round abundant forage base of clupeids.

In summary, white perch are not utilized as a major food source for Kerr Reservoir sportfishes, but the occasional occurrence of white perch consumption indicates that they might become more important in the event of weak year classes of clupeids.

Sportfish Performance

Observed egg predation by white perch and potential trophic competition with white perch indicates that crappies are the sportfish species most likely to be adversely affected by white perch introductions. In B. Everrett Jordan Reservoir, North Carolina abundances of black crappie declined with concurrent increases in white perch abundance (Wong et al. 1999). Unfortunately, comparison in abundance and growth of Kerr Reservoir crappies before and after white perch establishment was not possible in the present study due to a lack of available or reliable data.

Relative abundance of pelagic fishes (striped bass and clupeid species) collected from annual gillnet samples were similar in years prior to and after white perch introduction, except for CPUEs of white bass (which declined after white perch establishment). DiCenzo and Duval (2002) determined that declines in abundance of Kerr Reservoir white bass were related to low April inflows from the Roanoke and Dan Rivers, which negatively affected year-class strength of white bass. Although interactions between Kerr Reservoir white bass and white perch were not featured in my study, their known interactions in other waters give cause to believe that white perch may have contributed to reductions in white bass populations. In Lake Erie, declines in white perch populations were correlated to the introduction and establishment of white perch (Madenjian et al. 2000), and were thought to be caused by some form of egg predation (Shaffer and Margraf 1987), competition (Gopalan et al. 1998), and/or hybridization (Todd 1986; Irons 2002). Although CPUEs of striped bass did not differ before and after white perch establishment, stocking history of striped bass in Kerr Reservoir could have affected comparative results. In years after white perch were established (1996-present), average numbers of striped bass fingerlings supplementary stocked in Kerr Reservoir were nearly four times greater than in years prior to white perch introductions (1974-87; see Table 1). Increased number of striped bass stocked in years after white perch compared to years before white perch could have facilitated similar CPUEs between the two periods even if white perch were affecting recruitment success of striped bass.

Largemouth bass relative abundances obtained from VDGIF electrofishing surveys were higher in years after white perch establishment (mean CPUE 55 fish/hour) versus years before white perch introductions (mean CPUE 25 fish/hour). It may seem that the rise in relative abundance of largemouth bass is an indication that interactions with white perch are minimal, but relative abundance increases were mostly likely due to enhanced capture efficiency of largemouth bass in years after white perch establishment (post 1995). In 1997, VDGIF personnel upgraded their electrofishing equipment and procedures, and a new modernized electrofishing boat and gear was used then and in later years (V. DiCenzo, VDGIF, personal communication). In Briery Creek Lake, Virginia, Wilson and Dicenzo (2002) found similar significantly higher higher catch rates of largemouth bass in years when the new modernized electrofishing gear (boat mounted anodes) was used as opposed to years when the older methods (hand-held anode) was used. Difference in capture efficiency appears to be the probable cause for the increase in relative abundance of largemouth bass in the period after white perch establishment, and comparison of abundance between the two periods may lead to faulty conclusions. Largemouth bass stock density estimates (PSD and RSD-P) were similar in years before and after white perch establishment.

Growth of largemouth bass and striped bass was evaluated by comparing length at age-3 fish for each species. Lengths of age-3 largemouth and striped bass collected in Kerr Reservoir were not statistically different between pre- and post-white perch years. Although no difference in growth of these age-3 sportfish was observed, differences in ageing procedures between time periods could have led to misleading results. In years prior to white perch establishment, all sportfish were aged using scales, but otoliths were used to age fish in years after white perch were established. Unlike otoliths, aging using scales has been found to lead to overestimation on ages of younger largemouth bass (Long and Fisher 2001) and reduced precision in age estimates with striped bass (Welch et al. 1993). Largemouth bass growth may have been greater than reported during years that scale-aging procedures were used, and therefore the comparison between age-3 largemouth bass before and after white perch establishment may have been faulty.

Although growth and abundance of Kerr Reservoir fishes were similar in periods before and after white perch, except abundance of white bass, observed predation on the eggs of sportfish and potential competition with the young of sportfish leads to some concern. It is possible that changes in resident fish dynamics were not observed due to sampling inconsistencies among the two periods. For future collections, sampling and recording procedures should be standardized to permit accurate annual comparisons.

Analysis of growth and abundance of largemouth bass and striped bass indicates that both parameters were similar before and after white perch introductions for each species. It does not appear that these species are competing for food resources with white perch, but differences in sampling and aging procedure could have lead to faulty comparisons. Crappie growth could not be evaluated, but overlap results suggest the potential for trophic competition.

SUMMARY AND CONCLUSIONS

1. Stomach contents of white perch and piscivorous sportfishes were collected in 2004 and 2005 to examine the trophic impacts (predation and/or competition) and benefits (as a forage resource) of the white perch in Kerr Reservoir. Adult white perch were collected throughout the Roanoke River and in Kerr Reservoir by boat electrofishing gear to determine whether they preyed on sportfish eggs, larvae, and juveniles. Throughout the growing season (June-December), age-0 white perch, crappie, largemouth bass, and striped bass were collected in Kerr Reservoir by seining and boat electrofishing to examine the potential for trophic competition between white perch and other sportfishes. Adult piscivores were sampled by gillnetting and electrofishing to determine whether they utilized white perch as a prey resource. Additionally, data from VDGIF annual sampling were used to compare growth and abundance of piscivores and forage fish of Kerr Reservoir before and after white perch establishment.
2. Age-and-growth analysis of white perch indicated that white perch growth does not appear to be stunted in Kerr Reservoir at this time. Kerr Reservoir white perch are approaching sizes of 150 mm TL by age-2 and surpass 200 mm TL by age-4. Growth of Kerr Reservoir white does not appear to limit the fishery for white perch at this time, because anglers start harvesting white perch at sizes of 150 mm TL.
3. Predation by white perch on striped bass eggs during the striped bass spawning run up the Roanoke River was observed in 2004 but was more intense in 2005. Striped bass eggs were eaten by up to 100% of the white perch collected at certain locations on days during the peak striped bass spawn in 2005. In both years, egg predation only occurred during the peak striped bass spawning period. Spatially, egg predation primarily occurred within

or just below the mean spawning location of striped bass (Clarkton Bridge to Watkins Bridge). It appears that white perch opportunistically fed on striped bass eggs when and where eggs were in high abundance.

4. Although considerable egg predation was observed at times during 2005, projected population sizes of white perch large enough to significantly affect recruitment of striped bass likely were not present. Population densities greater than 5,000 perch/km would have been needed in the stretch of river where predation occurred to consume at least 50 % of the striped bass eggs spawned annually; electrofishing surveys captured fewer than 30 perch/km.
5. Predation by white perch on striped bass larvae was observed at several sites in the Roanoke River in May of 2005 during the striped bass spawning period, but appeared to be quite low. Only 4 of 986 (0.4 %) of white perch captured contained striped bass larvae. Instances of larval predation could have been higher than observed due increased digestion rates of larval prey, but still did not appear to be sufficiently intense to affect recruitment of striped bass. Striped bass larvae hatch in the 10-km stretch of the Roanoke River above Kerr Reservoir and are in the river less than one day. Larval predation by white perch may have been more intense in the upper end of Kerr Reservoir, but my sampling was not designed to assess this issue.
6. Predation by white perch on the eggs of crappie was detected during April of 2005 in Kerr Reservoir. White perch diets were not quantified during this period, so the frequency and impact of this predation to crappie populations in Kerr Reservoir is unknown. Further investigation into the food habits of white perch in Kerr Reservoir

needs to be accomplished during the crappie spawning period (March-April) to determine the effect of egg and larval predation by white perch on this popular sportfish.

7. Instances of predation on the young of other sportfish by white perch were observed from June through December in Kerr Reservoir, but only age-0 *Lepomis* species were consumed. Frequency of predation appeared to be low with less than 5 % of 1165 white perch collected in both years containing *Lepomis* prey. Only small (< 30 mm TL) age-0 lepomids were observed in the diets of white perch; young of largemouth and striped bass had outgrown the size of prey targeted by white perch by June, when my sampling began. White perch food habits should be examined in Kerr Reservoir from April through May to determine whether white perch prey on the young of other sportfish when they are of vulnerable size.
8. White perch consumed large amounts of clupeid prey, especially at times when clupeids were more abundant than alternative invertebrate prey types. Clupeids comprised greater than 90% by weight of perch stomach contents in the fall of 2005, indicating that white perch will feed heavily on fish prey.
9. Both age-0 crappie species and age-0 white perch were highly invertivorous throughout their first growing season. Aquatic invertebrates represented greater than 90 % of age-0 crappie stomach contents by weight throughout the growing season of both years, while 100 % of age-0 white perch diets were composed of invertebrates during both growing seasons.
10. Age-0 largemouth bass and striped bass displayed ontogenetic shifts in food habits from invertebrates to fish in both 2004 and 2005, but shift occurred at smaller sizes than previously reported in other Virginia reservoirs. Diet shifts in largemouth bass occurred

at sizes between 50 mm and 100 mm, while striped bass displayed shifts in diets at sizes between 70 mm and 130 mm.

11. Trophic overlap as an indicator of interspecific competition between age-0 white perch and young-of-year sportfishes was highest in early summer, when all fed heavily on zooplankton and aquatic macroinvertebrates. Largemouth bass and striped bass soon became piscivorous, but age-0 white perch did not. Significant diet overlap (>0.6, Schoener's index) occurred only between white perch and crappie; both species were essentially invertivores throughout their first growing season.
12. Schoener's (1970) Trophic Overlap Index revealed the potential for interspecific competition for food resources exists between adult white perch and adult crappie, but not between white perch and other adult sportfish species (catfishes, striped bass, largemouth bass, walleye, and white bass). Both adult white perch and crappie consumed considerable amounts of aquatic invertebrates whereas other sportfish were primarily piscivorous.
13. Analysis of food habits of Kerr Reservoir piscivores showed that utilization of white perch as forage was low. For both years, frequency of occurrence of white perch in piscivore diets was ~1% in a combined sampling of 526 striped bass, largemouth bass, and walleye. Most species fed primarily on the more abundant clupeid species, but the occurrence of predation on white perch indicates that perch could add an alternative forage base in times of low clupeid abundance.
14. Temporal comparisons of growth rates and relative abundance of major forage and sport fishes before and after white perch establishment in Kerr Reservoir revealed that white bass abundance has declined since white perch establishment. Low spring flows from the

Roanoke and Dan Rivers are thought to be the primary cause for this reduction, but interactions between white perch and white bass in other systems is cause for concern. Growth and abundance of all other species (clupeids, striped bass, and largemouth bass) examined were either similar or greater in the period after white perch establishment.

The introduction of the white perch in Kerr Reservoir was cause for concern for management biologists due to the track record of the white perch in other waters, and reductions of year class strength of striped bass in Kerr Reservoir during the early 1990s. Results of this study indicated that there are potentially negative interactions between white perch and striped bass as well as other popular sportfish in Kerr Reservoir.

White perch preyed on the eggs of striped bass, and at times predation was intense. Allowing for low capture efficiency of white perch, it is unlikely that white perch densities were sufficiently high to result in consumption of a large fraction of striped bass eggs produced in the Roanoke River. The intensity of predation on eggs of other sportfish species by white perch is unknown, but the observance of predation on crappie eggs reveals that the potential for a substantial impact exists in Kerr Reservoir.

Potential competitive trophic interaction of white perch with largemouth bass and striped bass seem to be minimal and restricted to early months of the growing season. The abundant forage base of age-0 clupeids provides juvenile piscivores the ability to consume fish throughout the growing season. Abundance of clupeid species can be quiet variable in reservoir systems, and competitive interactions between these species might occur in years when the clupeid forage base is low.

This study indicated that crappie appear to have the highest potential for competitive interactions with white perch. Trophic overlap was high between these species for all life stages (juveniles and adults). Without some quantification of available food supply, it is not possible to assess whether these similarities in diets are suppressing the growth of crappie. Further, reliable data on crappie growth were not available in periods before white perch were introduced into Kerr Reservoir, preventing comparison of crappie growth before and after white perch establishment.

Growth and abundance of most sportfish have not declined since white perch establishment. It is possible that effects on performance of sportfish were not observed due to sampling inconsistencies between periods before and after white perch. Of all the sportfish examined, only white bass relative abundance has decline since white perch introduction. Interactions between these species were not examined during this study, but white perch introductions have preceded white bass decline in other waters.

The benefits of white perch as a forage fish to resident piscivores of Kerr Reservoir are minimal to nonexistent. Adult piscivores rely heavily on the abundant clupeid forage and do not readily consume spiny-rayed white perch, but might at times that clupeids are unavailable.

In summary, white perch are adding little benefit (with the exception of a small pan-fish fishery) to the overall Kerr Reservoir fishery, but appear to have some negative interactions with resident sportfish of Kerr Reservoir. Further research on white perch in Kerr Reservoir should be undertaken to better understand how these interactions are affecting the dynamics of these resident sportfish. Food habits of white perch should be examined in Kerr Reservoir and the Roanoke and Dan Rivers throughout spring months to truly assess the predation and competition potential of white perch in Kerr Reservoir.

MANAGEMENT RECOMENDATIONS

This study identified potential impacts of white perch on resident fishes of Kerr Reservoir, some of which merit more directed study. An alternative stocking regime for striped bass and consistency in assessment monitoring are among my recommendations to managers of the Kerr Reservoir fishery. My specific recommendations follow.

1. **VDGIF should annually monitor year-class strength of striped bass in Kerr Reservoir and white perch relative abundance in the Roanoke and Dan Rivers. To assess year-class strength, monitoring of age-0 striped bass should take place in the upper end of Kerr Reservoir before supplemental stockings of striped bass occur (late May through June). During this time, age-0 striped bass could be collected with seining procedures described in Objective 2 of this study and/or with trawling techniques used by Whitehurst (1982). White perch relative abundance should be assessed during the peak spawning season of striped bass (April in the Dan River and May in the Roanoke River) using boat electrofishing gear.**

    Predation on striped bass eggs by white perch in the Roanoke River was observed in both years of this study. Although population sizes of white perch do not appear to be large enough in the Roanoke River to substantially affect natural recruitment of striped bass, the actual impact of egg predation is unknown. Further, the intensity of striped bass egg predation in the Dan River, the other important spawning tributary for Kerr Reservoir striped bass, was not examined. Having predictions on striped bass year-class strength and relative abundances of white perch in spawning waters of striped bass over multiple years would provide empiric evidence of a causal relationship (or its lack) between these two indices.

2. **A study on white perch abundance and food habits should be conducted in the upper end of Kerr Reservoir (section of lake above mouth of Buffalo Creek) directly after the striped bass spawning period (May-June).**

    White perch fed on striped bass larvae in the Roanoke River, but larval predation appeared to be infrequent. Although larval predation was low in the Roanoke River, the overall intensity of striped bass larval predation by white perch is unknown because food habits of white perch were not examined in the upper end of Kerr Reservoir where striped bass larvae aggregate after hatching.

3. **Future research should be accomplished to examine the food habits of white perch during spring months (April-May) and should be concentrated in the areas of Kerr Reservoir where Kerr Reservoir sportfish species (e.g. crappie and largemouth bass) primarily spawn.**

The observance of crappie egg and juvenile centrarchid predation by white perch raise concern for how this predation affects populations of these species. In this study, diets of white perch were not examined in Kerr Reservoir during or directly after the spring spawning period of crappie and largemouth bass. Future research should be designed to determine the intensity of egg, larvae, and juvenile predation of these species by white perch and competitive trophic interactions between these species during this spring period.

4. **I recommend stocking striped bass earlier in the growing season (May through early June) or at larger sizes (> 100 mm). Striped bass could be collected from the Roanoke River by Vic Thomas Hatchery personnel earlier in the spring than they have traditionally been collected, and spawning in these fish could be induced in hatchery facilities to provide earlier availability of fingerling striped bass for stocking (Sutton 1997).**

In Kerr Reservoir, populations of striped bass are sometimes sustained by supplemental stockings of fingerlings. Potential competitive interactions between age-0 striped bass and white perch for food resources were observed between these species early in the growing season (June) and between smaller fish (< 100 mm TL). To minimize these potential interactions between these species, stocking strategies of fingerling striped bass could be adjusted. Traditionally, striped bass fingerlings have been stocked at the end of June at sizes less than 60 mm. Stocking striped bass earlier in the growing would allow juveniles to grow to lengths where ontogenetic shifts from invertebrates to fish prey occur before age-0 white perch are abundant in Kerr Reservoir.

5. **VDGIF should continue to monitor abundance and growth of Kerr Reservoir crappies. Crappie species should be collected by traditional sampling gear and methods (spring trapnet surveys) for annual comparisons.**

Potential negative interactions (predation and/or competition) were observed between Kerr Reservoir white perch and crappie, but comparisons of growth and abundance before and after white perch establishment were not performed due to insufficient data. To determine if these population characteristics are declining in the presence of white perch, indices growth and abundance of crappies should be monitored annually.

6. **Future research should be conducted to examine the relationships between white bass and white perch in Kerr Reservoir. Specifically, intensity of white perch predation on eggs and juveniles of white bass and trophic competition with white bass should be accomplished.**

Populations of white bass experienced drops in abundance after white perch were established, and published studies have shown that white perch can negatively affect white bass population dynamics through forms of predation, competition, and/or hybridization. This study did not evaluate interactions between these species in Kerr Reservoir.

7. **VDGIF annual sampling should be performed with high consistency in regards to sampling gear and strategies, to assure future population data of Kerr Reservoir fishes can be used for comparative purposes.**

    Annual monitoring data collected by VDGIF personnel were essential to this research, but sampling inconsistencies between periods before and after white perch establishment in Kerr Reservoir created difficulties for comparisons between the two periods. In instances when sampling technologies are similar among years, consistency in sampling techniques ensures more accurate comparability in long-in data from long-term data set.

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VITA

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