AN ABSTRACT OF THE THESIS OF

Paul Michael Bennett for the degree of Master of Science in Fisheries Science presented on April 19, 2002. Title: Comparisons of Fish Assemblages and Habitat Associations in Littoral Zones of Reservoirs in the Willamette Basin, Oregon.

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The littoral zones of seven reservoirs in the southern Willamette Valley of Oregon were sampled with a boat electroshocker during the summer months of 1995 and 1996. Shoreline substrates were inventoried before sampling sites were randomly selected. Sampling sites consisted of 9 of 12 possible habitat types including four substrate types (bedrock, fines, gravel to small boulders, and large boulders), each with or without overlying vegetation or wood. Fish assemblages occupying these specific habitat types were compared. Various aspects of substrate distribution and dimensions were utilized to help explain differences in fish assemblages.

Significant differences in richness, diversity, mean length, mean weight, and catch per unit effort (CPUE) of fish assemblages occupying the specific habitat types were found. Fish assemblages using vegetated substrates were greatest in richness, diversity, and CPUE, while bedrock and unvegetated fines were lowest. Gravel to small boulder substrates tended to be intermediate for these variables. Large boulder substrates were consistently on the higher end of the range of these values. The largest and oldest fish

occupied habitats with wood and large boulder substrates; smaller, younger individuals tended to be found in fine substrates with vegetation. Largemouth bass, bluegill, and coarsescale suckers were well distributed across habitat types. Other species such as the yellow bullhead, white crappie, reticulate sculpin, longnose dace, and speckled dace were much more restricted in their use of habitat. Overlying structure tended to increase fish diversity and richness for fine but not for coarse size substrates.

Comparison of fish species between reservoirs, using regression analysis, was also performed. Fish sampled in Lookout Point Reservoir showed the overall greatest weight for length values, whereas, fish from Hills Creek and Green Peter Reservoirs were lowest in these values of the seven study reservoirs.

Regression analysis of specified substrate parameters to fish species richness and diversity indicated bedrock was generally a negative influence. The occurence of gravel to small boulder substrate was a positive influence over the range of segment sizes encountered. Large expanses of fines resulted in depressed richness and diversity. Conversely, smaller segments of fine habitat appear to have a strong positive effect on fish richness and diversity. Large boulders were found in too small a quantity to impact reservoir littoral zone fish assemblages.

The exotic/native ratio of fish abundance averaged about 3/1 in all habitats sampled except fine substrates without overlying structure. Only here were native fish more abundant than exotics.

Comparisons of Fish Assemblages and Habitat Associations in Littoral Zones of Reservoirs in the Willamette Basin, Oregon

by

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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

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Paul Michael Bennett, Author

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Dedication:

To my wife Beverly and my children Christopher and Lara, whom I love very much. They have made sacrifices, as well, in my advances towards fulfillment of this honor.

Composition of Fish Assemblages and Habitat Associations in Littoral Zones of Reservoirs in the Willamette Basin, Oregon

INTRODUCTION

Reservoirs are complex environmental and biological systems that change in temporal and spatial dimensions. They differ from both lakes and streams (Baxter, 1977). At a large scale, reservoirs are artificially influenced aquatic environments in which hydrologic levels and dynamics are manipulated, creating rapidly varying habitats throughout the year. These artificial environments sustain native cool and coldwater riverine fish species as well as introduced species (primarily warmwater fish species). Fish introductions have been shown to negatively impact native fish populations and other taxa as a result of competition, predation (Allendorf, 1991; Moyle and Light, 1996), hybridization, introduction of new diseases, (Allendorf, 1991), trophic and habitat modification, and gene pool deterioration (Crossman, 1991). They also change native fish distribution and cause shifts in their resource use (Brown et al., 2000). Reservoirs often contain fish species that have not coevolved, but rather have existed as an assemblage only briefly in evolutionary time. For this assemblage, the unstable hydrologic regime favors the evolution of generalist species (Fernando and Holcik, 1989).

Within reservoir systems, physical properties vary longitudinally from riverine to lacustrine conditions and latitudinally from littoral to limnetic conditions (Miranda and DeVries, 1996). Species that occupy habitats found in lacustrine conditions should survive in reservoirs. However, when riverine conditions are converted to lacustrine, native species can be locally extirpated and more tolerant species increase in abundance. Species that coexist over time will have different habitat and diet requirements (Hubert and O'Shea, 1992). Most fish stay close to shore leaving the deeper waters poorly utilized (Fernando and Holcik, 1989).

At the reservoir scale, conditions in different reservoirs vary because of morphological, operational, and biological differences. In lake studies system morphology has been demonstrated to influence fish species diversity, distribution of individual fish species, or distribution of fish species assemblages (Tonn and Magnuson, 1982; Rahel, 1984; Benson and Magnuson, 1992). However, habitat has been identified as the primary basis on which many biological communities are organized (Bain et al., 1988). For example, highly adapted bodyforms and mouth structures demonstrate the evolution of fish to exploit specific habitats (Keast and Webb, 1966). Within these habitats, fish distribution is neither even (Sammons and Bettoli, 1999) nor random (Keast and Fox, 1990) but is keyed to physiological and behavioral requirements as well as the availability of preferred habitat (Werner, 1986). Each species seeks its optimal habitat while feeding opportunistically on the available resources (Mendelson, 1975), although some food specialization can occur. Based on reviews of many current aquatic habitat studies, Weaver et al. (1996) concluded that the strength of the relationship between fish community structure and habitat is dependent on the scale (extent and resolution of the habitat structure), the processes that structure the community, and the variability of the habitat.

A fish assemblage can be defined as "fish that occur in a single place, such that they have at least a reasonable opportunity for daily contact with each other" (Matthews, 1998). In this context a fish assemblage simply refers to a group of species found together at a specific sampling site, while the word community often suggests predictable relationships between species. Many studies have documented the temporal and spatial patterns of species abundance and distribution in fish assemblages of various aquatic environments. In stream fish assemblages, abiotic factors such as temperature and substrate have been shown to determine the distribution and abundance of individual species as well as to influence community level properties, such as species richness and production (Rahel and Hubert, 1991). In Lakes, Tonn and Magnuson (1982) and Benson and Magnuson (1992) have described patterns in the species composition of fish assemblages as they relate to habitat complexity, while Rahel (1984) showed how the abiotic factors temperature, turbidity, and acidity could affect fish distribution. Other authors have shown differential habitat use by littoral zone fish according to the depth of water, distance from shore, vertical layer in the water column, and vegetative structure (Werner et al., 1977; Eadie and Keast, 1984). Benson and Magnuson (1992) noted that their research was only the second to quantify within lake spatial variation in fish communities. Studies of relationships between habitat and community are extensive and have been completed in marine environments (Abele, 1974), as well as nonfish communities in freshwater environments including benthic insects (Allan, 1975) and freshwater mollusks (Harman, 1972).

In reservoirs, by comparison, minimal knowledge exists with regard to how fish species assemblages are distributed across spatial and temporal habitat resources (Baxter, 1977; Hubert and O'Shea, 1991, 1992), especially for small fish (Hubert and O'Shea, 1991). Reservoirs have altered riverine habitats and changed species distribution and abundance (U.S. Army Corps of Engineers, 1980). Reservoir species associations have been described relative to elevation changes (Mcdonough and Barr, 1978) and trophic positions (Ploskey and Jenkins, 1982). Most reservoir studies have been limited to the southeast United States and often emphasize the distribution of game or forage fish (Hubert and O'Shea, 1991, 1992). Hubert and O'Shea (1992) suggest there is a need to determine the manner in which various fishes use spatial resources in reservoirs.

Habitat for warmwater species in many Oregon reservoirs is poor because of pre-impoundment clearing of vegetation, followed by reservoir operations that cause fluctuating water levels. Climate and ecological relationships also limit populations of warmwater fish in Oregon. For example less than optimal temperature regimes and decreased growth rates negatively affect spawning activities and may depress overwinter survival of young of year (y-o-y) fish. In Oregon the relationship of warmwater fish to their habitat has been characterized as poorly understood (Oregon Dept. of Fish and Wildlife, 1987).

The largemouth bass (*Micropterus salmoides*) and black and white crappie (*Pomoxis nigromaculatus* and *Pomoxis annularis*, respectively) are of particular interest in this study because these species appear to be the most abundant warmwater fish predator representatives in the littoral zone fish assemblages of the majority of the study reservoirs, based on previous sampling efforts. Largemouth bass is probably the principal nonnative warmwater fish predator in most systems it inhabits (Heidinger, 1975). Additionally, the life history traits, predator-prey relationships, reproduction, and other behaviors are well studied (Lagler, 1956; Bennett, 1971; Heidinger, 1975; Ploskey, 1983; Liston and Chubb, 1984; Chisholm et al., 1989). Largemouth bass are one of the few species plentiful in most Oregon reservoirs. They can have a significant impact on most other fish species in those systems by influencing their size, distribution, and presence. Such species are often referred to as "keystone species" (Power et al., 1996).

Although there has been increased concern about the presence of introduced species, bass continue to be utilized by anglers. In a 1997 Oregon Angler study, basses were cited as the preferred warmwater species, with crappies second (Oregon Dept. of Fish and Wildlife, 1987). Consequently, these species are of economic and social interest. However, most of the value of Oregon's sport fisheries lies in native salmonids, which may be noncompatible with introduced basses. Moehle and Davies (1993) reported that anglers in Idaho preferred fishing for coldwater species by a ratio of 3 to 1.

Although fish species are known to inhabit a wide range of habitats in the littoral zones of reservoirs (Miranda and DeVries, 1996) the fine grained characteristics of habitats and microhabitats (such as vegetation and large wood), are important to the spatial distribution of reservoir littoral zone fish populations. For example, many studies have documented the importance of aquatic plants and inundated vegetation to lakes, ponds, and reservoir fish community dynamics, especially to the growth (Zweracker et al., 1972; Aggus and Elliot, 1975; Shelton et al., 1979; Strange et al., 1982) and survival (Aggus and Elliot, 1975; Werner et al., 1977; Crowder and Cooper, 1982; Werner et al., 1983 a; Durocher et al., 1984; Benton et al., 1994; Paller, 1997) of resident fish, as well as the production of fish (Ginnelly, 1971; Shireman et al., 1981; Strange et al., 1982; Bettoli et al., 1992) and fish food organisms (Aggus, 1971; Allan and Romero, 1975; Mittlebach, 1981 b; Strange et al., 1982; Day et al., 1983).

Large wood can be an important habitat component in reservoir systems where drifting trees and stumps tend to accumulate. Wood structures have been shown to be important cover habitat for nesting largemouth bass adults (Annett, et al., 1996). Smallmouth bass (*Micropterus dolomiew*) populations will increase with the addition of logs to lakes otherwise lacking structure in their littoral zones (Hoff, 1991). Negative impacts have been realized to species composition as well as the plankton and benthos biota with the removal of wood structure (Everett and Ruiz, 1993; Poe et al., 1986).

Invertebrates are attracted to woody debris (Anderson et al., 1978; Dudley and Anderson, 1982; Swanson et al., 1976). For example, when submerged logs exist in moderate quantities, they can provide important cover for fishes and substrates for invertebrates in streams and in standing water (Claflin, 1968; Nilsen and Larimore, 1973;

Bryant, 1983) as well as provide thermal relief in shallow water when solar radiation is intense (Matthews, 1998).

The inundated trees and higher aquatic plants serve as substrates for the development of periphyton communities which subsequently are colonized by higher populations of benthic insects (Cowell and Hudson, 1967). Partially inundated trees also serve as sites for molting and subsequent mating flights of aquatic insects (Cowell and Hudson, 1967). The shattered structure of woody debris provides feeding and spawning sites for fish and other aquatic organisms (Matthews et al., 1986; Hooker, 1990) as well as retention sites for particulate organic matter (Hooker, 1990).

The specific nature as well as availability of physical structure in littoral habitats influences the behavior and survival of fish species (Keast et al., 1978; Johnson and Lynch, 1992). Crowder and Cooper (1979) suggest that structural complexity mediates the ecological interaction between littoral zone fish and their prey. Microhabitat selection is based not only on the availability of abiotic resources but also on other factors such as population density and presence of competitors and predators (Baltz et al., 1991). Jackson et al. (2000) suggest that whether a species occupies specific sites within its potential range is determined by historic biogeographic conditions which have defined the regional species pool as well as the local smaller scale factors such as predation and environmental gradients.

The specific type and complexity of physical structure and its abundance or availability may be important measures of the value of littoral habitat to fish (Benson and

Magnuson, 1992). Behavior, survival (Keast et al., 1978; Johnson and Lynch, 1992), and year class strength (Aggus and Elliot, 1975) have been shown to respond to differences in habitat characteristics.

Hubert and O'Shea (1992) discuss at length the lack of present knowledge concerning reservoir fish and their habitat. There has been minimal research on the relationship between the characteristics of macrohabitats, such as substrate, and microhabitats and their utilization by fish assemblages in reservoirs. Other studies have analyzed fish habitat utilization in lentic habitats using parameters other than substrate size such as bottom gradients (Okeyo and Hassler, 1985; Markham et al., 1991) and water depth (Tonn and Magnuson, 1982; Werner et al., 1977). Stream fish habitat studies generally include water depth and velocity as additional parameters to substrate for study (Gorman and Karr, 1978; Leonard and Orth, 1988; Aadland, 1993). Only a few studies have investigated substrates with or without overlying structure as primary habitat types for fish utilization in a reservoir (Sammons and Bettoli, 1999) or lake setting (Keast et al., 1978; Stang and Hubert, 1984). In a study of Normandy Reservoir (Tennessee), Sammons and Bettoli (1999) determined three black bass species to be most abundant in larger rock or riprap substrates. Largemouth bass, in particular, used the rare riprap habitat type throughout the year. Keast et al. (1978) was able to show habitats of Lake Opinicon (Ontario, Canada) to support characteristic assemblages differing in the number of species, diversity, and abundance while Stang and Hubert (1984) quantified differences in fish use by species in habitats of Clear Lake, Iowa. A review of the literature found no other study analyzing the correlation of substrate segment distribution patterns to fish richness and diversity.

Microhabitats are typically difficult to sample and often overlooked or analyzed in a way that severely limits the scope of inference. Studies which assess the assemblages of fish in lakes and reservoirs that use qualitatively different microhabitats are rare, making it difficult to achieve management goals through habitat manipulation (Summerfelt, 1993). Often reservoir and lake studies investigate habitat influences at too narrow a scope to discern effects of microhabitat on population dynamics (Annett and Dibble et al., 1996). Examples include studies of coves, bays, side channels, sloughs, mainlake habitats, and tributary stream confluences (Meals and Miranda, 1991; Faurot and White, 1994; Brewer et al., 1995), vegetated habitats and habitats with wood (Werner et al., 1978; Gelwick and Matthews, 1990), and complex habitats versus simple habitats (Macrae and Jackson, 2001). Also, traditional fisheries studies have focused on a population rather than the community level (Weaver et al., 1996).

Understanding species distributional patterns and relating them to environmental and biotic factors at an assemblage or community level can lead to a more powerful understanding of the ecological processes that determine the distribution and abundance at the fish community and population level. Results of such a study may also be used as a baseline to monitor ecosystem health (Karr, 1981; Lyons, 1992; Jennings et al., 1998).

Spatial habitat utilization by fish in Willamette River Basin reservoirs, in particular, have not been studied quantitatively. Benson and Magnuson (1992) related the diversity of fish assemblages to slope diversity of specific sites in six Wisconsin lakes. They considered substrate complexity from muck to cobbles but did not consider overlying structure such as wood and vegetation and they considered their study one of only two to quantify within-lake spatial variation in fish communities.

Agencies managing the study reservoirs have altered shoreline habitats by planting grasses, shrubs and trees, and by anchoring large woody structures such as logs. The objectives of such activities have been to reduce erosion and to enhance fish and wildlife habitat. However, the utilization and relative difference in effect to fish community dynamics with the addition of vegetation or wood as overlying structure has been only minmally studied, especially the influence of substrate type to such habitat enhancement projects.

In the study reported here, both substrate size and overlying structure were used to classify reservoir habitats. Substrates are primarily defined by particle size, as was done in this study. However, others have qualified substrate categories in more ecological terms. Kreiger and Ito (1999) described substrates as either being soft (mud or sand) or hard (bedrock, cobble, and pebble) in a study of shortraker rockfish (*Sebastes borealis*) and rougheye rockfish (*S. aleutianus*) in the Gulf of Alaska. Similarly, Bain et al. (1985), in developing a new technique to quantify measures of stream surface coarseness and substrate heterogeneity, reported substrates to be either smooth (flat bedrock and fine material) or rough (larger particle sizes and irregular bedrock).

A major goal of this study was to describe the species composition and habitat utilization of the littoral zone fish assemblages in seven reservoirs of the Willamette Basin, as a contribution to the further understanding of the influence of habitat on fish communities. Greater understanding of these reservoir ecosystems may also provide a basis for manipulating fish species composition and distribution through the modeling of the effects of habitat modification.

The specific objectives of this study were to:

1. Determine the relative abundance and distribution of habitat in the littoral zone of each of seven study reservoirs.
2. Characterize the fish assemblages occupying littoral zone habitats, including estimation of:
    a. Fish species richness, diversity, and composition.
    b. Fish density index.
    c. Composition by percent piscivorous and percent benthic species.
3. Determine, for selected fish species, age, length and weight relationships, including relative weight.

STUDY AREAS

General Characterization

Location

The study reservoirs include five of ten water storage projects and two of three reregulating projects designed, constructed, and operated by the United States Army Corps of Engineers (COE), Portland, Oregon District, in the Willamette River Basin of Oregon. See Figure 1 for a map of the study reservoirs and Table 1 for physical characteristics of the study reservoirs. The five storage reservoirs included in this study are Cottage Grove, Dorena, Green Peter, Hills Creek, and Lookout Point. The two reregulating reservoirs are Dexter and Foster. Foster Reservoir is unique in having both reregulating and flood storage functions. The reregulating reservoirs control water flow fluctuations from upstream hydroelectric dams.

These reservoirs were originally authorized for the multiple purposes of 1) flood control, 2) hydroelectric power generation, 3) navigation, and 4) irrigation (U.S. Army Corps of Engineers, 1982). Reservoirs can also provide recreation as well as fish and wildlife habitat and water quality enhancement. However, reservoir operational practices are not based on fishery needs and these practices are often detrimental to aquatic communities (Oregon Dept. of Fish and Wildlife, 1987).

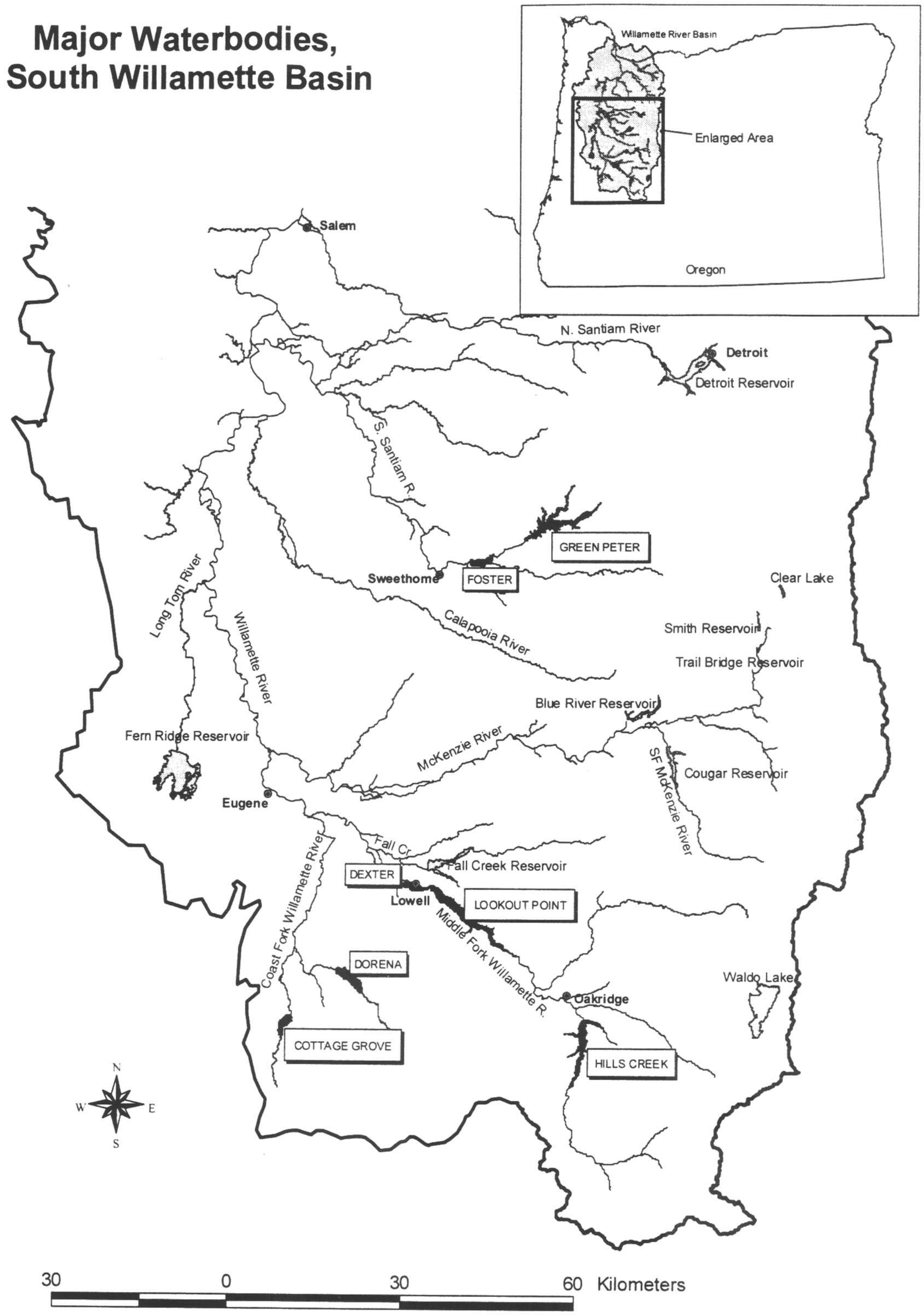


Figure 1. Map of study reservoirs.

Table 1. Physical characteristics of study reservoirs.

Variable	Reservoir						
	Cottage Grove	Dorena	Dexter	Foster	Green Peter	Hills Creek	Lookout Point
Year Completed	1942_5	1948_4	1954_3	1968_1	1968_1	1961_2	1954_3
Length (km)	4.8_5	8.1_4	4.5_3	5.6_1	16.1_1	12.2_2	22.8_3
Elevation (m)	246.3_5	264.0_4	214.1_3	196.0_1	310.9_1	471.8_2	286.8_3
Surface Area (ha)	486.6_5	708.4_4	415.2_3	493.7_1	1505.4_1	1106.8_2	1764.5_3
Basin Area (ha)	26936.0_6	68634.9_6	1295.0_6	56203.0_6	71742.9_6	100750.9_6	155917.9_6
Precipitation (cm)	$120\text{-}160_6$	$130\text{-}200_6$	$120\text{-}180_6$	$150\text{-}360_6$	$180\text{-}250_6$	$110\text{-}180_6$	$120\text{-}180_6$
Volume (10000 m^3)	4132.19_6	9571.88_6	3392.10_6	7524.28_6	53040.04_6	43912.22_6	55877.07_6
Mean Depth (m)	9.0_6	12.9_6	8.2_6	15.2_6	34.7_6	39.6_6	31.7_6
Maximum Depth (m)	22.3_6	29.6_6	17.1_6	33.5_6	96.0_6	91.1_6	71.3_6
Shoal Area $_6$ (%)	17_6	15_6	21_6	10_6	6_6	5_6	3_6
Shoreline Length (km)	12.2_6	20.9_6	11.3_6	31.7_6	77.2_6	51.5_6	56.0_6
Mean Width (km)	1.0_7	1.0_7	0.8_7	0.6_7	1.0_7	0.8_7	0.8_7
Maximum Width (km)	1.3_7	1.6_7	1.1_7	1.3_7	3.5_7	1.4_7	1.4_7
Volume Development	1.20_6	1.37_6	1.27_6	1.36_6	0.98_6	1.00_6	1.24_6
Shoreline Development	1.61_7 2.05_6	3.83_7 1.80_6	1.56_7 1.78_6	3.67_7 4.06_6	5.60_7 6.43_6	4.37_7 3.88_6	1.42_7 4.00_6

$_1$ U.S Army Corps of Engineers, 1987
$_2$ U.S. Army Corps of Engineers, 1990a
$_3$ U.S. Army Corps of Engineers, 1989a
$_4$ U.S. Army Corps of Engineers, 1990b
$_5$ U.S. Army Corps of Engineers, 1989b
$_6$ Johnson et al., 1985
$_7$ U.S. Army Corps of Engineers, 1982

The Willamette River is the last major tributary to the Columbia River from Oregon before the Columbia River reaches the Pacific Ocean. The Willamette River basin is a 29,689 km^2 watershed (U.S. Army Corps of Engineers, 1982). The basin is roughly rectangular in shape, approximately 240 km long and 120 km wide, and oriented in a north south direction (Richert et al., 1976). The basin covers approximately 12% of the state of Oregon (Oregon Dept. of Environmental Quality, 1992).

Climate

The general climate of the Willamette River basin is temperate maritime with moderately dry, warm summers and mild wet winters (Oregon Dept. of Fish and Wildlife, 1992). The average annual precipitation in this basin is 160 cm with a range of 102 cm to 508 cm (U.S. Army Corps of Engineers, 1982). In the Willamette Valley, 70% of the precipitation occurs between November and March, whereas, only 5% occurs from June to August (Pacific Northwest River Basins Commission, 1972). The average annual air temperature in the Willamette Valley is 11.6 °C, with an average winter temperature of 4.4 °C and an average summer temperature of 19.4 °C (U.S. Army Corps of Engineers, 1982).

Geomorphology

The geographic region of the study reservoirs is characterized by steep ridges, narrow valleys, and volcanic soils (Franklin and Dryness, 1973) derived from basalt, andesite and volcanic debris (Richert et al., 1976). Soils are generally fine textured and unstable with high clay contents. Surface erosion forms large quantities of sediment downstream and often results in turbid water (Oregon Dept. of Fish and Wildlife, 1997). In particular, erosion of clay soils is reported as a cause of high turbidity in Hills Creek Reservoir (Klingeman et al., 1971). Within this reservoir, exposure of unstable shorelines to erosion by winter storms at low pool contributes to this turbidity problem (Klingeman et al., 1971), which can persist downstream.

Limnology

All of the study reservoirs show warm monomictic mixing patterns except Hills Creek, which is marginally dimictic (U.S. Army Corps of Engineers, 1982). Additionally, all reservoirs appear to be generally mesotrophic based on Carlsons' (1977) trophic status index. However, Hills Creek and Dexter Reservoirs show eutrophic tendencies (U.S. Army Corps of Engineers, 1980). See Table 2 for water quality characteristics of the study reservoirs.

Table 2. General limnological data for all study reservoirs.

Variable	Cottage Grove	Dorena	Dexter	Reservoir Foster	Green Peter	Hills Creek	Lookout Point
Na (mg/l)	4.5_1	3.1_1	2.8_1	3.0_1	2.1_1	3.2_1	2.9_1
K (mg/l)	1.0_1	0.5_1	0.7_1	0.5_1	0.3_1	0.8_1	0.8_1
Ca (mg/)l	6.4_1	5.5_1	4.7_1	4.4_1	4.0_1	5.3_1	4.9_1
Mg (mg/)l	2.1_1	1.3_1	1.8_1	1.1_1	0.8_1	1.6_1	1.7_1
Cl (mg/l)	2.4_1	1.3_1	1.5_1	1.2_1	1.0_1	0.9_1	1.3_1
Alkalinity (CaCO3) (mg/l)	24	24	24	23	23	22	24
Total P (mg/l)	0.002_1	0.003_1	0.015_1	0.006_1	0.002_1	0.015_1	0.003_1
Conductivity (Microhoms per cm)	63_1	49_1	47_1	42_1	34_1	52_1	48_1
pH (mid-summer)	7.7_1	7.9_1	7.6_1	7.2_1	7.3_1	8.1_1	8.0_1
	7.6	7.6	7.7	7.4	7.6	7.8	7.8
Secchi Depth (m)	5.8_1	4.8_1	4.1_1	6.2_1	3.6_1	4.6_1	4.8_1
	5.5	4.9	3.6	6.3	4.9	6.0	3.9
Trophic State Index (Carlson 1977)	39_3	36_3	51_3	33_3	45_3	51_3	31_3

$_1$ Johnson et al., 1985

$_3$ U.S.Army Corps of Engineers, 1982

Individual Reservoir Characterization

Cottage Grove and Dorena Reservoirs

Cottage Grove Reservoir is located on the Coast Fork of the Willamette River and is 8.1 km south of Cottage Grove, Oregon, whereas Dorena Reservoir is located on the Row River, 9.7 km east of Cottage Grove, Oregon.

Cottage Grove and Dorena Reservoirs both receive high recreation use because of their close proximity to the towns of Cottage Grove and Eugene, fishing, aesthetically pleasing environment, and well developed recreation facilities. Due to their high recreation use the COE insures that these systems attain maximum conservation pool levels each summer through Labor Day before being drawn down to minimum conservation pool levels in the fall and winter. The water is maintained at this minimum conservation pool level by release of winter storm runoff until spring fill-up begins.

Cottage Grove and Dorena Reservoirs are moderate in size and depth in comparison to the other study reservoirs and have extensive shallow littoral zones (i.e., high percentage of shoal area) (Table 1), with extensive areas of dense vegetation. Water retention times are moderate in comparison to the other study reservoirs (Table 3). Extensive growths of rooted macrophytes are usually associated with reservoirs exhibiting such large areas of shallow water that receive good light penetration. Such reservoirs generally have a relatively shallow mean depth as well (Table 1). The physical and chemical release of minerals is probably of comparatively greater magnitude in these reservoirs with small volume to soil ratios.

Hills Creek, Lookout Point, and Dexter Reservoirs

Hills Creek, Lookout Point, and Dexter Reservoirs are all located on the Middle Fork of the Willamette River. Hills Creek Dam is 72.4 km southeast of Eugene, whereas Lookout Point and Dexter Dams are downstream and 35.4 and 32.2 km southeast of Eugene, respectively.

Dexter Reservoir is unique among the seven study reservoirs in having large areas of very shallow water (Table 1) and two point sources of major nutrient loading on the reservoir shoreline. Several hundred meters of the reservoir are bordered by homes with large lush lawns. Consequently, fertilizers applied to these lawns may ultimately reach the reservoir (Oregon Dept. of Environmental Quality, 1974). Also, the Lowell Sewage Treatment Plant discharges about 113,560 liters/day of secondarily treated municipal sewage into the reservoir (Oregon Dept. of Environmental Quality, 1974). The combination of those nutrients has resulted in extensive coverage of nearshore habitats by rooted aquatic plants, especially *Elodea canadensis* and *Potomogeton sp.*. Despite the heavy nutrient loading, the water quality of Dexter Reservoir remains high as evidenced by relatively low levels of nitrogen and phosphorous (Oregon Dept. of Environmental Quality, 1974). The short retention times of this reservoir (Table 3) may limit nutrient storage in this system. Also the large plant community is probably removing nutrients from the water fast enough to prevent substantial increases in water nutrient levels during most of the year. However, this reservoir experiences heavy annual algal blooms, primarily in late summer and early fall when temperatures and bacteria decomposition rates are generally high, which suggests concentration levels of nitrogen and phosphorous may be high at certain times of the year. Since the water released to Dexter Reservoir from Lookout Point Reservoir hypolimnion is cool water, usually 7-10° C, the Oregon Dept. of Environmental Quality (1974) suggests that this restricts excessive vegetative growth .

Hills Creek Reservoir also has some unique tendencies among the seven study reservoirs. Klingeman et al. (1971) reported seasonally large quantities of algae, as well as suspended clays from drainage basin soil erosion and slumping activity, result in highly turbid waters in that system. Fluctuating water levels also accelerate erosion from wave action on unconsolidated shoreline deposits. This erosion is accentuated by natural turbidity levels, ultimately reducing sunlight penetration and negatively affecting biological production levels, including macrophyte community development (Ploskey, 1981; Jenkins, 1982). When water is at minimum conservation pool, winter storms erode exposed banks within the fluctuation zone and contribute further to the turbidity problems at Hills Creek Reservoir (Klingeman et al., 1971; Skeesick and Jones, 1988; Oregon Dept. of Fish and Wildlife, 1997).

Green Peter and Foster Reservoirs

Green Peter Reservoir is located on the Middle Santiam River 4.0 km NE of Sweet Home, Oregon. Foster Reservoir is located just downstream at the mouth of this river and its junction with the South Santiam River, about 12.9 km NE of Sweet Home. Foster Reservoir is unique in having both a reregulating function and flood storage capacity.

Green Peter Reservoir shares characteristics with Lookout Point and Hills Creek Reservoirs in that these systems are all relatively long, deep, narrow, and straight with relatively steep hillsides. These conditions often result in long wind fetches, accompanied by high wave activity. When these conditions are coupled with shorelines of silts and clays, turbid waters can result. Also, all these reservoirs have extensive water fluctuation zones and long water retention times relative to the other study reservoirs (Table 3). Maximum conservation pool levels are not always attained during the summer months in these reservoirs. During those years the highest water level attained tends to be much lower than the maximum conservation level (Table 4).

Water Management-Retention Times

Dexter Reservoir exhibits daily water fluctuations up to 1.5 m and extremely short water retention times that can prevent thermal stratification

Table 3. Water management levels (U.S. Army Corps of Engineers, 1989c) and median theoretical water retention time summaries (U.S. Army Corps of Engineers, 1979).

	Reservoir						
	Cottage Grove	Dorena	Dexter	Foster	Green Peter	Hills Creek	Lookout Point
Minimum Flood Conservation Pool (m above sea level)	229_1	235_1	210_1	187_1	281_1	441_1	251_1
Maximum Flood Conservation Pool Level (m above sea level)	241_1	254_1	212_1	194_1	308_1	470_1	282_1
Water Fluctuation Zone (m)	12	19	2	7	27	29	31
Mean Water Retention Time-Annual Average (Months)	3.9_2	4.3_2	0.2_2	0.6_2	9.5_2	6.9_2	2.3_2
Mean Water Retention Time May-August (Months)	8.5_2	10.1_2	0.3_2	1.0_2	18.6_2	10.4_2	3.9_2

$_1$ U.S. Army Corps of Engineers, 1989c
$_2$ U.S. Army Corps of Engineers, 1979

Table 4. Historical rule curve fill data (unpublished data obtained from U.S. Army Corps of Engineers, 1996,1997). Data listed for years 1988-1996 for each reservoir are: Rule Curve Maximum Conservation Pool (M.C.P.) elevation achieved annually-(yes or no/ percent of M.C.P. period achieved annually/ meters below M.C.P. at maximum annual water level).

	Reservoir						
	Cottage Grove	Dorena	Dexter	Foster	Green Peter	Hills Creek	Lookout Point
1996	yes/74/NA	yes/74/NA		yes/100/ NA	yes/66/NA	yes/100/ NA	yes/48/NA
1995	yes/68/NA	yes/74/NA		yes/100/ NA	yes/36/NA	yes/91/NA	yes/42/NA
1994	no/NA/-2	yes/46/NA		yes/100/ NA	yes/44/NA	no/NA/-15	no/NA/30
1993	yes/59/NA	yes/55/NA		yes/100/ NA	yes/89/NA	yes/63/NA	yes/42/NA
1992	no/NA/-2	no/NA/-2		yes/100/ NA	no/NA/-1	no/NA/34	no/NA/39
1991	yes/59/NA	yes/52/NA		yes/100/ NA	yes/61/NA	yes/90/NA	yes/58/NA
1990	yes/39/NA	yes/57/NA		yes/100/ NA	yes/78/NA	yes/100/ NA	yes/55/NA
1989	yes/36/NA	yes/43/NA		yes/100/ NA	yes/56/NA	yes/76/NA	yes/43/NA
1988	yes/61/NA	yes/64/NA		yes/100/ NA	yes/61/NA	yes/79/NA	yes/43/NA
Historic Achieve-ment of M.C.P. Elev.(% of years)	100	100		100	100	78	78
Historic Ahieve-ment of Scheduled M.C.P. Duration	57	58		100	56	86	47
Length of Specified Annual M.C.P. (Months)	3.5	3.5		4.75	3.75	3.5	3.75
Specified Annual M.C.P. Duration	May 15-Sept. 1	May 15-Sept. 1		May 7-Oct. 1	May 7-Sept. 1	May 15-Sept. 1	May 7-Sept. 1

(U.S. Army Corps of Engineers, 1982). All the study reservoirs are managed according to a yearly regulation schedule or rule curve composed of three seasons: 1) the winter flood control season in which much drainage basin runoff enters the reservoir system and water levels fluctuate about a minimum conservation pool level; 2) the conservation storage season in which water is stored during the spring; and 3) the conservation holding-and-release season in which water is either held at a maximum conservation pool throughout the summer or reaches a maximum summer level and is then released slowly to enhance downstream flows and hydroelectric capacity, with subsequent release in the fall to minimum pool levels (Table 3, Figure 2). The timing of the regulation schedules varies slightly between reservoirs (see Table 4).

Seasonal changes in water retention time correspond to flood control regulation seasons described above: 1) water retention times are reduced from summer levels in the late fall as the reservoirs are emptied to a minimum conservation pool level and reach their lowest values in the winter as the reservoir is kept at the minimum conservation pool level accompanied by high winter stream flows; 2) water retention times are increased in the spring as filling occurs; and 3) the highest retention times occur in the summer and early

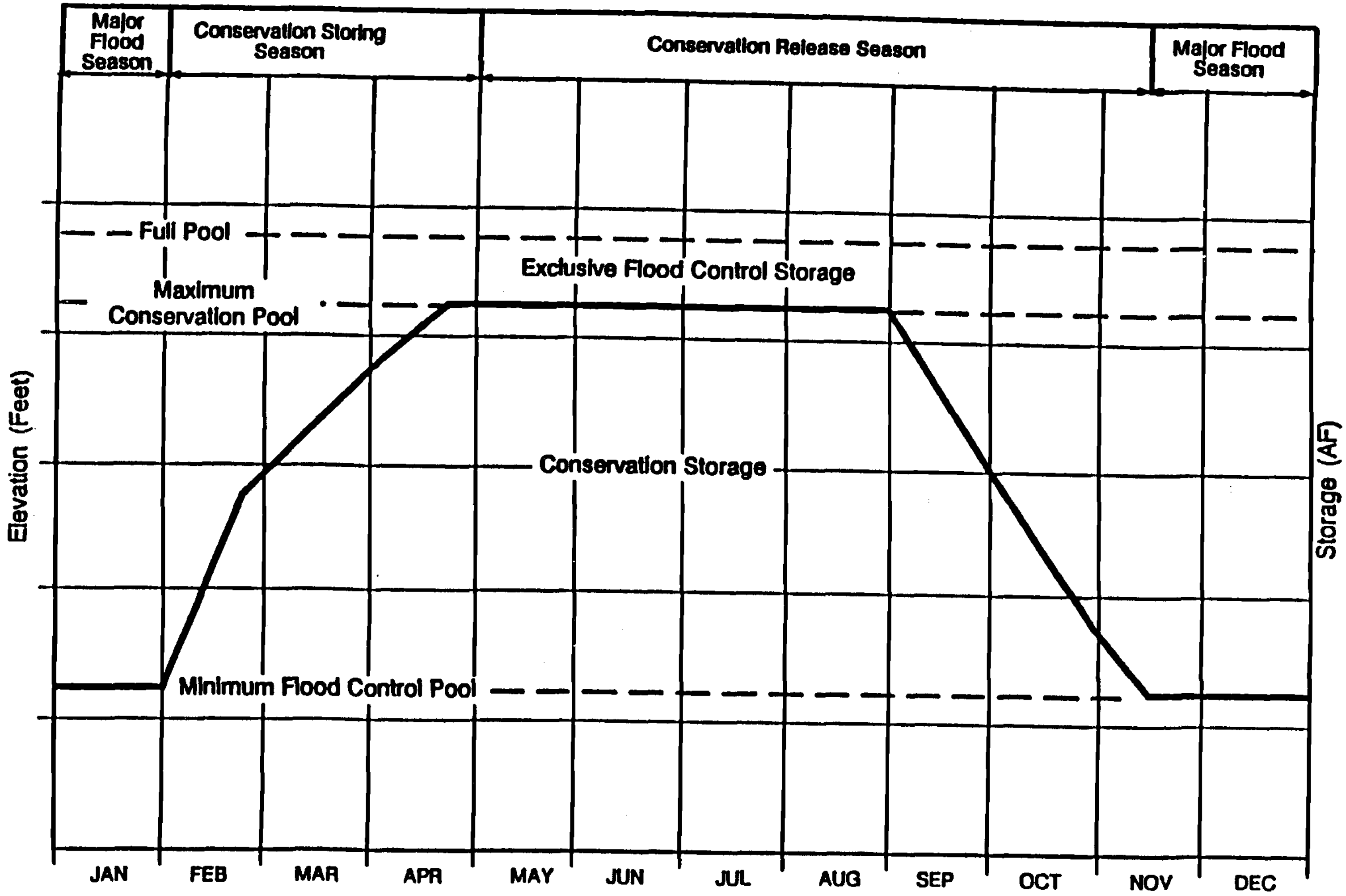


Figure 2. Generic flood control rule curve and reservoir regulation schedule (U.S.Army Corps of Engineers, 1989 c).

Table 5. Median theoretical water retention time in days (U.S. Army Corps of Engineers, 1979).

Reservoir	Median Theoretical Water Retention Times (Days)											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Cottage Grove	4	7	17	38	85	161	329	446	261	38	5	3
Dorena	5	7	13	31	57	170	484	505	218	47	8	5
Dexter	3	8	11	10	6	8	9	8	6	4	3	3
Foster	3	9	13	16	9	29	44	32	19	17	5	3
Green Peter	30	52	86	98	116	368	847	899	624	182	99	29
Hills Creek	40	70	108	111	106	218	401	519	463	273	116	48
Lookout Point	27	29	46	50	52	107	179	134	92	81	30	15

fall as inflows decline, and water is conserved for irrigation, recreation, and low flow augmentation. Monthly water retention times, in days, shown in Table 5 are a result of dividing the average monthly reservoir volume by the average monthly inflow over the lifetime of the reservoir operation (U.S. Army Corps of Engineers, 1979). The median value for each individual month represents the monthly theoretical retention time. For summary purposes, a 12-month and growing season (May-August) monthly mean for water retention times are also shown in Table 3.

METHODS

Habitat Classification

Littoral zone fish assemblages in freshwater are often associated with shoreline cover (Betsill et. al., 1986; Hubert and O'Shea, 1992; Wildhaber and Neill, 1992). Littoral zone habitat types sampled for this study were classified according to substrate particle size class (macrohabitat structure) (Table 6) and the structure in the overlying water column (microhabitat). The microhabitats sampled were large wood and vegetation (aquatic or terrestrial macrophytes). The habitat classification scheme includes eleven habitat types (Table 6). Most habitat types were found in each reservoir (Table 7).

Macrohabitat Structural Component

Shoreline substrates were inventoried in all study reservoirs during the spring of 1995 with the exception of Green Peter and Foster, which were inventoried in the spring of 1996. Representative ground slopes were measured with a clinometer.

Substrate sizes in the littoral zone were categorized according to the classification of the National Research Council in 1947, as reported by Fairbridge and Bourgeois (1978):

1) fine sediments- sand, silt, clay- 0 to 2 mm
2) gravel to small boulder- >2 to 1024 mm
3) large boulder- >1024 to 4096 mm
4) bedrock- consolidated rock structure >4096 mm

Table 6. Classification of habitat types in reservoir littoral zones by substrate (macrohabitat) and overlying water column habitat (microhabitat). Substrate size categories were adapted from the National Research Council (Fairbridge and Bourgeois, 1978).

Water Column Habitat (Microhabitat)	Substrate Particle Size (Macrohabitat)			
	Bedrock (Consolidated Rock > 4096mm)	Fine (≤2 mm)	Gravel-Small Boulder (>2-1024 mm)	Large Boulder (>1024-4096 mm)
Vegetation (inundated terrestrial grasses, sedges, and aquatic plants)	N/A	F/Veg	G-SB/Veg	LB/Veg
Large wood (logs, stumps)	BR/Wood	F/Wood	G-SB/Wood	LB/Wood
No overlying material in water column	BR/None	F/None	G-SB/None	LB/None

Microhabitat Structural Component

. The microhabitats analyzed in this study include large wood and vegetation. Vegetation was classified to be an overlying structure type if it existed visually at more than ten stems per square meter in a 50-m section of shoreline. Large wood was considered to be an overlying structure type when either of the following criteria was satisfied: 1) stumps of 0.3 m or greater existed in quantities between six and twelve in a 50 m section of shoreline or 2) logs of 15.2 cm in diameter and 4.6 m in length existed in quantities between six and twelve in a 50-m section of shoreline. Areas with more than 12 stumps or large logs present were considered too difficult to sample effectively.

Table 7. Habitat types present in each study reservoir in sections of at least 50 meters of shoreline length.

Habitat Type	Reservoir						
	Cottage Grove	Dorena	Dexter	Foster	Green Peter	Hills Creek	Lookout Point
BR/None	X	X	X	X	X	X	X
BR/Wood	---------	X	---------	---------	X	X	X
F/None	---------	X	X	X	X	X	---------
F/Veg	X	X	X	X	X	X	X
F/Wood	---------	X	---------	X	X	X	X
G-SB/None	X	X	X	X	X	X	X
G-SB/Veg	X	X	X	X	X	X	X
G-SB/Wood	---------	X	X	X	X	X	X
LB/None	X	X	---------	X	X	X	X
LB/Veg	---------	---------	---------	---------	---------	---------	X
LB/Wood	---------	---------	---------	---------	---------	X	X
Total	5	9	6	8	9	10	10

Sampling Design

Reservoir Selection

Reservoirs within the Willamette Basin were selected for this study based on their reasonably close proximity to each other and a historical presence of introduced fish species.

Macrohabitat Inventory

Macrohabitats were inventoried in each reservoir according to dominant (>80% surface area cover) substrate categories along the entire shoreline littoral zone. Habitats were not sampled in coves separated from the reservoir by a road where access by boat was generally unavailable and potential for open reservoir conditions was limited. The minimum macrohabitat segment length considered to be ecologically significant at the reservoir scale and therefore inventoried was arbitrarily set at 15 m. These macrohabitats were marked on a 1-inch: 1000-feet contour map based on visual field correlations to map location. Segments on maps were measured in the office using a Scalex Plan Wheel and converted to metric measurements.

The majority of the macrohabitat mapping was conducted in the spring of 1995 and between 3/19/96 and 5/15/96, when the water was well below maximum conservation pool level and substrate particle sizes of the surface layer could easily be discerned.

Dexter Reservoir, where the water level changes daily up to 1.5 m, was mapped at its lowest level.

The inventory process consisted of the identification of macrohabitat segments from a boat moving slowly around the perimeter of each reservoir. Tick marks were made on the reservoir map at each change in substrate size category. The following were determined and noted during the inventory process: 1) dominant, secondary, and tertiary substrates, 2) nature of the bedrock (i.e., fractured or continuous), and 3) the general arrangement of the substrate classes (i.e., size class uniformly dispersed or clumped).

Fish Electroshocking

General Fish Electroshocking Procedures

Habitats were sampled only during the daytime hours of 09:00 A.M. and 04:00 P.M. The reservoirs were sampled only during late spring, summer, and early fall when they are typically at maximum conservation pool level and shoreline areas are inundated with water.

The sampling area was confined to the area between the shoreline and outside boundary of the middle infralittoral zone (zone of floating macrophytes). The entire length of all reservoirs was available for sampling except those areas in the vicinity of high recreation use areas such as boat ramps and camping areas, areas physically blocked by roads and log booms, areas where water was too shallow for the electroshock boat to operate or along dam faces where sampling can be unsafe and conditions are often not representative of the general reservoir shoreline.

Fish were sampled with electroshocking equipment generating at a level to produce approximately 3 amps of direct current between the submerged electrodes. The electroshocking equipment consisted of a 2.5 GPP, 5 horsepower generator, and two 2.3 m, 180-degree adjustable booms from which two 0.9-m diameter umbrella anode arrays with four stainless steel drop electrodes were attached.

Sampling passes consisted of maneuvering the boat in arcs which became perpendicular to the shoreline in such a way that successive arcs were parallel with each other and not overlapping. Electroshock pass lengths began at approximately a 3 m depth and then continued into the shoreline. Each site was sampled for approximately four minutes (see Appendix). Shocked fish were collected with a 1/4-inch mesh dip net from the bow and/or sides of the boat. Each fish sampled was weighed to the nearest gram, measured to the nearest millimeter total length, and identified to species. Additionally, unusual fish condition was noted.

Water and air temperature, and weather conditions were recorded during each sampling period. Also, shocking time, in seconds, and the time of day when sampling operations were conducted were recorded. Additional observations and characterizations were noted during the habitat electroshocking phase of work in 1996 and include: 1) species of vegetation and growth form (i.e., emergent rooted, floating leave rooted, or submerged rooted), 2) percent slope of the site based on clinometer measurement, 3) classification of the habitat type directly to the left and right of the sampling site, 4) general site substrate particle size, 5) number and type (logs, stumps) of large wood, and 6) a determination of an overall sheltered or unsheltered condition in respect to wind and wave action.

1995 Reservoir Block Sampling

The purpose of the initial sampling effort in 1995 was 1) to obtain both a representative number and size range of bass and crappie species for otolith removal and subsequent age analysis, 2) to collect representative length and weight data for fish inhabiting each study reservoir, and 3) to become familiar with the types of habitats, both their similarities and differences, represented in each reservoir so that an acceptable experimental design could be developed to investigate the relationship of littoral zone fish assemblages to littoral zone habitat characteristics in the study reservoirs the following year.

The 1995 sampling work was conducted between 6/22/95 and 9/07/95. With the assistance of Oregon State University Statistics Department staff, a block sampling protocol was developed to obtain representative fish samples for otolith extraction as well as representative littoral zone fish population data described earlier. All reservoirs were divided on a 1-inch: 1000-feet contour map into approximately equal shoreline segments

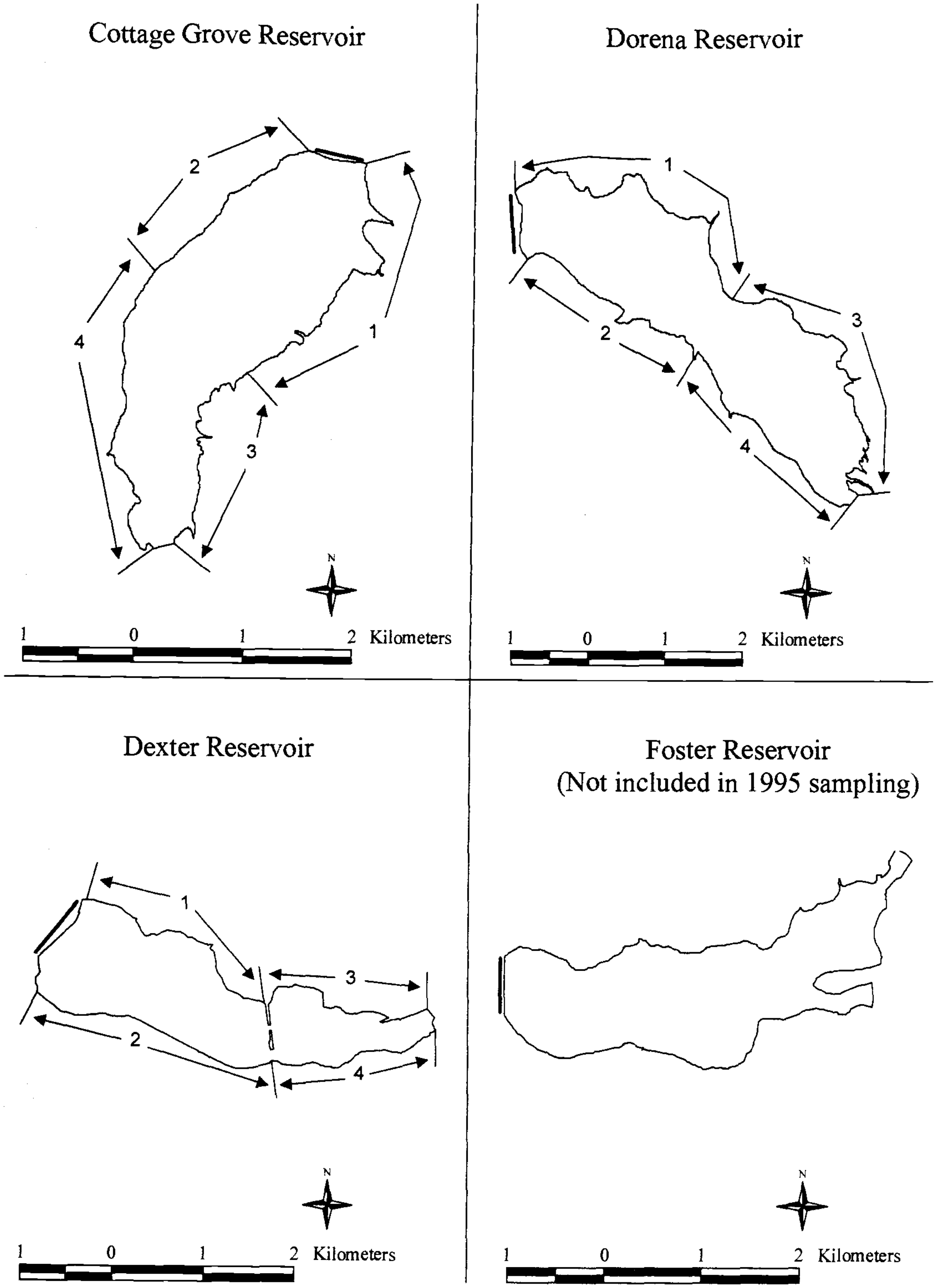


Figure 3. Map of locations for 1995 sampling at Cottage Grove, Dorena, Dexter, and Foster Reservoirs, Willamette Basin, Oregon.

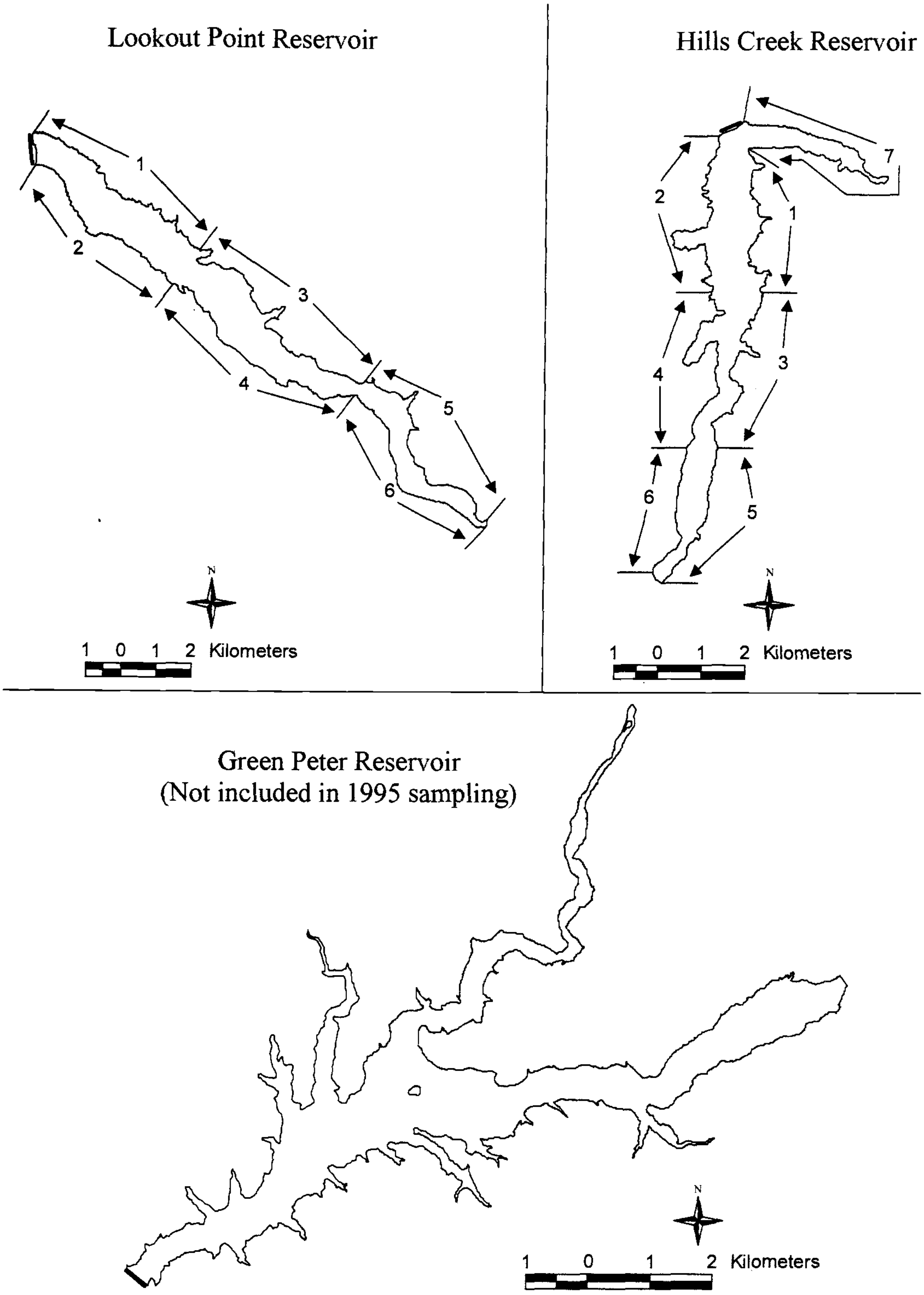


Figure 4. Map of locations for 1995 sampling at Lookout Point, Hills Creek, and Green Peter Reservoirs, Willamette Basin, Oregon.

representing a length that could be effectively sampled in one day using the standard boat electroshocking techniques described earlier. Dexter, Dorena, and Cottage Grove Reservoirs were divided into four sampling blocks (Figure 3), while Lookout Point Reservoir was divided into six sampling blocks (Figure 4), and Hills Creek (Figure 4) was divided into seven sampling blocks. Foster (Figure 3) and Green Peter (Figure 4) reservoirs were added after 1995 to maximize the potential ecological inference and statistical validity.

Sampling segments for each day were selected by a roll of a dice, and direction of movement (i.e., up reservoir or down reservoir) along the shoreline was alternated each day, until all sampling segments in all study reservoirs had been sampled. Efforts were made to insure that a different reservoir was sampled each day or if a reservoir was sampled twice in a row several days had passed between sampling times. On days when more than one sampling segment could be completed, the second sampling segment was selected on the other side of the reservoir to standardize sampling protocol and maximize time efficiency.

Age Determination-Otolith Analysis

Otoliths were used for age analysis in this study because the sample size was small and otolith measurements are more accurate in comparison than scale measurements in aging fish (Ambrose, 1983). However, scales were used to validate age estimates from otoliths.

The largest otoliths, the sagittae, were chosen for age analysis because of their ease of removal and handling and because they contain the widest increments and clearest resolution of general otolith features. The otoliths were removed from the saccular vestibule of the pars inferior by ventral incision (Secor et. al., 1991). The macula and otolithic membrane material were removed from the otoliths to the extent possible in the field with forceps. The otoliths were stored in envelopes until analysis.

The otoliths were cleaned and cleared prior to age analysis. Otoliths were immersed into a Hagert Sonic Cleaner containing a 12% sodium hypochlorite solution for cleaning. The otoliths were then rinsed in distilled water and immersed briefly in a 190 proof alcohol bath. Otoliths were air dried prior to the clearing process.

Initially, two different solutions were used to clear the otoliths; glycerin (assay 99.8%) and low viscosity (150 cs) immersion oil. One otolith from each pair was placed in a 1.5 ml polypropylene microcentrifuge tube containing one of the solutions to determine the effectiveness of each solution in providing a readable otolith for age determination. Otolith vials were stored for a minimum of 2 wk in microcentrifuge vial racks prior to reading. The immersion oil was more effective in clearing otoliths of bass and crappie species in these reservoirs. The otoliths were more readible if they were left in the clearing solution for longer periods. Consequently, the majority of the otoliths were cleared in immersion oil. When immersion oil was used exclusively for clearing, only one of each otolith pair was placed in this solution, the other was stored dry.

The otoliths were placed in a petri dish containing a sufficient quantity of immersion oil to cover the otolith. The otoliths were then read whole against a black background using a dissecting microscope.

1996-Habitat Sampling

Habitat conditions were sampled in 1996. Sampling sites were chosen at random from a list of all segments of each substrate type $\geq$50 m from a random number chart. In those reservoirs having only a few sites of a specific macrohabitat, all of the macrohabitat may have been sampled. When segments of a particular habitat type were less than 100 m, the sampling site was located in the middle of the segment. For longer segments of a particular habitat type (>100 m), the segment was divided into 50-m lengths, and the sampling site was chose randomly within the segment. Habitat conditions were measured between 7/02/96 and 10/09/96 (see Appendix).

Boundaries of two 50-m replicates representing each habitat type, for a potential total of 18 sampling sites per reservoir, were marked with orange and pink fluorescent ribbon attached to shoreline objects. The sites were measured by stretching a fiberglass tape between the boundaries.

Water Quality

At least one temperature and oxygen profile was measured at each reservoir. Alkalinity, secchi depth, and pH also were measured to assess differences in water quality. These water quality parameters were measured approximately 500 m up reservoir from the dam in the center of the waterway.

Oxygen profiles were recorded to a depth of 30 m using a Yellow Springs Instrument Co. (YSI) oxygen meter, model 51B with an accuracy and precision of ± 0.2 mg/l. The oxygen sensor automaticly compensated for pressure. Temperature was also recorded with this meter, and surface temperature was measured using a digital thermometer.

Alkalinity was measured with a Lamotte alkalinity test kit. pH readings were measured with a Schott pH Meter.

Secchi disk measurements were recorded because it is an easily performed measurement that can be used to show the general trophic status of a reservoir (U.S. Army Corps of Engineers, 1980). Carlson (1977) originally developed a transparency index to estimate the relative biomass and consequently the trophic status of lakes. This index has been widely applied to reservoirs as well. The trophic status index = 10(6-$\log_2$ Secchi Disk value in meters). The oligotrophic state index is considered to have a trophic state index of 0 to 25 units. The mesotrophic range is 30 to 45 units and the eutrophic range is 50 to 65 units. The transition zones are between 25 and 30 units and 45 to 50 units.

Relative Weight

The relative weight index (W_r), based on a standard curve derived from western warmwater fish (Murphy and Willis, 1991), was used in this study to assess fish condition and is calculated by the general equation $W_r = W/W_s*100$, where W is the weight (g) of an individual fish and W_s is the standard weight (g) of a fish of the same length. The minimum length applicable to each equation is specified. A standard weight equation has been developed for some but not all warmwater fish species in western environments. Equations are available for the following species in this study: 1) black and white crappie (Neumann and Murphy, 1991), 2) bluegill (Hillman, 1982), 3) largemouth bass (Henson, 1991), and 4) smallmouth bass (Anderson, 1980) (Table 8).

Table 8. Standard weight (W_s) equations for warmwater fish species sampled. L = Total length. (Adapted from Murphy and Willis 1991).

Species	Minimum Length (mm)	Standard Weight Equation
Black Crappie	100	$Log_{10}W_s = -5.618 + 3.345*(Log_{10}L)$
Bluegill	80	$Log_{10}W_s = -5.374 + 3.316*(Log_{10}L)$
Largemouth Bass	150	$Log_{10}W_s = -5.528 + 3.273*(Log_{10}L)$
Smallmouth Bass	180	$Log_{10}W_s = -4.983 + 3.055*(Log_{10}L)$
White Crappie	100	$Log_{10}W_s = -5.642 + 3.332*(Log_{10}L)$

Statistical Analysis

Prior to statistical analysis, most data were transformed to compensate for skewed sample distributions with uneven spread and to adhere to analysis model guidelines. Two transformations were applied. Arc-sine transformation was used when data were binomial proportions (Snedecor and Cochran, 1980). With this transformation, proportions near zero or one were modified to non-zero values. Zero values were modified to 1/4n and 100% values were modified to (n-1/4)/n prior to arc sine transformation. The arc sine transformation equation used was: Transformed X = ASIN (SQRT(X/100)) *180/pi where ASIN = arc sine, SQRT = square root and pi = (3.141592654.....). Log transformation was used to stabilize variance when the standard deviation varies directly with the mean (Snedecor and Cochran, 1980).

The generalized randomized block design, as described by Hinkelmann and Kempthorne (1994), was used to analyze differences between habitat types. Tukeys HSD test was used to test for significant differences between means. Significant relationships were generally determined at $\geq$95% confidence intervals and not less than 90%. The generalized randomized block design was chosen for its ability to address the potential for substantial variability in habitat types across reservoir systems and to be able to make the maximum inference in conjunction with this variability. In this statistical analysis, for a given treatment variable, two mean replicate values per habitat type from each reservoir were compared across reservoirs to determine if significant differences exist between habitat types.

One-way ANOVA was generally used for all analyses performed at the reservoir or combined reservoir scale. One-way ANOVA was also the primary statistical tool used to analyze mean substrate segment length, mean ground slope, and mean length at age for largemouth bass. Significant differences were generally determined at $P \leq 0.05$ (Tukey HSD) but not less than $P<0.10$ (Tukey HSD).

Regressions of length vs. weight of 10 fish species and age vs. length for largemouth bass were also compared across reservoirs, with multiple regression analysis, to determine if significant differences in y-intercept and/or slope exist.

All statistical analyses were performed utilizing Statgraphics (Statistical Graphics Corporation, 1996).

RESULTS

Macrohabitat Inventory

The total inventoried shoreline lengths for each study reservoir are shorter than the total shoreline length for these reservoirs (Johnson et al., 1985). The inventoried lengths of Hills Creek (37.52 km), Lookout Point (43.61 km), and Green Peter (62.36 km) Reservoirs were much larger than Dexter (9.94 km), Cottage Grove (11.73 km), Foster (14.49 km), and Dorena (17.01 km) reservoirs. Lengths and quantity data for individual segments are summarized by substrate size category and reservoir (Tables 9-12).

Bedrock Substrates

In general, the larger reservoirs in this group, with the steepest mean slopes contained the greater amount of bedrock substrates. The mean lengths for bedrock segments of Foster (256.24 m), Green Peter (308.97 m), and Lookout Point (212.06) Reservoirs were significantly different ($P<0.05$) from Hills Creek Reservoir (81.46 m) (Table 9). At $P<0.05$, bedrock mean segment length in Green Peter Reservoir (308.97 m) was also significantly different from bedrock segment length in Dexter Reservoir (55.58 m). These two reservoirs also represent the longest and shortest bedrock mean segment lengths.

Green Peter, Hills Creek, and Lookout Point, the three largest reservoirs studied, had much higher numbers of bedrock segments per kilometer at 1.49, 1.49, and 0.80,

Table 9. Bedrock substrate specifications. Superscript (^{4,5,6}) numbers indicate significant differences between reservoirs, i.e., column differences.

	Reservoir						
	Cottage Grove 1	Dorena 2	Dexter 3	Foster 4	Green Peter 5	Hills Creek 6	Lookout Point 7
Total Segments	2	7	5	8	93	56	35
Mean Length (m)±SE	188.49 ±1.91	277.00 ±1.41	55.58 ±1.50	256.24^{6} ±1.38	308.97^{6} ±1.10	$81.46^{4,5,7}$ ±1.13	212.06^{6} ±1.17
Range (m)	170.83-206.17	30.48-1272.35	30.48-106.03	35.34-812.89	23.56-1814.27	23.51-381.85	23.56-824.67
Total Bedrock Length (km)	0.38	1.94	0.28	2.05	28.73	4.56	7.42
Percent of Total Shoreline Length	3	11	3	14	46	12	17
Mean Distance Between Segments (m)	967.86	147.67	243.01	122.65	5.86	15.97	24.41
Segments per Kilometer	0.17	0.41	0.50	0.55	1.49	1.49	0.80

respectively (as compared to Cottage Grove, Dorena, and Dexter Reservoirs, at 0.17, 0.41, and 0.5, respectively) and a much shorter mean distance between segments, 5.86 m, 15.97 m, and 24.41 m, respectively (as compared to Cottage Grove, Dorena, and Dexter Reservoirs, at 967.86 m, 147.67 m, and 243.01 m, respectively). Green Peter Reservoir had 46% of its shoreline represented by bedrock, whereas the other study reservoirs only contained between 3 and 17%. Hills Creek and Lookout Point Reservoirs were similar to the other reservoirs in terms of % shoreline in bedrock. Green Peter Reservoir also has the shortest mean distance between nearest bedrock segments at 5.86 m.

Fine Substrates

The mean lengths for segments of fine substrates in Cottage Grove (1049.16 m), Dorena (439.12 m), Hills Creek (353.39 m) and Lookout Point (379.87 m) Reservoirs were significantly different ($P<0.05$) from Green Peter Reservoir (145.72 m) (Table 10). At $P<0.10$, the very long mean length of fine segments at Dexter Reservoir (1450.62 m) was also significantly different from Green Peter Reservoir. The range of mean lengths for total reservoir fine substrate segments across reservoirs was also the largest of all substrate size categories at 145.72-1049.16 m (range interval 903.44 m), with the shortest at Green Peter Reservoir and the longest at Cottage Grove Reservoir. Foster Reservoir, which like Green Peter Reservoir is on the South Santiam River, had the second shortest mean length for fine substrate segments at 228.89 m.

Table 10. Fine substrate specifications. Superscript ([4,5,6]) numbers indicate significant differences between reservoirs, i.e., column differences.

	Reservoir						
	Cottage Grove 1	Dorena 2	Dexter 3	Foster 4	Green Peter 5	Hills Creek 6	Lookout Point 7
Total Segments	9	22	8	7	71	50	34
Mean Length (m)±SE	1049.16[5] ±1.30	439.12[5] ±1.18	450.62 ±1.32	228.89 ±1.34	145.72[1,2,6,7] ±1.10	353.59[5] ±1.12	379.87[5] ±1.14
Range (m)	206.16-4641.72	60.96-4052.68	106.03-1237.00	58.91-577.27	35.33-471.24	30.48-1616.80	47.13-2497.57
Total Fine Length (km)	9.44	9.66	0.45	1.60	10.35	17.68	12.90
Percent of Total Shoreline Length	81	57	5	11	17	47	30
Mean Distance Between Segments (m)	24.36	20.58	91.05	148.24	11.92	10.79	21.34
Segments per Kilometer	0.77	1.29	0.80	0.48	1.14	1.33	0.77

Dexter Reservoir had the lowest percent of shoreline represented by fine substrates with 5% while Cottage Grove Reservoir had the highest observed value at 81% (Table 10).

The shortest mean distance between fine segments across reservoirs was 10.79 m at Hills Creek, and the longest was 148.24 m at Foster (Table 10). Also the mean distance between fine segments for the reregulating reservoirs, Foster and Dexter, was almost four times larger than all other reservoirs.

The number of segments composed of fine substrates per kilometer across reservoirs appears to be fairly consistent without regard to reservoir size or location. The number of fine substrate segments per kilometer was 0.48-1.29 (range interval 0.81) with the fewest at Foster and the most at Dorena.

Gravel to Small Boulder Substrates

The mean length for the gravel to small boulder segments of Foster Reservoir (494.24 m) was significantly different ($P<0.05$) from Dorena (254.91 m), Dexter (336.53 m), Green Peter (231.64 m), Hills Creek (202.77 m), and Lookout Point (236.80 m) Reservoirs (Table 11).

Values for gravel to small boulder substrate segments per kilometer were about 1.5, suggesting this was one of the most common substrate types. Only fine substrates comprised a greater percent of shoreline than gravel to small boulder. The total shoreline represented by gravel to small boulder of three study reservoirs was $\geq$ 49% (Table 11).

The shoreline composed of gravel to small boulder for Dexter and Foster reregulating reservoirs (67% and 72%, respectively) was much greater than for the other reservoirs (Table 11). Also, while mean segment lengths and segments per kilometer for the gravel to small boulder substrate were reasonably similar across reservoirs, the mean distances between segments were much shorter for the larger reservoirs.

Table 11. Gravel to small boulder substrate specifications. Superscript ([4,5,6]) numbers indicate significant differences between reservoirs, i.e., column differences.

	Reservoir						
	Cottage Grove 1	Dorena 2	Dexter 3	Foster 4	Green Peter 5	Hills Creek 6	Lookout Point 7
Total Segments	9	21	18	21	95	70	91
Mean Length (m)±SE	192.42 ±1.28	254.91[4] ±1.17	336.53[4] ±1.19	494.24[2,3,5,6,7] ±1.17	231.64[4] ±1.08	202.77[4] ±1.09	236.80[4] ±1.08
Range (m)	88.36-329.87	60.96-812.89	30.48-2049.90	82.47-848.23	35.34-1413.72	23.56-753.99	35.34-836.45
Total G-SB Length (km)	1.73	5.35	6.06	10.38	22.01	14.19	21.55
Percent of Total Shoreline Length	15	31	61	72	35	38	49
Mean Distance Between Segments (m)	106.54	34.27	22.98	14.19	6.88	9.01	5.62
Segments per Kilometer	0.77	1.23	1.81	1.45	1.52	1.86	2.09

Large Boulder Substrates

The mean length of large boulder segments at Lookout Point Reservoir (217.86 m) was significantly different ($P<0.05$) from those at Dorena Reservoir (30.48 m) (Table 12). At $P<0.10$, the mean length of large boulder segments at Green Peter Reservoir (141.37 m) was also significantly different from Dorena Reservoir. In the four reservoirs where more than one segment of large boulder substrate was found, the segments had the shortest segment length range interval for all substrate size categories at 22.86-518.37 m (range interval 495.51 m), with both the shortest and longest at Lookout Point Reservoir. The shortest mean length of 30.48 m occurred at Dorena Reservoir while the longest mean length of 217.86 m was found at Lookout Point Reservoir (Table 12).

The large boulder substrate particle size was the rarest substrate category in all seven study reservoirs. Although this substrate category was found in six of the seven reservoirs, it represented only from a low of 0.4% in Dorena Reservoir to a high of 4% in Lookout Point Reservoir. Only one area of large boulder substrate was present in Cottage Grove and Foster Reservoirs. The least number of segments per kilometer for large boulders was at Foster Reservoir (0.07) and the highest was at Hills Creek Reservoir (0.27).

Table 12. Large boulder substrate specifications. Superscript (^{4,5,6}) numbers indicate significant differences between reservoirs, i.e., column differences.

	Reservoir						
	Cottage Grove 1	Dorena 2	Dexter 3	Foster 4	Green Peter 5	Hills Creek 6	Lookout Point 7
Total Segments	1	2	0	1	9	10	8
Mean Length (m)±SE	176.71 N/A	30.48^{7} ±1.46	N/A N/A	459.46 N/A	141.37 ±1.19	108.24 ±1.18	217.86^{2} ±1.21
Range (m)	N/A	N/A	N/A	N/A	58.91-223.84	30.48-270.96	22.86-518.37
Total Large Boulder Length (km)	0.18	0.06	0	0.46	1.27	1.08	1.74
Percent of Total Shoreline Length	1	0.4	0	3	2	3	4
Mean Distance Between Segments (m)	11550.0	996.42	N/A	14030.0	122.45	107.91	137.15
Segments per Kilometer	0.09	0.12	0	0.07	0.14	0.27	0.18

Conversely, the mean nearest distances between segments for large boulders is the largest for all substrate size categories. The shortest nearest mean distance between segments was found at Hills Creek Reservoir (107.91 m) and the longest was found at Foster Reservoir (14030.0 m).

In terms of percent shoreline length covered for substrate size categories across reservoirs, the fine and gravel to small boulder substrates were the most common. Fine substrates were the most common substrate category at Cottage Grove (81%), Dorena (57%), and Hills Creek (47%) Reservoirs while gravel to small boulder substrates were most common at Foster (72%), Dexter (61%), and Lookout Point (49%) (Table 10 and 11). Bedrock substrate was the third most common substrate across reservoirs in terms of percent shoreline length covered at five of the seven study reservoirs, specifically Cottage Grove (3%), Dorena (11%), Dexter (3%), Hills Creek (12%), and Lookout Point Reservoir (17%) (Table 9). Bedrock substrate was the most common substrate category in only one reservoir, Green Peter at 46%. The large boulder substrate was rarest of all substrate categories in all seven reservoirs, with only 1% of shoreline length represented at Cottage Grove, 0.4% at Dorena, 3% at Foster, 2% at Green Peter, 3% at Hills Creek, 4% at Lookout Point, and 0% at Dexter Reservoirs (Table 12).

Ground Slope

All substrate size categories were significantly different ($P<0.05$) in mean percent slope across reservoirs based on measurements at sites of random segment selection (Table 13). The mean percent slopes for fines ranged from a low of 14.0 at Dexter Reservoir to a high of 37.8 at Hills Creek Reservoir. The high value reported for Hills Creek Reservoir is probably due to large abundances of consolidated clays in this system.

The overall reservoir mean slope for fine substrates was the lowest of any substrate category at 25.4%.

The mean percent slope of the gravel to small boulder substrate category across reservoirs ranged from a low of 24.0 at Foster Reservoir to a high of 58.5 at Lookout Point Reservoir. Gravel to small boulder is not only the next largest substrate category with respect to fines across reservoirs, but also exhibited the next highest mean percent slope at 44.8. With another increase in size category, from gravel to small boulder to large boulder, across reservoirs, there was a corresponding further increase in mean slope to 72.1%.

The bedrock slope ranged across reservoirs from a low of 23.3% at Cottage Grove Reservoir to a high of 117.5% at Lookout Point Reservoir. The overall reservoir slope mean was 93.8%, which is the steepest among the size categories.

Table 13. Mean slope (±SE), in percent, of substrate size categories at each study reservoir. Superscript (^{4,5,6}) numbers indicate significant differences between reservoirs, i.e., column differences, while superscript letters indicate significant differences between substrate size categories, i.e., row differences at $P<0.05$ (Tukey HSD).

Sub-strate	Reservoir							
	Cottage Grove 1	Dorena 2	Dexter 3	Foster 4	Green Peter 5	Hills Creek 6	Look-out Point 7	All Reser-voir Mean (±SE)
BR	23.3^{2,6,7}	110.0^{1}	71.3	111.5	84.0	100.6^{1}	117.5^{1}	93.8^{B,C,D}
A	±24.1	±13.9	±17.0	±29.5	±20.9	±13.9	±17.0	±4.5
Fine	19.4	28.3^{3}	14.0^{2,5,6}	17.0	28.3^{3}	37.8^{3}	19.0	25.4^{A,C,D}
B	±8.8	±6.6	±7.0	±8.1	±8.1	±5.5	±8.8	±3.9
G-SB	49.1	38.2	42.8	24.0^{7}	48.3	46.9	58.5^{4}	44.8^{A,B,D}
C	±5.9	±5.6	±5.2	±8.2	±8.2	±5.4	±6.4	±3.2
LB	100.4	70.0	NP	50.0	52.5	66.4	84.0	72.1^{A,B,C}
D	±11.6	±10.1		±0.0	±14.3	±7.6	±10.1	±5.6

NP = Not Present

Fish Species Richness and Diversity

Species Richness

A total of 19 fish species were sampled in 1995 and 17 species were sampled in 1996 (Table 14, 15). However, two fish species not sampled in 1996: black bullhead, *Ameiurus melas*, and chinook salmon, *Oncorhynchus tshawytscha.* Even in 1995 these two species were very rare in the littoral zone, with only one black bullhead individual sampled at Dexter Reservoir during the sampling period of 07/14/95 to 08/25/95 and two chinook salmon individuals sampled at Lookout Point Reservoir during the sampling period of 07/20/95 to 08/03/95.

Dexter and Lookout Point Reservoirs had the highest richness for 1995 (11 and 10 species, respectively), as well as for the combined 1995-1996 sample at 11 and 13, respectively (Table 15). Cottage Grove reservoir had the lowest reservoir richness for both these data sets, at four and five, respectively.

Table 14. Species codes for all fish species sampled in the study reservoirs. ** indicates exotic species. Fish species shown in order of decreasing numbers sampled.

Code	*Species*	
LB	Largemouth Bass	(*Micropterus salmoides*) **
BG	Bluegill	(*Lepomis macrochirus*) **
RS	Redside Shiner	(*Richardsonius balteatus*)
LS	Largescale Sucker	(*Catostomus macrocheilus*)
SB	Smallmouth Bass	(*Micropterus dolomieu*) **
PS	Prickly Sculpin	(*Cottus asper*)
NP	Northern Pikeminnow	(*Ptychocheilus oregonensis*)
BC	Black Crappie	(*Pomoxis nigromaculatus*) **
MS	Mottled Sculpin	(*Cottus bairdi*)
BR	Brown Bullhead	(*Ameiurus nebulosus*) **
WC	White Crappie	(*Pomoxis annularis*) **
SD	Speckled Dace	(*Rhinichthys osculus*)
RT	Rainbow trout	(*Oncorhynchus mykiss*)
CS	Chinook Salmon	(*Oncorhynchus tshawytscha*)
YB	Yellow Bullhead	(*Ameiurus natalis*) **
BB	Black Bullhead	(*Ameiurus melas*) **
CT	Cutthroat Trout	(*Oncorhynchus clarki*)
LD	Longnose Dace	(*Rhinichthys cataractae*)
RE	Reticulate Sculpin	(*Cottus perplexus*)

Foster and Lookout Point Reservoirs had the highest fish richness, for the 1996 habitat type sampling effort, at nine species each (Table 15). Dexter Reservoir had the next highest richness (eight). Green Peter and Cottage Grove each had only four species present in these samples. Species not collected in this study but collected by others include: 1) whitefish, *Coregonus sp.*, 2) coho salmon, *Oncorhynchus kisutch*, 3) sockeye salmon, *Oncorhynchus nerka*, 4) Oregon chub, *Oregonichthys crameri*, 5) chiselmouth, *Acrocheilus alutaceus*, 6) mountain sucker *Catostomus platyrhynchus*, 7) sandroller, *Percopsis transmontana* (Hasselman and Garrison, 1957).

F/Veg, G-SB/None, G-SB/Veg, and LB/None habitat types contained the largest number of species at 11 for F/Veg and 10 for each of the other habitat types (Table 16). The BR/Wood (4), F/None (4), and F/Wood (5) habitat types contained the lowest number of fish species. The sculpin and dace species data are combined in Table 16 due to the small numbers sampled in the study reservoirs. A more detailed summary of sculpin and dace species is provided in Table 17.

Largemouth bass was the most common species, occurring in all seven study reservoirs (Table 15). For the combined 1995-1996 sample, largemouth bass ranged from 1.95% of the sample in Dexter Reservoir to 80.53% in Dorena Reservoir by number and from 5.35% to 85.88%, respectively, by weight across reservoirs (Table 18). Largemouth bass was the only species found in all nine habitat types (Table 16). Those habitat types with low percentages of largemouth bass were F/None (12% of the total fish sample from F/None across reservoirs) and G-SB/None (31% of the total sample from G-SB/None

Table 15. Fish species and total number of species sampled at each reservoir in 1995 and 1996.

Species Code	Reservoir							
	Cottage Grove	Dorena	Green Peter	Foster	Dexter	Look-out Point	Hills Creek	Total Reser-voirs
LB	X	X	X	X	X	X	X	7
SB				X	X			2
BR	X	X			X	X	X	5
BB					X			1
YB		X		X		X	X	4
BG	X	X		X	X	X	X	6
BC	X	X			X		X	4
WC					X	X	X	3
NP			X	X	X	X		4
LD						X		1
SD	X		X	X		X		4
CT				X				1
RT						X	X	2
LS		X	X	X	X	X	X	6
RS				X	X	X	X	4
PS					X			1
MS						X		1
RE		X						1
CS						X		1
Total Fish Richness 1995	4	6	---	---	11	10	8	
Total Fish Richness 1996	4	6	4	9	8	9	7	
Total Fish Richness 1995-1996	5	7	4	9	11	13	9	

across reservoirs) (Table 19). However, most habitat types were represented by substantial percentages (34-66) of largemouth bass in the sample (i.e., 1) BR/None at 62, 2) F/Veg at 44, 3) F/Wood at 65, 4) GS-B/Veg at 50, and 5) LB/None at 39). BR/Wood (95% of fish sampled) and GS-B/Wood (87% of fish sampled) contained the highest percentages of largemouth bass in the total sample from individual habitats for 1996. The apparent use of BR/Wood in Dorena was atypical as this was one of only two reservoirs where largemouth bass were sampled in this habitat type. However, Dorena reservoir was the only reservoir where this species was collected in large abundance (91% of the total BR/Wood sample). In only two reservoirs were largemouth bass found in F/None, and F/Wood, as well.

Table 16. Mean length (±SE), number () by fish species, and total fish species sampled in each habitat type (HT) across all study reservoirs. NP = Not present in samples.

Table 16.

						Species Code								
HT	LB	BG	LS	SC	RS	SB	BC	NP	BR	Dace	YB	WC	CT	Total Sp./(n)
BR/ None	111.0 (±7.4) (28)	46 (1)	NP	91.0 1/ (±12.7) (6)	52.3 (±7.6) (6)	70.3 (±16.5) (3)	NP	NP	NP	NP	127 (1)	NP	NP	8/ (45)
BR/ Wood	119.6 (±4.06) (93)	100.0 (±16.6) (2)	450.5 (±76.0) (2)	NP	NP	NP	63 (1)	NP	NP	NP	NP	NP	NP	4/ (98)
F/ None	75.6 (±12.4) (10)	NP	132 (1)	68 (1)	41.8 (±2.2) (73)	NP	NP	NP	NP	NP	NP	NP	NP	4/ (85)
F/ Veg	80.1 (±3.7) (110)	59.6 (±3.7) (40)	125.7 (±19.9) (29)	100.9 (±6.8) (14)	52.4 (±4.3) (19)	NP	82.7 (±6.8) (13)	184.8 (±23.1) (4)	97.5 (±15.0) (8)	77.0 (±4.65) (2)	NP	107.7 (±4.4) (9)	NP	11/ (248)
F/ Wood	116.9 (±7.2) (30)	95 (2)	252.7 (±43.9) (6)	NP	NP	87.8 (±12.8) (5)	149 (1)	247.5 (±32.7) (2)	NP	NP	NP	NP	NP	5/ (46)
G-SB/ None	93.5 (±6.5) (36)	86.8 (±4.4) (28)	307.5 (±76.0) (2)	93.31 (±7.0) (13)	58.9 (±6.2) (9)	83.2 (±6.24) (21)	NP	135.0 (±26.7) (3)	94.5 (±29.9) (2)	NP	NP	NP	92 (1)	10/ (115)
G-SB/ Veg	78.5 (±3.6) (121)	44.5 (±3.1) (58)	264.6 (±32.4) (11)	103 (1)	96.8 (±4.37) (18)	79.5 (±20.2) (2)	101.0 (±10.9) (5)	111.8 (±9.6) (23)	84 (1)	59.5 (±4.65) (2)	NP	NP	NP	10/ (242)
G-SB/ Wood	111.7 (±3.1) (159)	116.5 (±16.6) (2)	171.5 (±53.7) (4)	86.7 (±7.3) (12)	NP	82.0 (±20.2) (2)	153.0 (±17.3) (2)	NP	NP	74 (1)	NP	NP	NP	8/ (182)
LB/ None	106.2 (±5.1) (58)	102.3 (±3.11) (57)	222.4 (±35.8) (9)	62.3 (±14.7) (3)	90 (1)	132.9 (±7.6) (14)	114.0 (±12.2) (4)	201 (1)	153 (1)	NP	153 (1)	NP	NP	10/ (149)
Total HT/(N)	9/(645)	8/(190)	8/ (64)	7/ (50)	6/(126)	6/ (47)	6/ (26)	5/(33)	4/ (12)	3/ (5)	2/ (2)	1/ (9)	1/ (1)	(1210)

At the reservoir scale, samples from Dexter (0.54%), Foster (5.43%), and Lookout Point (5.21%) contained the lowest proportions of largemouth bass numbers in the 1996 sample, while Cottage Grove and Hills Creek were moderate (65.91% and 46.04%, respectively) (Table 20). Dorena (81.63%) and Green Peter (80.00%) had the highest proportion of largemouth bass in the 1996 samples. The percent of habitat types in which largemouth bass were present in samples for 1996 was also lowest in Dexter, Foster, and Lookout Point (17%, 25%, and 30% of available habitats, respectively)

Table 17. Number of sculpin and dace collected in each habitat type.

Habitat Type			Species		
	Mottled Sculpin	Reticultate Sculpin	Prickly Sculpin	Longnose Dace	Speckled Dace
BR/ None	1	1	4	NP	NP
BR/ Wood	NP	NP	NP	NP	NP
F/ None	NP	NP	1	NP	NP
F/ Veg	2	NP	12	NP	2
F/ Wood	NP	NP	NP	NP	NP
G-SB/ None	4	NP	9	NP	NP
G-SB/ Veg	NP	NP	1	NP	2
G-SB/ Wood	4	NP	8	1	NP
LB/None	3	NP	NP	NP	NP
Total Habitats/ Fish	5/14	1/1	6/35	1/1	2/4

NP = Not Present in Sample

Table 18. Percent by number and weight of the total 1995-1996 reservoir fish sample represented by each fish species.

Species	Reservoir													
	Cottage Grove		Dorena		Dexter		Foster		Green Peter		Hills Creek		Lookout Point	
	% No.	% Wt.	% No.	% Wt.	% No.	% Wt.	% No.	% Wt.	% No.	% Wt.	% No.	% Wt.	% No.	% Wt.
LS	NP	NP	0.12	0.07	1.30	12.07	1.55	2.05	11.11	60.37	8.07	39.98	13.80	51.12
PS	NP	NP	NP	NP	17.21	3.63	NP	NP	NP	NP	NP	NP	NP	NP
MS	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	4.78	0.69
RE	NP	NP	0.12	0.02	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP
YB	NP	NP	0.22	1.40	NP	NP	0.78	1.41	NP	NP	2.02	3.75	0.18	0.27
BR	5.11	9.21	1.22	3.97	0.65	1.64	NP	NP	NP	NP	0.67	1.03	0.53	2.31
BC	15.69	2.46	7.45	3.68	0.32	0.86	NP	NP	NP	NP	0.50	0.24	NP	NP
BG	23.36	6.42	10.34	4.98	0.97	0.64	54.25	36.24	NP	NP	19.33	5.92	1.24	2.81
LB	55.47	81.90	80.53	85.88	1.95	5.35	5.43	9.60	80.00	17.46	52.60	35.04	57.34	24.30
Dace	0.37	0.01	NP	NP	NP	NP	NP	NP	2.22	0.25	NP	NP	0.35	0.02
RT	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	0.34	0.36	NP	NP
RS	NP	NP	NP	NP	58.44	5.72	0.78	0.35	NP	NP	4.71	1.53	9.56	2.31
WC	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	11.76	12.15	10.09	12.72
NP	NP	NP	NP	NP	12.99	45.60	1.55	4.86	6.67	21.92	NP	NP	1.95	3.37
CS	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	0.18	0.08
SB	NP	NP	NP	NP	6.17	24.49	34.88	45.02	NP	NP	NP	NP	NP	NP
CT	NP	NP	NP	NP	NP	NP	0.78	0.47	NP	NP	NP	NP	NP	NP

NP = Not present in samples

Table 19. Number of largemouth bass and total ( ) fish sampled, by habitat type, in each reservoir. The total percentage and reservoirs with largemouth bass in each habitat type along with the percent largemouth bass representation of the entire seven reservoir sample, by habitat type, also shown.

Habitat Type	Reservoir									
	Cottage Grove	Dexter	Dorena	Foster	Green Peter	Hills Creek	Lookout Point	Total No. LB	Total % LB	Total Res./ % of All LB
Fine/None	0 (0)	0 (74)	9 (9)	0 (0)	1 (2)	0 (0)	0 (0)	10 (85)	12	2/ 2
Fine/Veg	7 (9)	0 (29)	77 (103)	2 (19)	12 (18)	12 (37)	0 (33)	110 (248)	44	5/ 17
Fine/Wood	0 (0)	0 (0)	28 (30)	0 (5)	0 (3)	2 (4)	0 (4)	30 (46)	65	2/ 5
G-SB/None	8 (16)	1 (24)	19 (33)	0 (25)	1 (1)	7 (11)	0 (5)	36 (115)	31	5/ 6
G-SB/Veg	11 (14)	0 (4)	63 (80)	5 (48)	35 (38)	7 (11)	0 (11)	121 (243)	50	5/ 19
G-SB/Wood	0 (0)	0 (9)	153 (157)	0 (2)	3 (3)	2 (3)	1 (8)	159 (182)	87	4/ 24
LB/None	2 (4)	0 (0)	50 (96)	0 (26)	4 (9)	1 (3)	1 (10)	58 (148)	39	5/ 9
BR/None	1 (1)	0 (9)	14 (16)	0 (4)	12 (12)	1 (1)	0 (2)	28 (45)	62	5/ 4
BR/Wood	0 (0)	0 (0)	89 (91)	0 (0)	4 (4)	0 (1)	0 (2)	93 (98)	95	2/ 14
Total	29 (44)	1 (186)	502 (615)	7 (129)	72 (90)	32 (71)	2 (75)	645 (1210)	53	
% of Habitats w/LB	100	17	100	25	88	80	30			

Table 20. Percent by number and weight of the total 1996 reservoir fish sample represented by each fish species.

Species	Reservoir													
	Cottage Grove		Dorena		Dexter		Foster		Green Peter		Hills Creek		Lookout Point	
	% No.	% Wt.	% No.	% Wt.	% No.	% Wt.	% No.	% Wt.	% No.	% Wt.	% No.	% Wt.	% No.	% Wt.
BC	NP	NP	3.74	2.77	NP	NP	NP	NP	NP	NP	3.95	1.79	NP	NP
BG	29.55	26.84	13.01	8.21	0.54	0.43	54.26	36.24	NP	NP	38.16	11.15	NP	NP
BR	2.27	0.46	1.30	0.53	0.54	3.69	NP	NP	NP	NP	1.32	1.13	NP	NP
LB	65.91	72.24	81.63	88.15	0.54	5.12	5.43	9.60	80.00	17.46	46.04	32.97	5.21	1.85
SC	NP	NP	0.16	0.03	18.82	22.69	NP	NP	NP	NP	NP	NP	17.71	0.71
YB	NP	NP	0.16	0.31	NP	NP	0.78	1.41	NP	NP	NP	NP	NP	NP
Dace	2.27	0.46	NP	NP	NP	NP	NP	NP	2.22	0.25	NP	NP	2.08	0.04
LS	NP	NP	NP	NP	1.08	43.17	1.54	2.05	11.11	60.37	3.95	50.39	60.42	91.30
RS	NP	NP	NP	NP	63.96	12.08	0.78	0.35	NP	NP	1.32	0.61	8.33	0.97
WC	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	5.26	1.96	5.21	0.84
NP	NP	NP	NP	NP	13.44	12.22	1.55	4.86	6.67	21.92	NP	NP	1.04	4.29
SB	NP	NP	NP	NP	1.08	0.60	34.88	45.02	NP	NP	NP	NP	NP	NP
CT	NP	NP	NP	NP	NP	NP	0.78	0.47	NP	NP	NP	NP	NP	NP

NP = Not present in samples

(Table 19). Cottage Grove, Dorena, Green Peter, and Hills Creek Reservoirs again had high percentages of available habitats in which largemouth bass were present (100, 100, 88, and 80, respectively) (Table 19). This suggests the latter reservoirs contained larger largemouth bass populations that were dispersed into more habitat types.

Bluegill and largescale sucker were the second most common species sampled, both occurring in six of the seven study reservoirs (Table 15) and in eight of the nine habitat types studied (Table 16). Bluegill were not present in F/None while largescale suckers were not present in BR/None. Both habitats are smooth-textured and lacked interstitial spaces for cover from predators. Bluegill ranged from 0.97% of the sample in Dexter Reservoir to 54.25% in Foster Reservoir, by number, and from 0.64% to 36.24%, respectively, by weight (Table 18). Largescale suckers ranged from 0.12% of the sample in Dorena Reservoir to 13.80% in Lookout Point Reservoir, by number, and from 0.07% in Dorena Reservoir to 60.37% in Green Peter Reservoir, by weight.

The yellow bullhead, found in 4 reservoirs and 2 habitat types, brown bullhead, found in 5 reservoirs and 4 habitat types, and speckled dace, found in 4 reservoirs and 2 habitat types, were much more restricted in distribution than those species listed above. The yellow bullhead was present only in low numbers ($\geq$ 2.02% of fish sampled, Table 18) across reservoirs. In this study, yellow bullhead were highly restricted in their use of habitat, occurring in only the deep rock habitats of BR/None and LB/None which may provide hiding cover from largemouth bass and other predator fish (Table 16).

The highest percentage, by number, of brown bullheads sampled was found in Dorena and Cottage Grove Reservoirs at 5.11 and 1.22 of total fish sampled, respectively (Table 18). Speckled dace also occurred in low numbers ($\geq$2.22% of fish sampled, Table 18) and was found only in vegetated habitats. The white crappie and cutthroat trout were sampled in only one habitat type, specifically F/Veg and G-SB/None, respectively.

Along with white crappie, the redside shiner, longnose dace, rainbow trout, chinook salmon, and mottled sculpin were primarily found in the large deep reservoirs (i.e., Hills Creek, Lookout Point, and Green Peter Reservoirs). White crappie were only found in the structurally complex vegetated habitats (only in F/Veg) in this study. Although rooted vegetation is relatively rare in these large reservoirs, it commonly contains white crappie. With a large abundance of rocky habitats (G-SB, LB, and BR) Lookout Point Reservoir appears to provide a variety of adequate habitats for this species. However, longnose dace species was only found in the G-SB/Wood habitat type.

Coldwater salmonid species, rainbow and cutthroat trout and chinook salmon, were rarely found in the warmer littoral zone of the study reservoirs in summer due to water temperature limitations. Only one coldwater species, one individual cutthroat trout in Foster Reservoir, was sampled during 1996.

The reticulate sculpin was only found at Dorena Reservoir and only in the BR/None habitat type (Table 17). The reticulate sculpin was not found on smaller substrates in this study.

Black crappie was the only crappie species in samples from Cottage Grove and Dorena Reservoirs. Limited numbers, however,were also found in Dexter and Hills Creek Reservoirs, along with white crappie. The largest numbers of black crappie were found in the highly vegetated and wind protected Cottage Grove and Dorena Reservoirs. Black crappie, found in six habitats, were more widely distributed across habitats than white crappie, which was found in only one habitat. This may be due to higher densities of black crappies and large expanses of vegetated habitats increasing the chance of movement to other habitat types. This species was not found in the BR/None, F/None, or G-SB/None habitat types, all of which lack overlying structure. On the other hand, in the large, deep reservoirs there are often long distances between vegetated habitats. Here white crappie were restricted to the F/Veg habitat type. Both crappie species were found in habitats of higher structural complexity.

Four species were only collected in the reregulating reservoirs; smallmouth bass, black bullhead, cutthroat trout, and prickly sculpin. Only one black bullhead individual was found in 1995 at Dexter Reservoir.

Smallmouth bass tended to be in only in rocky habitats, which are known to be strongly preferred by this species (Okeyo and Hassler, 1985; Sammons and Bettoli, 1999). The only exception was presence in F/Wood.

The prickly sculpin in Dexter were generally associated with the habitats known to be utilized by this species, i.e., sand, gravel, rubble sized substrates, including vegetated habitats for smaller individuals (Wydoski and Whitney, 1979). However, this sculpin species was also found on bedrock.

The northern pikeminnow was collected in both reregulating reservoirs and two out of the three largest reservoirs, Lookout Point and Green Peter Reservoirs. In Dexter and Foster reservoirs, where northern pikeminnow and smallmouth bass coexist, the northern pikeminnow appears to be generally restricted to the structurally complex vegetated habitats, specifically, G-SB/Veg at Dexter and F/Veg at Foster. The only other habitat used by the northern pikeminnow was G-SB/None at Dexter. However, smallmouth bass were found in six habitat types of these systems, overlapping in presence with the northern pikeminnow in only G-SB/Veg and G-SB/None.

Northern pikeminnow are known to inhabit a variety of habitat types ranging from sand and mud bottoms to rubble and gravel, as well as vegetated areas (Wydoski and Whitney, 1979). In the larger reservoirs where densities of fish tend to be lower and smallmouth bass were absent, northern pikeminnow were found in two additional habitats, F/Wood and G-SB/Wood, habitats associated with other large predator fish.

Exotic species dominated the fish assemblages (% of fish sampled by number) across reservoirs in all but one habitat type, F/None. (Table 21). Here, native species numbers represented 88% of the assemblage. The lowest representation by native species was in BR/Wood at 0%, although G-SB/Wood and LB/None were also low at 9% each. Generally there was about a 3 to 1 ratio of exotic to native fish across the reservoir habitat types.

Table 21. Native and exotic fish species representation (% by number) across reservoirs in each habitat type.

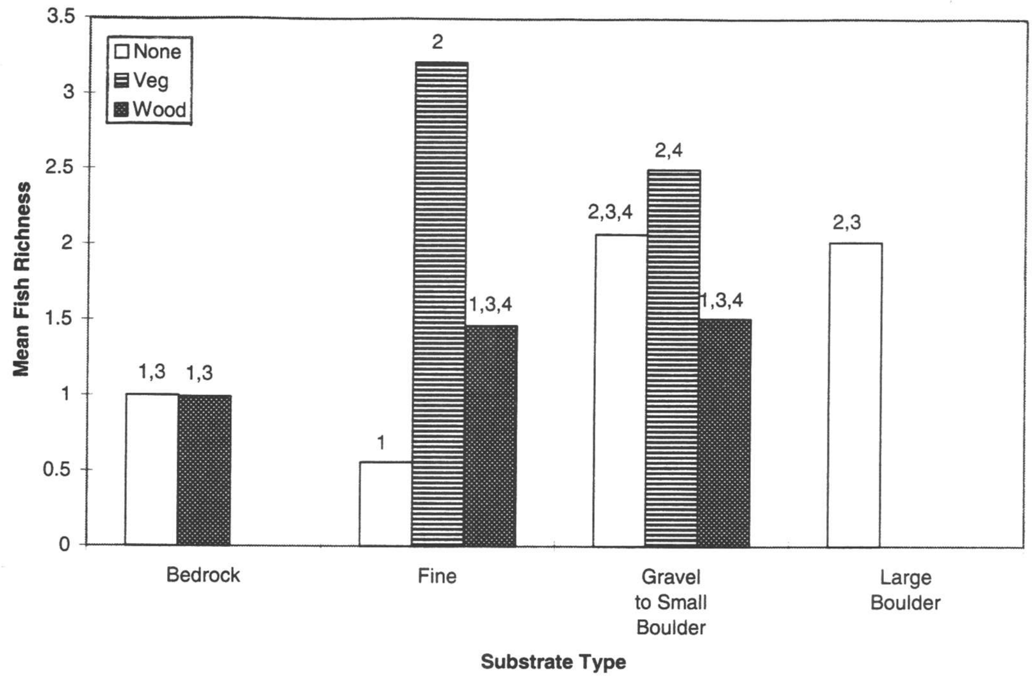
Habitat Type	Native Fish Species (% representation by numbers across reservoirs)	Exotic Fish Species (% representation by numbers across reservoirs)
BR/None	27	73
BR/Wood	0	100
F/None	88	12
F/Veg	27	73
F/Wood	17	83
G-SB/None	24	76
G-SB/Veg	23	77
G-SB/Wood	9	91
LB/None	9	91
Mean	25 (±8)	75 (±8)

Significant differences ($P<0.05$ (Tukey HSD)) in fish richness between habitat types were found across reservoirs (Table 22, Figure 5). Those habitat types with vegetation had the greatest total fish richness and also the greatest values for mean habitat replicate fish richness. Total/mean richness values were 4.00/3.21 for F/Veg and 3.43/2.50 for G-SB/Veg. The LB/None and G-SB/None were next highest at 2.83/2.02 and 2.86/2.07, respectively. The F/None and BR/Wood habitat types were the lowest in

Table 22. Total and (mean) fish richness of specified habitat types at each study reservoir and mean (±SE) of each across reservoirs. Superscript $(^{4,5,6})$ numbers and letters indicate significant differences between habitat types and reservoirs. NP = not present.

Habitat Type	Reservoir: Cottage Grove A	Dorena B	Foster C	Dexter D	Green Peter E	Hills Creek F	Lookout Point	Mean
BR/None 1	1	3	2	2	1	1	2	1.71^{4} ±0.39
	(0.5)	(2)	(1)	(1)	(1)	(0.5)	(1)	($1.00^{4,7}$ ±0.26)
BR/Wood 2	NP	3	NP	NP	1	1	1	1.50^{4} ±0.53
		(2)			(1)	(0.5)	(0.5)	($0.99^{4,7}$ ±0.36)
F/None 3	NP	1	0	2	2	0	NP	1.00^{4} ±0.47
		(1)	(0)	(1.5)	(1)	(0)		($0.56^{4,6,7,9}$ ±0.32)
F/Veg 4	2	4	5	3	4	7	3	$4.00^{3,5,8,1,2}$ ±0.39
	(2)	(3.5)	(4)	(2.5)	(3.5)	(4)	(3)	($3.21^{3,5,8,1,2}$ ±0.26)
F/Wood 5	NP	3	1	NP	2	3	1	2.00^{4} ±0.47
		(3)	(1)		(1)	(1.5)	(1)	(1.46^{4} ±0.34)
G-SB/ None 6	3	3	3	6	1	2	2	2.86 ±0.39
	(2.5)	(2)	(2.5)	(4.5)	(0.5)	(1.5)	(1)	(2.07^{3} ±0.26)
G-SB/ Veg 7	3	4	3	5	3	3	3	3.43 ±0.39
	(2)	(3.5)	(2.5)	(3.5)	(2)	(2)	(2)	($2.50^{3,1,2}$ ±0.26)
G-SB/ Wood 8	NP	3	1	2	1	2	4	2.17^{4} ±0.42
		(3)	(0.5)	(1.5)	(1)	(1)	(2.5)	(1.51^{4} ±0.29)
LB/None 9	2	4	2	NP	3	2	4	2.83 ±0.42
	(1.5)	(3.5)	(1.5)		(2)	(1)	(2)	(2.02^{3} ±0.29)
Reservoir Fish Richness 1996	4	6	9	8	4	7	9	6.71
	(1.70 ±0.30)	(2.59^{F} ±0.26)	(1.63 ±0.34)	(2.42 ±0.42)	(1.44 ±0.26)	(1.33^{B} ±0.35)	(1.63 ±0.29	

Figure 5. Mean fish richness and diversity (by numbers) for habitat types, grouped by substrate type. Different numbers above bars indicate significant differences between habitat types.


3.5
3
2.5
2
1.5
1
0.5
0
None
Veg
Wood
Mean Fish Richness
2
2,4
2,3,4
2,3
1,3,4
1,3,4
1,3 1,3
1
Bedrock
Fine
Gravel to Small Boulder
Large Boulder
Substrate Type

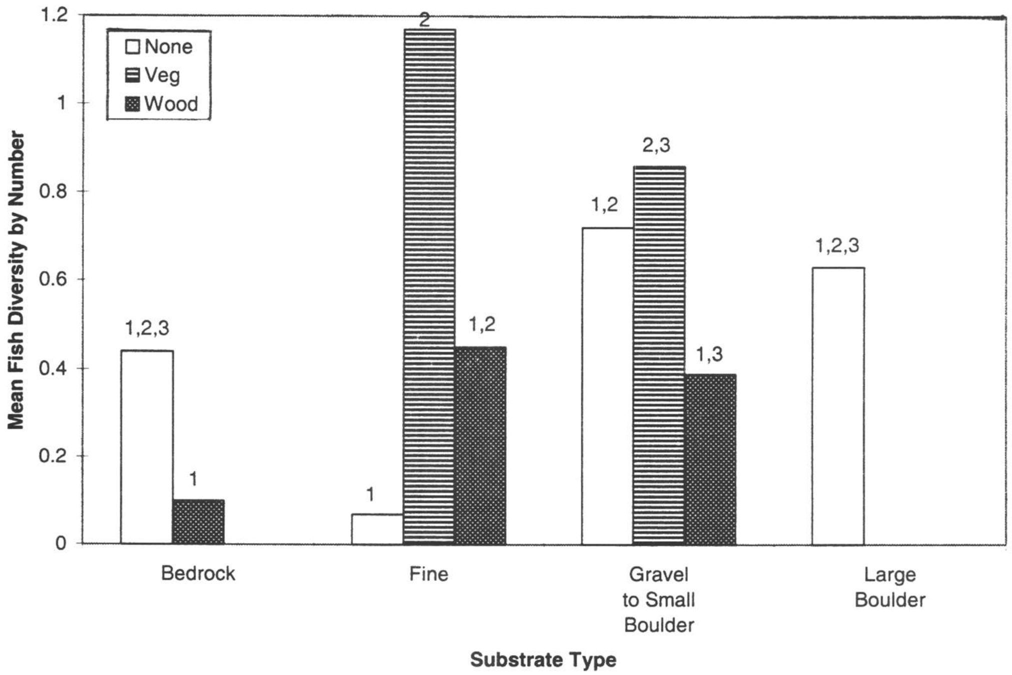

1.2
1
0.8
0.6
0.4
0.2
0
None
Veg
Wood
Mean Fish Diversity by Number
2
2,3
1,2
1,2,3
1,2,3
1,2
1,3
1
1
Bedrock
Fine
Gravel to Small Boulder
Large Boulder
Substrate Type

Figure 5.

richness at 1.00/0.56 and 1.50/0.99, respectively. The largest effect of vegetation on the number of fish species occurred for the fine particle size, with 1.00/0.56 for F/None, 4.00/3.21 for F/Veg and 2.00/1.46 for F/Wood. Wind is an associated factor. Fines with vegetation typically occurs in wind protected areas of reservoirs.

Diversity

The mean Shannon-Weiner Diversity Index (H') (Shannon and Weaver, 1949) for fish was calculated for both number of individuals and total weight in grams per species for all habitat types at each reservoir, across reservoirs, and as reservoir totals for the 1996 sampling period (Table 23).

Fish H', by both numbers and weight of species, of the habitat types were significantly different ($P<0.05$ (Tukey HSD)) across reservoirs (Table 23, Figure 5). In terms of fish H' (by numbers), the F/None (0.07) was significantly lower than F/Veg at 1.17 and G-SB/Veg at 0.86. Fish H' in F/Veg was also significantly different from H' in those habitats with wood, specifically, G-SB/Wood (0.39) and BR/Wood (0.10). Very similar differences were observed with the analysis of fish H' by weight. H' for F/None (0.03) was again significantly different from H' in F/Veg (1.00) and F/Veg was significantly different from the wooded habitats, G-SB/Wood (0.25) and BR/Wood (0.07). Additionally, H' in F/Veg was significantly greater than BR/None (0.23).

Mean fish H' (by numbers or weight) did not appear to increase with particle size; a tendency observed for richness (Figure 5).

The vegetated habitats, F/Veg and G-SB/Veg, showed the greatest fish H' for both numbers and weight at 1.17/1.00 and 0.86/0.75, respectively. The F/None and BR/Wood habitat types were the least diverse at 0.07/0.02 and 0.10/0.71, respectively (Table 23). As observed for fish richness, the largest difference in mean fish H' between a substrate with or without overlying structure occurred in the fine substrate size category with fish H' of 0.07/0.02 for F/None, 1.17/1.00 for F/Veg and 0.44/0.35 for F/Wood (Table 23).

The effect of wood or vegetation on fish H' and richness was influenced by the substrate at that site. For example, within the bedrock substrate size category, the fish H' and richness of the BR/Wood habitat type was lower than the fish H' and richness of the BR/None habitat type across reservoirs. For fine substrates, fish richness and H' were lowest in F/None, intermediate in F/Wood and highest in F/Veg across reservoirs. The three fine substrate habitat types showed the largest range for both fish richness and diversity at 2.65 and 1.10, respectively.

Fish richness and H' for gravel to small boulder substrates were relatively highest for the G-SB/Veg habitat type, lowest for G-SB/Wood, with G-SB/None being intermediate. The addition of wood to fine substrate may result in an increase in values of fish richness and H', while doing the same in gravel to small boulder and bedrock substrates resulted in a decrease in these same values.

Table 23. Habitat type and overall sampling diversity by reservoir and mean (±SE) across reservoirs. Diversity data are shown for both numbers and (weight) of fish sampled. Superscript (^{4,5,6}) numbers and (^{A,B,C}) letters indicate significant differences between substrate types (row) and reservoirs (column).

Habitat Type	Reservoir							Reservoir Grand Mean
	Cottage Grove A	Dorena B	Foster C	Dexter D	Green Peter E	Hills Creek F	Look-out Point G	
BR/None 1	0	0.58	0.41	0.99	0	0	1.00	0.44 ±0.19
	(0)	(0.17)	(0.47)	(0.42)	(0)	(0)	(0.35)	(0.23^{4} ±0.16)
BR/Wood 2	---	0.23	---	---	0	0	0	0.10^{4} ±0.24
		(0.04)			(0)	(0)	(0)	(0.07^{4} ±0.20)
F/None 3	---	0	0	0.09	0	0	---	0.07^{4,7} ±0.24
		(0)	(0)	(0.25)	(0)	(0)		(0.02^{4} ±0.20)
F/Veg 4	0.78	1.06	1.51	0.90	1.35	1.61	0.96	1.17^{3,8,2} ±0.15
	(0.76)	(0.72)	(1.57)	(0.81)	(1.29)	(1.47)	(0.41)	(1.00^{3,8,1,2} ±0.13)
F/Wood 5	---	0.42	0	---	0.92	1.50	0	0.44 ±0.22
		(0.38)	(0)		(0.85)	(1.17)	(0)	(0.35 ±0.18)
G-SB/ None 6	0.94	0.60	0.88	1.87	0	0.46	0	0.72 ±0.15
	(0.43)	(0.58)	(1.16)	(1.25)	(0)	(0.35)	(0)	(0.57 ±0.13)
G-SB/ Veg 7	0.58	1.18	0.60	1.47	0.73	0.81	0.65	0.86^{3} ±0.15
	(0.48)	(1.06)	(1.22)	(1.26)	(0.38)	(0.76)	(0.87)	(0.75 ±0.12)
G-SB/ Wood 8	---	0.14	0	0.32	0	0.92	1.23	0.39^{4} ±0.18
		(0.24)	(0)	(0.09)	(0)	(0.26)	(0.80)	(0.25^{4} ±0.15)
LB/None 9	0.46	1.18	0.49	---	0.63	0	0.68	0.63 ±0.16
	(0.49)	(1.02)	(0.50)		(0.38)	(0)	(0.08)	(0.45 ±0.14)
Reservoir Mean 1/	0.61 ±0.16 (0.48 ±0.14)	0.61 ±0.13 (0.47 ±0.12)	0.65 ±0.17 (0.82^{G} ±0.19)	0.94 ±0.21 (0.70 ±0.18)	0.40 ±0.16 (0.31 ±0.12)	0.68 ±0.21 (0.55 ±0.20)	0.57 ±0.18 (0.22^{C} ±0.10)	

1/ Littoral Zone

The highest values for both richness and H' across reservoirs were found for the vegetated habitat types, specifically F/Veg and G-SB/Veg at 4.00/1.67 and 3.43/0.86, respectively. The lowest values for both richness and H' were found for the F/None and BR/Wood habitat types, 1.00/0.02 and 1.50/0.07, respectively.

Mean Fish Length and Weight

The mean length and weight of all fish species sampled at each habitat type replicate across reservoirs were analyzed with a generalized randomized block design (Table 24). Significant differences between habitat types were found for both mean length and weight at $P \leq 0.10$ (Tukey HSD), but not at $P < 0.05$ (Tukey HSD). Significant differences found with mean length were between the F/Wood (162.19 mm) and F/None (81.73 mm) habitat types. There may be a general trend of increasing length of fish with increasing particle size as evidenced by the increase in fish length values from F/None (81.73 mm) to G-SB/None (96.96 mm) and then to LB/None (117.76 mm). Mean weight of fish in F/None (29.24 g) was significantly different from F/Wood (102.10 g) and from BR/Wood (176.66 g) (Table 24).

Additionally, the mean length of fish sampled tended to increase with the addition of either vegetation or wood as structural components within a substrate. With fine substrates the mean length values increased from 81.73 mm for the F/None habitat to 91.64 mm for the F/Veg habitat and to 162.19 mm for the F/Wood habitat. The gravel to small boulder substrate showed this same trend as mean fish length of 96.96

Table 24. Mean length (±SE) and mean weight (±SE), across reservoirs, for all fish species combined and largemouth bass only, by habitat type. Superscript (^{4,5,6}) numbers indicate significant differences between reservoirs, i.e., row differences.

Habitat Type		Mean Length All Fish Species (mm)	Mean Length Largemouth Bass (mm)	Mean Weight All Fish Species (g)	Mean Weight Largemouth Bass (g)
BR/None	1	98.86(±19.69)	110.95(±12.86)	25.31 (±37.11)	25.53 (±9.00)
BR/Wood	2	160.48(±24.76)	119.60(±16.42)	176.66^{3}(±46.67)	31.64 (±11.49)
F/None	3	81.73^{5}(±25.17)	75.58(±18.80)	29.24^{2,5}(±47.43)	7.27 (±13.16)
F/Veg	4	91.64(±15.70)	80.10(±11.04)	15.96 (±29.58)	11.28 (±7.73)
F/Wood	5	162.19^{3}(±22.80)	116.94(±22.60)	102.10^{3}(±42.96)	27.18 (±15.82)
G-SB /None	6	96.96(±16.33)	93.50(±11.86)	23.11 (±30.77)	19.79 (±8.30)
G-SB /Veg	7	109.36(±15.70)	78.48(±11.04)	49.12 (±29.58)	10.19 (±7.73)
G-SB /Wood	8	107.43(±18.92)	111.68(±14.41)	30.96 (±35.66)	20.10 (±10.08)
LB/None	9	117.76(±17.19)	106.18(±12.86)	45.84 (±32.39)	40.29 (±9.00)

mm for the G-SB/None habitat increased to 109.36 mm for the G-SB/Veg habitat and to 107.43 mm for the G-SB/Wood habitat. The fish collected from the bedrock substrate also showed an increase for mean fish length with the addition of structure. Fish sampled in the BR/None habitat type averaged 98.86 mm in length but those in the BR/Wood habitat type averaged 160.48 mm in length where wood was present as a structural component. For fine substrates fish size increased with the presence of either vegetation or wood with a much larger increase for wood presence than for vegetation. Conversely, the presence of either wood or vegetation with G-SB substrate resulted in about the same increase in mean fish length, although the increase was not significant. The mean weight of fish appears to only increase with the addition of wood rather than vegetation, as shown by an increase of values from 1) 29.24 g for the F/None habitat type to 102.10 g for

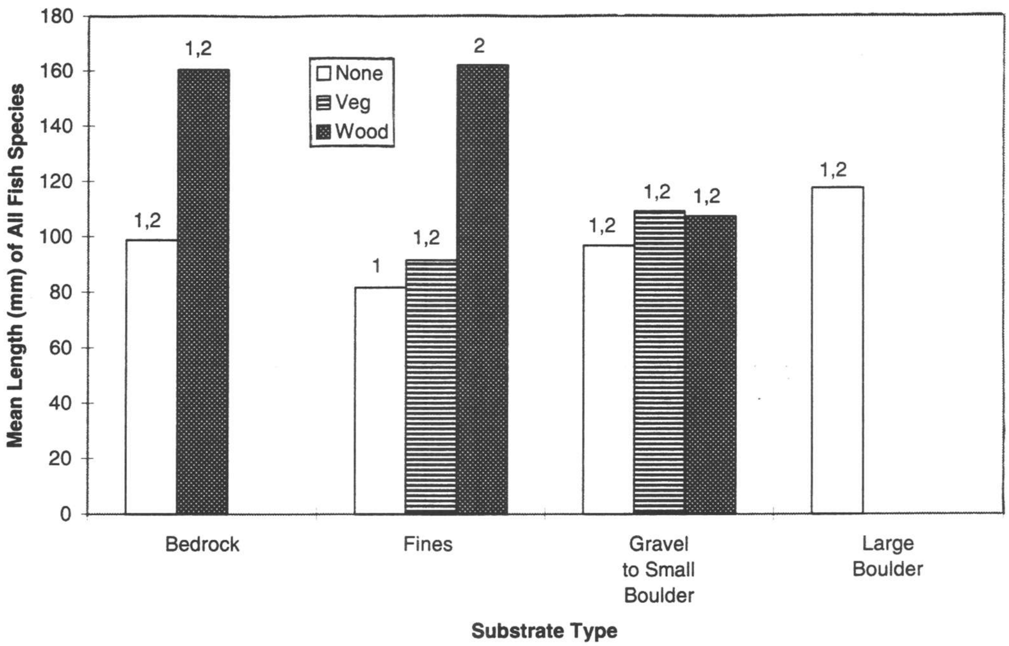
F/Wood, 2) 23.11 g for the G-SB/None habitat type to 30.96 g for G-SB/Wood, and 3) 25.31 g for the BR/None habitat type to 176.66 g for BR/Wood.

Largemouth bass was the most common species sampled. A separate generalized randomized block design was performed on data for this species (Table 24). However, no significant differences could be found for either mean length or weight, although there appears to be a general trend of increasing length with increasing particle size from fines to large boulders (Figure 6) as was seen with this same analysis for all fish species combined. This is shown by an increase in mean length from the F/None habitat type (75.58 mm) to 93.50 mm for G-SB/None and 106.18 mm for the LB/None habitat type. Unlike all fish species combined this trend appears to also occur for mean weight as there is an increase in values from F/None (7.27 g) to G-SB/None at 19.79 g and to LB/None at 40.29 g.

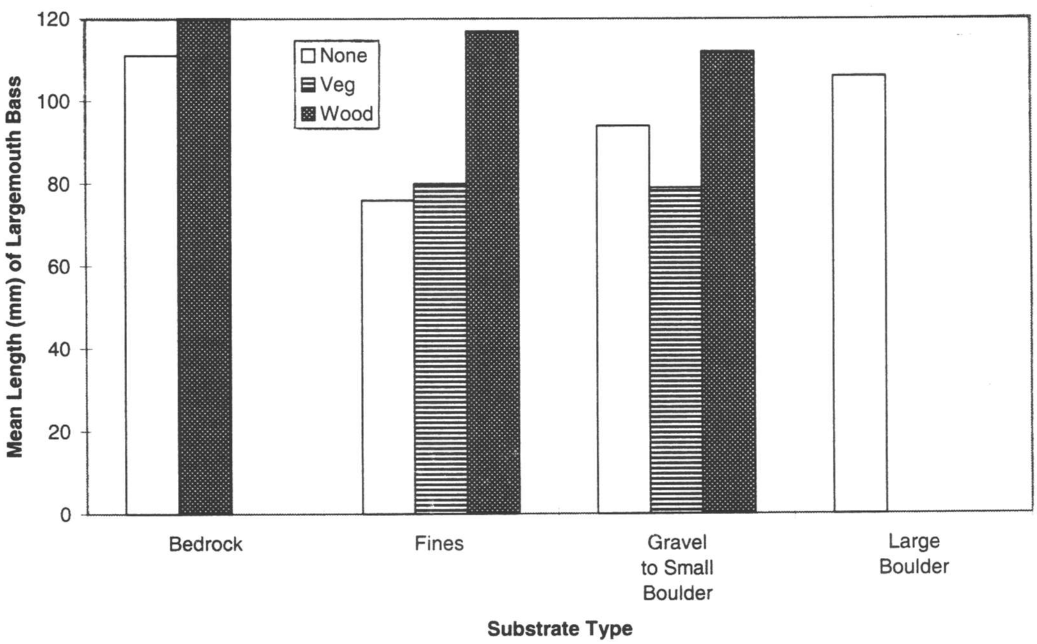
While mean length data for all fish species combined showed a general trend to increase with the presence of either vegetation or wood as a substrate structural component, the mean length data for largemouth bass showed a trend for increasing fish length for all substrates only with the addition of wood (Table 24). The fine substrates was the only substrate where fish mean length was greater with the addition of both vegetation and wood compared to the F/None habitat (Table 24). This trend in fine substrates seemed to occur for both fish length and weight. Largemouth bass showed this same general increasing size trend for weight where wood was present with: 1) F/None

(7.27 g), F/Wood (27.18 g), 2) G-SB/None (19.79 g), G-SB/Wood (20.10 g), and 3) BR/None (25.53 g), BR/Wood (31.64 g).

Figure 6. Mean length for all fish species and largemouth bass alone sampled in each habitat type, grouped by substrate type. Different numbers above bars indicate significant differences between habitat types.



180
160
140
120
100
80
60
40
20
0
Mean Length (mm) of All Fish Species
1,2
1,2
1
1,2
2
1,2
1,2
1,2
1,2
None
Veg
Wood
Bedrock
Fines
Gravel to Small Boulder
Large Boulder
Substrate Type



120
100
80
60
40
20
0
Mean Length (mm) of Largemouth Bass
None
Veg
Wood
Bedrock
Fines
Gravel to Small Boulder
Large Boulder
Substrate Type

Figure 6.

Minimum and Maximum Fish Lengths, Weights

Minimum and maximum lengths and weights for fish from each habitat type were not analyzed statistically because of the high potential for these lengths and weights to change with sample size. However, maximum values tend to increase with increasing substrate particle size in the specific reservoir habitats utilized by these fish. This was shown for all fish species combined (Table 25, Figure 7) and for largemouth bass alone (Table 26, Figure 7) in the 1996 sample. Minimum values for length and weight tended to remain reasonably constant with the same increase in substrate particle size.

The range of fish sizes associated with both bedrock and fine substrate habitat types tended to be greater with the addition of large wood structure. Wood apparently plays an important role in facilitating coexistence of a wide range of fish sizes. The addition of vegetation to fine substrates also appears to permit a larger range of fish sizes to coexist as compared to fine substrates without vegetation or wood, although not to the same degree as the addition of wood (Table 25). The structure associated with large boulders appears to allow for the largest range of fish sizes to coexist. Again, these patterns can be distinguished for the fish assemblage as a whole as well as the single species analysis for largemouth bass (Tables 25, 26; Figure 7).

The addition of wood and vegetation structure to the intermediate sized gravel to small boulder substrate does not appear to have a strong effect on fish size ranges as compared to bedrock and fine substrates. Fish length and weight do not increase substantially or at all for those gravel to small boulder substrate habitat types with this added structure in contrast to the same situation with the bedrock and fine substrates.

Table 25. Minimum and maximum lengths and weights of all fish sampled, by habitat type.

Habitat Type	Minimum Length (mm)	Maximum Length (mm)	Range Interval for Length (mm)	Minimum Weight (g)	Maximum Weight (g)	Range Interval for Weight (g)
BR/None	29	205	176	1	101	100
BR/Wood	44	457	413	1	1071	1070
F/None	29	171	142	0.5	60	59.5
F/Veg	29	354	325	0.5	395	394.5
F/Wood	62	453	391	4	717	713
G-SB /None	28	440	412	0.5	934	933.5
G-SB /Veg	23	473	450	0.5	862	861.5
G-SB /Wood	41	425	384	1	628	627
LB/None	37	524	487	0.5	2343	2342.5

Figure 7. Relationship of maximum length to minimum length for all fish species and largemouth bass alone sampled in each habitat type.

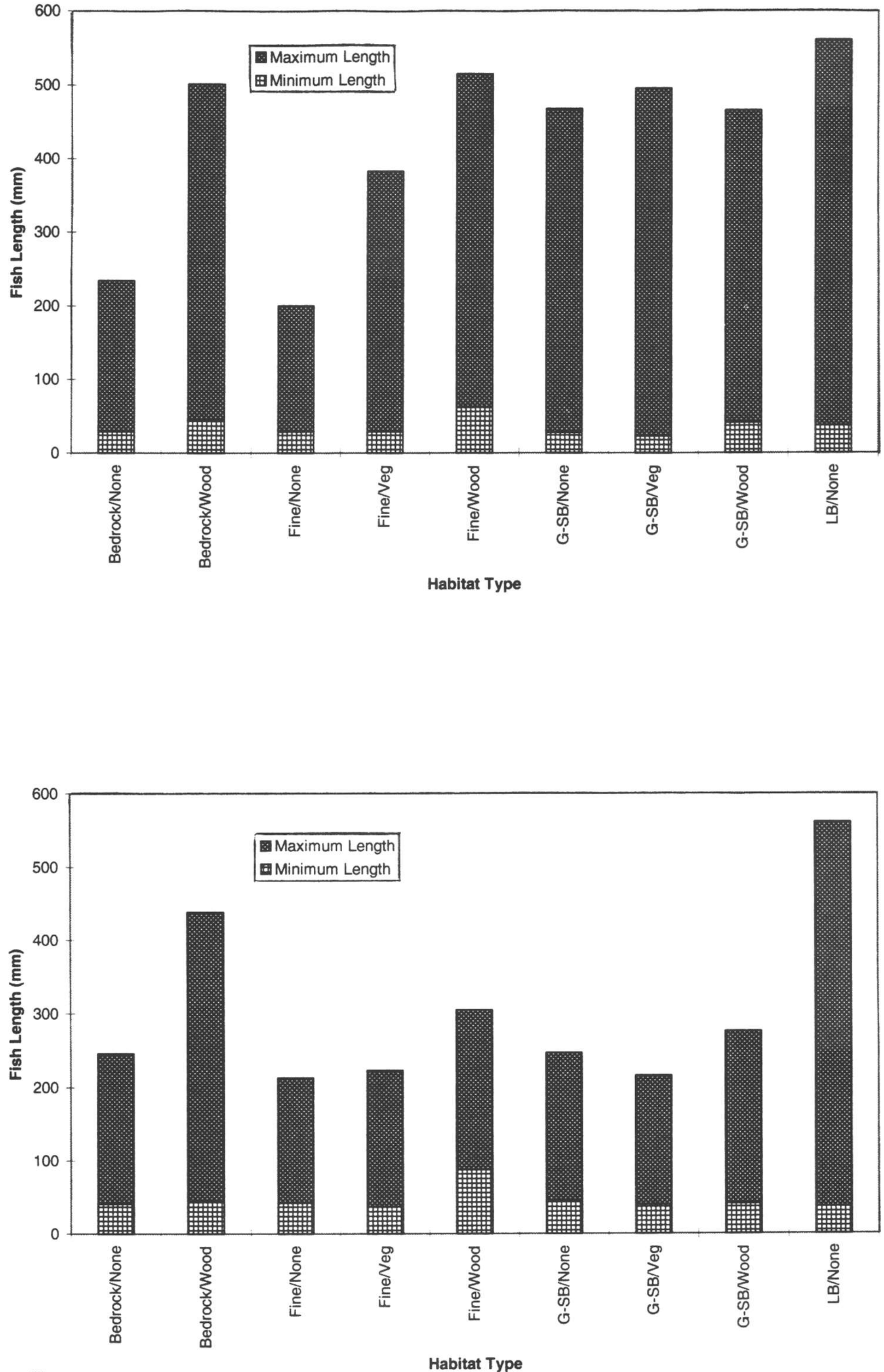

Maximum Length
Minimum Length
Fish Length (mm)
600
500
400
300
200
100
0
Bedrock/None
Bedrock/Wood
Fine/None
Fine/Veg
Fine/Wood
G-SB/None
G-SB/Veg
G-SB/Wood
LB/None
Habitat Type
Maximum Length
Minimum Length
Fish Length (mm)
600
500
400
300
200
100
0
Bedrock/None
Bedrock/Wood
Fine/None
Fine/Veg
Fine/Wood
G-SB/None
G-SB/Veg
G-SB/Wood
LB/None
Habitat Type

Figure 7.

Table 26. Minimum and maximum lengths and weights of largemouth bass sampled, by habitat type.

Habitat Type	Minimum Length (mm)	Maximum Length (mm)	Range Interval for Length (mm)	Minimum Weight (g)	Maximum Weight (g)	Range Interval for Weight (g)
BR/None	41	205	164	1	101	100
BR/Wood	44	395	351	1	1071	1070
F/None	42	171	129	1	60	59
F/Veg	37	186	149	1	79	78
F/Wood	88	217	129	8	163	155
G-SB /None	44	203	159	1	100	99
G-SB /Veg	40	176	136	1	69	68
G-SB /Wood	41	235	194	1	183	182
LB/None	37	524	487	1	2343	2342

Catch Per Unit Effort (CPUE)

Catch per unit effort (CPUE) is an important index of relative fish abundance (Gilliland, 1991; Cohen et al., 1993; Maceina et al., 1995; and MacRae and Jackson, 2001) and is an indicator of habitat preference or suitability (Meals and Miranda, 1991). CPUE has been found useful for correlations to recruitment (Buynak et al., 1999), condition (Fletcher et al., 1993), and seasonal variation in fish abundance (Cohen et al., 1993). Cohen et al. (1993) showed CPUE changed over the years of study but was unique at each location. At a site in Rainy Lake, Canada, their CPUE was not significantly different over the summer months. Thus, CPUE can be a useful tool to assess assemblage characteristics.

For this study, CPUE was measured in numbers of fish per hour (CPUEN) of pedal down time for the electrofishing gear and in weight in kilograms of fish sampled per hour (CPUEW). Analysis was performed for all fish species combined and largemouth bass sampled in each habitat type across reservoirs in 1996. Significant differences in CPUEN and CPUEW between habitat types were observed for all species combined but not for largemouth bass alone.

One pairwise comparison of habitat type CPUEN for all species was different at $P \leq 0.05$ (Tukey HSD) (Table 27). This was for fish in F/Veg versus F/Wood. Two additional pairwise comparisons of habitat type CPUEN were different at $P<0.10$. These were 1) F/Veg to BR/None and 2) F/Wood to GS-B/Wood.

The BR/None habitat type had the lowest CPUEN at 74.5, which was significantly different from the highest CPUEN at 312.24 in the F/Veg habitat (Table 27). The CPUEN for G-SB/Veg and LB/None were also relatively high at 291.05 and 289.31, respectively, but not significantly different from the other habitat types.

In each substrate category, those habitat types with the additional structure of vegetation or wood higher CPUEN values than those without, and the habitat types with vegetation had higher CPUEN values than those with wood, although the differences were not always significant at $P<0.10$ (Table 27).

Table 27. Mean catch per unit effort (CPUEN ±SE) in total number of individuals sampled for all fish species per hour pedal down time, and weight of catch per unit effort (CPUEW ±SE) in kilograms of total number of individuals for all fish species sampled per hour. CPUEN data followed by superscript numbers indicates signficant differences at $P \leq 0.05$ (Tukey HSD). CPUEW data followed by superscript numbers indicates significant differences at $P < 0.09$ (Tukey HSD).

Habitat Type		CPUEN (Number/Hour)	CPUEW (Kilograms/Hour)
BR/None	1	74.15 (±85.04)	0.38 (±4.06)
BR/Wood	2	172.24 (±106.95)	11.80 (±5.11)
F/None	3	106.43 (±108.69)	2.87[4,9,7] (±5.19)
F/Veg	4	312.24[5] (±67.79)	3.55[3] (±3.24)
F/Wood	5	135.38[4] (±98.45)	5.68 (±4.71)
G-SB/None	6	182.05 (±70.50)	4.42 (±3.37)
G-SB/Veg	7	291.05 (±67.79)	5.45[3] (±3.24)
G-SB/Wood	8	225.20 (±81.73)	4.52 (±3.91)
LB/None	9	289.31 (±74.22)	14.02[3] (±3.55)

No significant differences were found among pairs of habitat types for CPUEW with all fish species combined at $P \leq 0.05$ (Tukey HSD). However, at $P < 0.09$ (Tukey HSD) three pairwise comparisons were found significantly different. These were: 1) F/Veg and F/None, 2) GS-B/Veg and F/None, and 3) LB/None and F/None. Like CPUEN, the CPUEW for the BR/None habitat type had the lowest value at 0.38 kg per hour. The LB/None habitat type was the highest at 14.02 kg per hour. The BR/Wood habitat type was the second highest value at 11.80 kg per hour. All other habitat type values were less than 6. Again, within substrate categories, the CPUEW for those habitat types with vegetation or wood had higher values than those without, but only fine substrates showed a higher value where vegetation was present than where wood was present.

Figure 8. Mean fish CPUE (by numbers and weight (kg)/ hour) of habitat types, grouped by substrate type. Different numbers above bars indicate significant differences between habitat types.

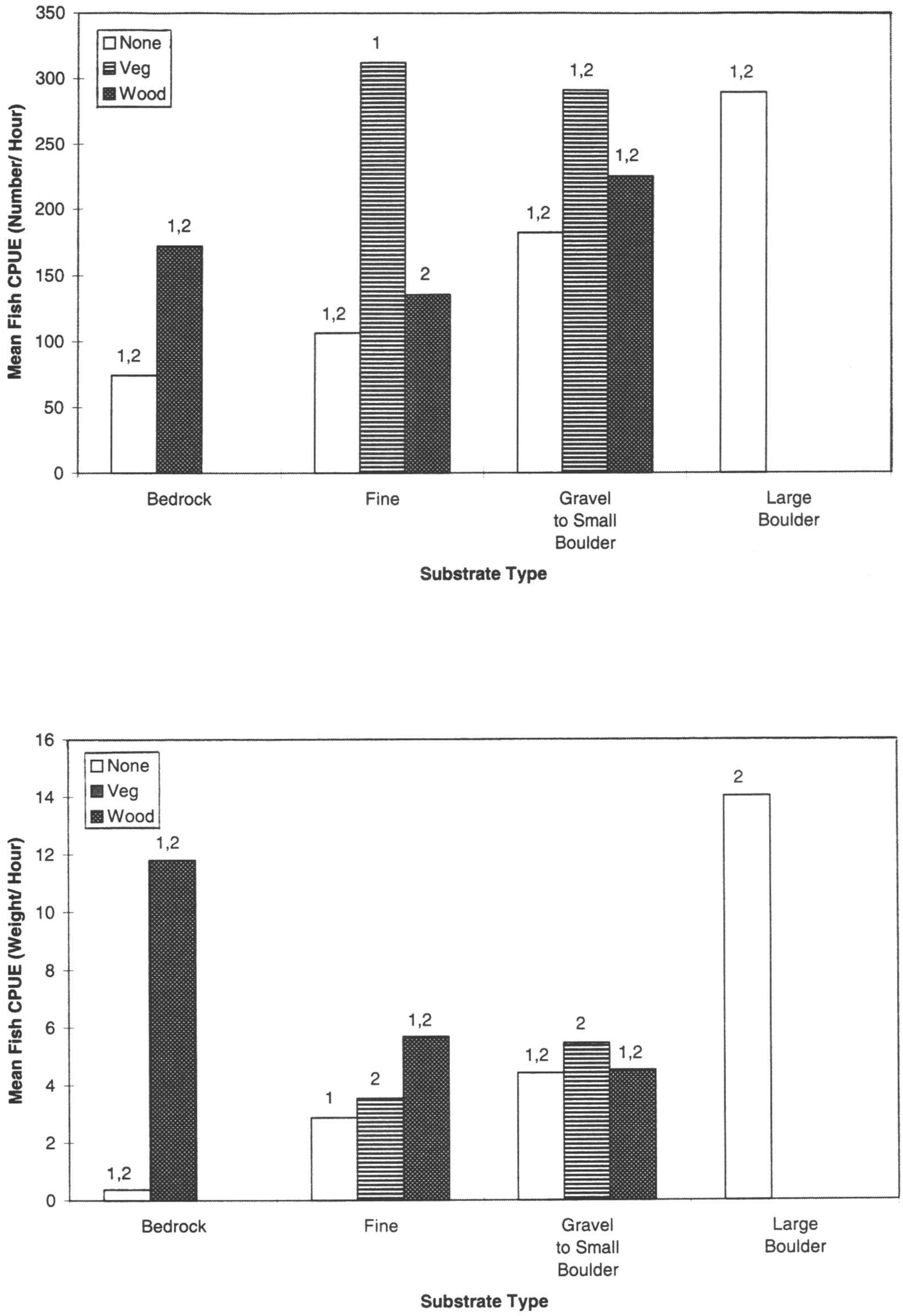

350
300
250
200
150
100
50
0
None
Veg
Wood
Mean Fish CPUE (Number/ Hour)
1,2
1,2
1,2
1
2
1,2
1,2
1,2
1,2
Bedrock
Fine
Gravel to Small Boulder
Large Boulder
Substrate Type
16
14
12
10
8
6
4
2
0
None
Veg
Wood
Mean Fish CPUE (Weight/ Hour)
1,2
1,2
1
2
1,2
1,2
2
1,2
2
Bedrock
Fine
Gravel to Small Boulder
Large Boulder
Substrate Type

Figure 8.

Relative Weight

Two techniques can be used to compare condition: length vs. weight relationships and condition factor analysis (Fletcher et al., 1993). Both analyses were performed in this study. Van Den Avyle and Carlander (1977) suggested both were required to interpret seasonal condition in largemouth bass of McFarland Lake, Iowa. They recommended length-weight regressions should not be utilized for collections over long periods of time as condition factors can change significantly. Annual or seasonal trends in condition have often been attributed to changes in growth rate, food availability, and population size (Cooper et al., 1963).

Relative weight analysis was used in this study as an indicator of potential differences in condition both between habitat types and between reservoirs while length vs. weight analysis was used only to assess between reservoir differences. Other studies have used condition to analyze the effects of sex, age, and season for largemouth bass (Van Den Avyle and Carlander, 1977; Blazer et al., 1987) and white crappie (Gabelhouse, 1991). Also, condition has been shown to be negatively correlated with high adult and total population densities (Van Den Avyle and Carlander, 1977; Post et al., 1998) and excessive vegetation levels (Colle and Shireman, 1980).

The relative weight index (W_r), based on a standard curve derived for western warmwater fish (Murphy and Willis 1991), was used in this study to assess fish condition at the scale of the habitat type for the 1996 sample (Table 28) as well as individual and combined reservoirs for the 1995-1996 sample (Table 29).

No significant differences were found ($P \leq 0.10$ (Tukey HSD)) between mean fish W_r for different habitat types (Table 28) of 1996 samples combined across reservoirs. W_r from the two most common species found across reservoirs, i.e., largemouth bass and bluegill, were analyzed separately. Again, no significant differences ($P \leq 0.10$ (Tukey HSD)) were found for W_r for either species between habitat types (Table 28).

Table 28. Combined reservoir mean W_r (±SE) of largemouth bass (LB), bluegill (BG) and all species combined (includes largemouth bass, smallmouth bass, bluegill, white crappie and black crappie) sampled at each habitat type in 1996.

Habitat Type		Species	
	LB	BG	All Species
BR/None	101.06 (±3.66)	NP	103.15 (±7.46)
BR/Wood	1/ 113.46	101.96 (±12.30)	111.31 (±9.20)
F/None	1/ 99.44	NP	1/ 99.44
F/Veg	103.77 (±3.66)	66.72 (±12.30)	96.47 (±5.16)
F/Wood	1/ 112.23	90.96 (±12.30)	106.29 (±9.20)
G-SB/None	106.65 (±3.31)	94.91 (±8.62)	98.90 (±5.17)
G-SB/Veg	102.76 (±4.36)	95.27 (±9.66)	104.78 (±6.00)
G-SB/Wood	103.72 (±3.97)	1/ 100.22	100.08 (± 7.61)
LB/None	108.77 (±3.95)	97.11 (±6.67)	100.27 (±5.01)

1/ Only one reservoir represented
NP = Not present at minimum size required for W_r calculations

For combined samples from all reservoirs (1995-1996), the mean W_r of largemouth bass in all reservoirs was greater than 100, suggesting that the largemouth bass larger than 150 mm in all systems are growing well and in good condition (Table 29).

Table 29. Combined reservoir, reservoir, and species mean relative weight (W_r) for largemouth bass, bluegill, white crappie, black crappie, and smallmouth bass. Superscript (^{1,2,3}) numbers indicate significant row differences. Superscript (^{A,B,C}) letters indicate significant column differences.

Reservoir	Species: Largemouth Bass A W_r	N	Bluegill B W_r	N	White Crappie C W_r	N	Black Crappie D W_r	N	Smallmouth Bass E W_r	N	Total N
Cottage Grove 1	101.59^{7} (±1.67)	55	94.70 (±2.39)	51	NP	NP	101.16^{6} (±2.60)	29	NP	NP	135
Dorena 2	106.04^{7} (±1.74)	54	94.45 (±2.03)	61	NP	NP	101.30^{6} (±2.10)	31	NP	NP	146
Dexter 3	109.88 (±4.06)	5	100.35 (±4.40)	2	113.43^{6} (±1.33)	34	99.37	1	107.75 (±2.46)	16	58
Foster 4	111.44	1	94.30 (±2.23)	12	NP	NP	NP	NP	90.16	1	14
Green Peter 5	105.40^{7} (±1.66)	5	NP	NP	NP	NP	NP	NP	NP	NP	5
Hills Creek 6	106.34^{7} (±2.18)	30	99.41 (±1.22)	34	101.64^{3,7} (±1.02)	67	117.91^{1,2} (±0.29)	2	NP	NP	133
Lookout Point 7	124.91^{1,2,5,6} (±2.81)	18	107.69 (±2.83)	6	113.32^{6} (±1.32)	43	NP	NP	NP	NP	67
Mean RW/Total Number	106.79^{B} (±1.06)	168	96.10^{A,C,D,E} (±1.11)	166	107.91^{B,D} (±0.84)	144	101.89^{B,C} (±1.64)	63	106.72^{B} (±2.60)	17	558

NP= Not present at greater than the minimum size required for relative weight calculations or not present in reservoir.

Largemouth bass at Lookout Point Reservoir appear to be especially robust. W_r for largemouth bass in samples from Lookout Point Reservoir (124.91) was significantly greater at $P \leq 0.05$ (Tukey HSD) than for those collected at Cottage Grove (101.59), Dorena (106.04), Green Peter (105.40), or Hills Creek (106.34) Reservoirs. The mean W_r for white crappie from Dexter (113.43) and Lookout Point (113.32) Reservoirs were significantly greater at $P \leq 0.05$ (Tukey HSD) than for those from Hills Creek Reservoir (101.64). Again, all mean W_r for individual reservoirs were above 100 suggesting larger white crappie are in good condition in the study reservoirs as well.

W_r for black crappie (117.91) at Hills Creek Reservoir was significantly greater at $P \leq 0.08$ than the black crappie sampled at Cottage Grove (101.16) and Dorena (101.30) Reservoirs. Like largemouth bass and white crappie, all the reservoirs showed mean W_r in excess of 100 for black crappie, except Dexter where sufficient numbers of this species were not collected.

Smallmouth bass appear to be in good condition in Dexter Reservoir with a mean W_r of 107.75. Smallmouth bass in Foster Reservoir were not collected in sufficient numbers for a valid determination.

The mean W_r values for bluegill were under 95.00 in three of six reservoirs, Cottage Grove, Dorena, and Foster, indicating this species may not be growing as well as other warmwater species in the reservoir environments studied. These lower W_r values may be due to greater intraspecific competition. No significant differences in W_r for bluegills were found at $P \leq 0.10$ (Tukey HSD) between reservoirs.

Pooled relative weight values for each species, individually across all reservoirs, were over 100 for most species, except bluegill at 96.10. Bluegill were significantly less robust at $P \leq 0.05$ (Tukey HSD) than black crappie (101.89), smallmouth bass (106.72), largemouth bass (106.79), and white crappie (107.91). Additionally, the mean W_r of black crappie (101.89) was significantly less than white crappie in this analysis.

Length vs. Weight Regression Analysis

Length vs. weight regressions were completed for individual fish species at each reservoir when a particular fish species was represented by three or more individuals of varying lengths and was found in at least two reservoirs (Tables 30 and 31). Ten species met this criteria. Regression lines include the combined data from the 1995 and 1996 sampling efforts. A multiplicative regression model (power equation) of the form $y = a*x^b$ was used to describe the relationship between length (x) and weight (y) (Statistical Graphics Corporation, 1996). All regressions showed strong relationships between the variables of length and weight. All R^2 values were at least 0.84, and 94% of R-Squared values exceeded 0.90. Correlation coefficients were all in excess of 0.90 with 94% greater than 0.95.

While not necessarily significant from each other (see following section), the heaviest to lightest with respect to length were typically fish from: 1) Lookout Point,

Table 30. Length vs. weight regression line ($y = a*x^b$) specifications for largemouth bass, smallmouth bass, and bluegill. Length (X) in mm, weight (Y) in grams. SE = Standard deviation of the residuals.

Reservoir	Regression Line Specifications					
	Equation	N	P	SE	Correlation Coefficient	R^2
		Largemouth Bass				
Cottage Grove	$Y = 0.00000780675*X^{3.09735}$	141	0.0000	0.22	0.99	0.98
Dorena	$Y = 0.00000718387*X^{3.11854}$	724	0.0000	0.12	0.99	0.98
Dexter	$Y = 0.0000184663*X^{2.95378}$	6	0.0000	0.07	0.99	0.99
Foster	$Y = 0.00000760402*X^{3.09737}$	7	0.0000	0.11	0.99	0.99
Green Peter	$Y = 0.0000113167*X^{3.01142}$	72	0.0000	0.23	0.98	0.96
Hills Creek	$Y = 0.0000102847*X^{3.03448}$	308	0.0000	0.20	0.98	0.97
Lookout Point	$Y = 0.00000720889*X^{3.1313}$	318	0.0000	0.29	0.97	0.94
		Smallmouth Bass				
Dexter	$Y = 0.000016453*X^{2.98544}$	18	0.0000	0.09	0.99	0.99
Foster	$Y = 0.0000177909*X^{2.92655}$	45	0.0000	0.11	0.99	0.98
		Bluegill				
Cottage Grove	$Y = 0.00000897455*X^{3.14755}$	60	0.0000	0.15	0.98	0.96
Dorena	$Y = 0.0000182727*X^{2.99035}$	89	0.0000	0.18	0.98	0.97
Dexter	$Y = 0.0000111064*X^{3.12446}$	3	0.0499	0.20	0.99	0.99
Foster	$Y = 0.0000141947*X^{3.00946}$	70	0.0000	0.42	0.96	0.93
Hills Creek	$Y = 0.00000624738*X^{3.22727}$	111	0.0000	0.21	0.96	0.93
Lookout Point	$Y = 0.0000100206*X^{3.15989}$	7	0.0000	0.10	0.99	0.99
		Sculpin Sp.				
Dexter	$Y = 0.00000564329*X^{3.15019}$	52	0.0000	0.10	0.98	0.97
Lookout Point	$Y = 0.00000687286*X^{3.12204}$	26	0.0000	0.19	0.95	0.91

Table 31. Length vs. weight regression line ($y = a*x^b$) specifications for black crappie, white crappie, northern pikeminnow, brown bullhead, largescale sucker, and redside shiner. Length (X)in mm, weight (Y) in grams. SE = standard deviation of the residuals.

Reservoir		Regression Line Specifications				
	Equation	N	P	SE	Correlation Coefficient	R^2
		Black Crappie				
Cottage Grove	$Y = 0.00000465887*X^{3.20482}$	42	0.0000	0.13	0.98	0.96
Dorena	$Y = 0.0000070945*X^{3.12136}$	67	0.0000	0.12	0.98	0.97
		White Crappie				
Dexter	$Y = 0.00000580545*X^{3.18368}$	34	0.0000	0.06	0.99	0.98
Hills Creek	$Y = 0.00000378309*X^{3.23075}$	70	0.0000	0.09	0.99	0.98
Lookout Point	$Y = 0.00000183079*X^{3.39873}$	55	0.0000	0.07	0.99	0.98
		Northern Pikeminnow				
Dexter	$Y = 0.0000050909*X^{3.08812}$	40	0.0000	0.10	0.99	0.99
Green Peter	$Y = 0.00000257476*X^{3.19961}$	6	0.0001	0.09	0.99	0.98
Lookout Point	$Y = 0.00000359646*X^{3.15764}$	11	0.0000	0.17	0.99	0.98
		Brown Bullhead				
Cottage Grove	$Y = 0.000008321*X^{3.07387}$	12	0.0000	0.06	0.99	0.99
Dorena	$Y = 0.00000836713*X^{3.0957}$	11	0.0000	0.21	0.99	0.98
Lookout Point	$Y = 0.000000593532*X^{3.57934}$	3	0.0137	0.02	0.99	0.99
		Largescale Sucker				
Green Peter	$Y = 0.000015161*X^{2.89482}$	10	0.0000	0.11	0.99	0.99
Hills Creek	$Y = 0.0000179088*X^{2.87557}$	45	0.0000	0.12	0.99	0.99
Lookout Point	$Y = 0.0000100275*X^{2.97941}$	78	0.0000	0.22	0.99	0.98
		Redside Shiner				
Dexter	$Y = 0.0000471732*X^{2.63717}$	180	0.0000	0.23	0.98	0.97
Hills Creek	$Y = 0.00000318792*X^{3.25099}$	28	0.0000	0.16	0.92	0.85
Lookout Point	$Y = 0.0000401209*X^{2.70466}$	54	0.0000	0.33	0.91	0.83

2) Dexter), 3) Dorena, 4) Foster, 5) Cottage Grove, 6) Hills Creek, and 7) Green Peter Reservoirs.

Overall, of the ten species in which length vs. weight regression line analysis was performed, nine species had Lookout Point Reservoir with the greatest fish weight to length values. The redside shiner was the only exception.

Comparison of Length vs. Weight Regression Lines

Length vs. weight regressions were compared statistically (Statistical Graphics Corporation, 1996) by species following a natural log (Log) transformation of the length and weight data (Table 32, 33 and 34).

No significant differences for length vs. weight regression line slope were found for any species between reservoirs with the exception of white crappie. The slope of the white crappie length vs. weight regression line for Lookout Point Reservoir was significantly greater than Dexter and Hills Creek Reservoirs, indicating white crappie are more robust in this system (Table 34). However, many significant differences were found for the intercepts of largemouth bass, smallmouth bass, and bluegill (Table 33), as well as white crappie and redside shiners (Table 34). The differences in intercepts of the length vs. weight relationships indicate Lookout Point fish were significantly heavier and Hills Creek significantly thinner than fish in other reservoirs compared at very early ages. Similar slopes of the curves suggests growth was similar thereafter in all reservoirs.

Table 32. Regression line comparison single model specifications (Statistical Graphics Corporation, 1996). Standard Error (SE) = Standard Deviation of the residuals. * = significant differences between reservoir regression lines.

Species (All Reservoirs)	Regression Line Comparison Single Model Specifications					
	Parameters	R^2	SE	Model P-Value	Intercept P-Value	Slope P-Value
Largemouth Bass	Age vs. Length	0.81	0.17	0.0000	0.0000 *	0.8544
Bluegill	Length vs. Weight	0.96	0.25	0.0000	0.0159 *	0.3494
Black Crappie	Length vs. Weight	0.97	0.05	0.0000	0.1834	0.4696
Brown Bullhead	Length vs. Weight	0.99	0.14	0.0000	0.2541	0.5377
Largescale Sucker	Length vs. Weight	0.98	0.08	0.0000	0.3515	0.3269
Largemouth Bass	Length vs. Weight	0.97	0.19	0.0000	0.0008 *	0.1585
Redside Shiner	Length vs. Weight	0.96	0.25	0.0000	0.0026 *	0.2548
Smallmouth Bass	Length vs. Weight	0.99	0.04	0.0000	0.0000 *	0.4488
Northern Pikeminnow	Length vs. Weight	0.99	0.11	0.0000	0.3544	0.7286
White Crappie	Length vs. Weight	0.99	0.03	0.0000	0.0000 *	0.0639 *

Table 33. Length (log) vs. weight (log) regression line (log y = a + b*log x) specifications and comparisons for largemouth bass, smallmouth bass, and bluegill sampled in the study reservoirs. Super script ([1,2,3]) numbers indicate significant differences. SE = standard deviation of the residuals.

Reservoir		Regression Line Specifications						
		Equation Intercept	Equation Slope	N	P	SE	Correlation Coefficient	R^2
				Largemouth Bass				
Cottage Grove	1	-11.7674[2,3,7]	3.09406LogX	141	0.0000	0.12	0.99	0.99
Dorena	2	-11.8067[1,6,7]	3.11037LogX	724	0.0000	0.12	0.99	0.99
Dexter	3	-10.8996[1,4,6]	2.95378LogX	6	0.0000	0.07	0.99	0.99
Foster	4	-11.7868[3]	3.09737LogX	7	0.0000	0.11	0.99	0.99
Green Peter	5	-11.3892	3.01142LogX	72	0.0000	0.23	0.98	0.96
Hills Creek	6	-11.4849[2,3,7]	3.03448LogX	308	0.0000	0.20	0.98	0.97
Lookout Point	7	-11.8402[1,2,6]	3.1313LogX	318	0.0000	0.29	0.97	0.94
				Smallmouth Bass				
Dexter	1	-11.015[2]	2.98544LogX	18	0.0000	0.09	0.99	0.99
Foster	2	-10.9368[1]	2.92655LogX	45	0.0000	0.11	0.99	0.98
				Bluegill				
Cottage Grove	1	-11.6211[4,6]	3.14755LogX	60	0.0000	0.15	0.98	0.96
Dorena	2	-10.9101[4,5,6]	2.99035LogX	89	0.0000	0.18	0.98	0.97
Dexter	3	-11.408	3.12446LogX	3	0.0499	0.20	0.99	0.99
Foster	4	-11.1626[1,2,6]	3.00946LogX	70	0.0000	0.42	0.96	0.93
Hills Creek	5	-11.9833[2,6]	3.22727LogX	111	0.0000	0.21	0.96	0.93
Lookout Point	6	-11.5109[1,2,4,5]	3.15989LogX	7	0.0000	0.10	0.99	0.99

Table 34. Length (log) vs. weight (log) regression line (log y = a + b*log x) specifications and comparisons for black crappie, white crappie, northern pikeminnow, brown bullhead, largescale sucker, and redside shiner sampled in the study reservoirs. Superscript ([1,2,3]) numbers indicate significant differences. SE = standard deviation of the residuals.

Reservoir		Regression Line Specifications					
	Equation Intercept	Equation Slope	N	P	SE	Correlation Coefficient	R^2
			Black Crappie				
Cottage Grove	-12.2767	3.20482LogX	42	0.0000	0.13	0.98	0.96
Dorena	-11.8562	3.12136LogX	67	0.0000	0.12	0.98	0.97
			White Crappie				
Dexter 1	-12.0567[2]	3.18368LogX[3]	34	0.0000	0.06	0.99	0.98
Hills Creek 2	-12.485[1,3]	3.23075LogX[3]	70	0.0000	0.09	0.99	0.98
Lookout Pt. 3	-13.2108[2]	3.39873LogX[1,2]	55	0.0000	0.07	0.99	0.98
			Northern Pikeminnow				
Dexter	-12.1881	3.08812LogX	40	0.0000	0.10	0.99	0.99
Green Peter	-12.8698	3.19961LogX	6	0.0001	0.09	0.99	0.98
Lookout Point	-12.5356	3.15764LogX	11	0.0000	0.17	0.99	0.98
			Brown Bullhead				
Cottage Grove	-11.6967	3.07387LogX	12	0.0000	0.06	0.99	0.99
Dorena	-11.6912	3.0957LogX	11	0.0000	0.21	0.99	0.98
Lookout Point	-14.3372	3.57934LogX	3	0.0137	0.02	0.99	0.99
			Largescale Sucker				
Green Peter	-11.0968	2.89482LogX	10	0.0000	0.11	0.99	0.99
Hills Creek	-10.9302	2.87557LogX	45	0.0000	0.12	0.99	0.99
Lookout Point	-11.5102	2.97941LogX	78	0.0000	0.22	0.99	0.98
			Redside Shiner				
Dexter 1	-9.96169[2,3]	2.63717LogX	180	0.0000	0.23	0.98	0.97
Hills Creek 2	-12.6561[1]	3.25099LogX	28	0.0000	0.16	0.92	0.85
Lookout Pt. 3	-10.1236[1]	2.70466LogX	54	0.0000	0.33	0.91	0.83

Age vs. Length Regression Analysis

Otolith age was analyzed for largemouth bass in six of the seven reservoirs in which this species was found. There was not a sufficient size range for bass collected at Foster Reservoir to make age determination a useful analysis tool in that reservoir. A logarithmic regression model of the form y = a + b*Logx was used to describe the relationship of Age (x) vs. Length (y) in all other reservoirs (Table 35 and Figure 9). All R^2 values were over 0.75 with the exception of 0.64 at Dexter and 0.29 at Hills Creek.

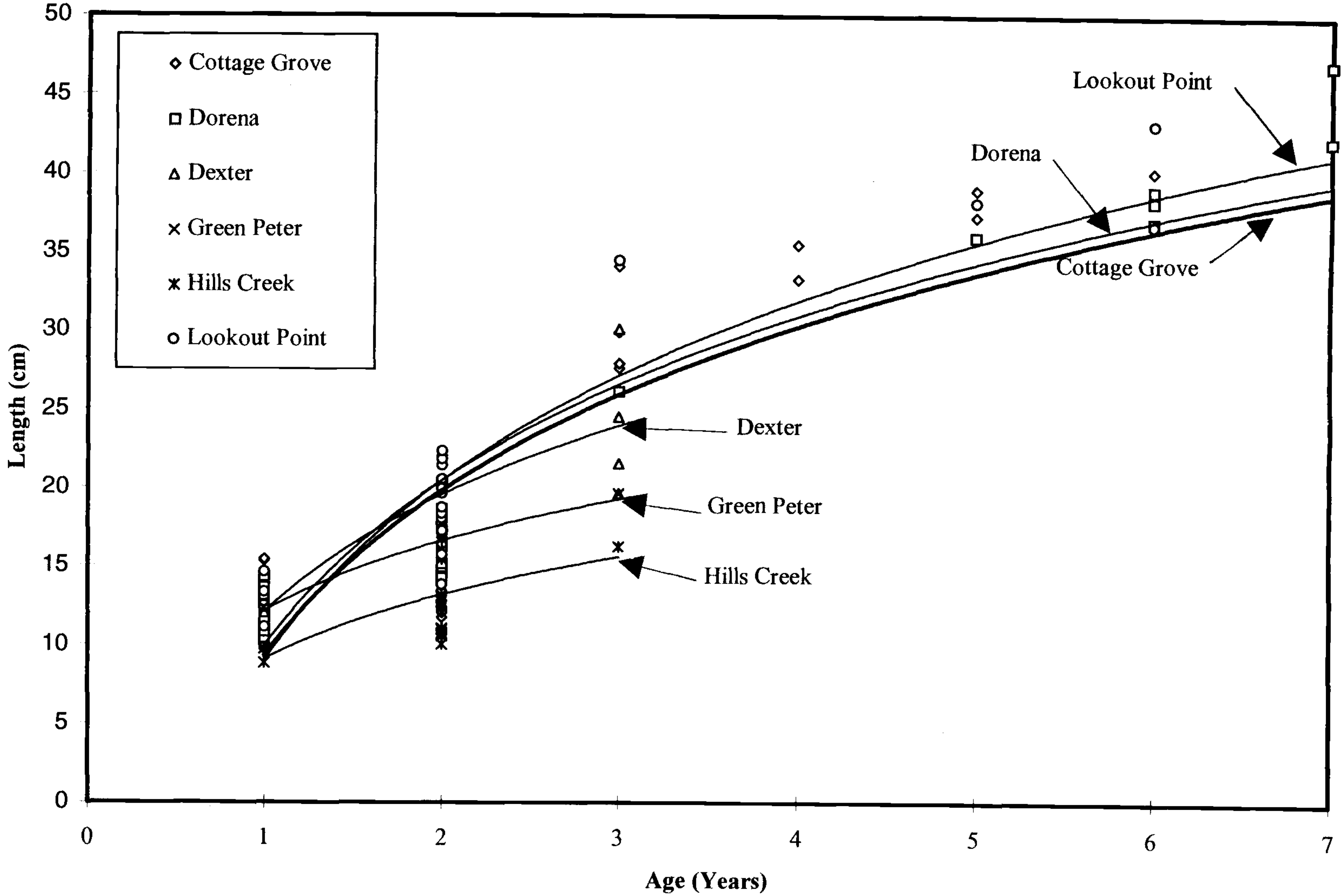
Age vs. length regression line slope was steepest for Lookout Point Reservoir while Hills Creek and Green Peter Reservoirs were the least steep, reflecting the same general reservoir pattern described for length vs. weight regressions (Table 35 and Figure 9).

The three slowest growth rates for largemouth bass, as indicated by the slope of the age vs. length relationship and in order of decreasing steepness, were found in Dexter, Green Peter, and Hills Creek Reservoirs. These reservoirs were represented by fish with a maximum age of three. Whereas, the other three reservoirs, Cottage Grove, Dorena, and Lookout Point Reservoirs were represented by fish up to 7 years. These sampling results

Table 35. Age (from otolith analysis) vs. length regression line (log y = a + b*log x) specifications for largemouth bass sampled in the study reservoirs. SE = standard deviation of the residuals.

Reservoir	Regression Line Specifications					
	Equation	N	P	SE	Correlation Coefficient	R^2
Cottage Grove	LogY = 9.27741 + 15.1482*LogX	34	0.0000	4.86	0.86	0.75
Dorena	LogY = 9.91819 + 15.1639*LogX	33	0.0000	3.37	0.95	0.90
Dexter	LogY = 12.00 + 10.8546*LogX	5	0.1025	4.58	0.80	0.64
Green Peter	LogY = 12.0821 + 6.5040*LogX	3	0.0905	0.73	0.98	0.97
Hills Creek	LogY = 7.63836 + 8.51668*LogX	24	0.0065	3.19	0.53	0.29
Lookout Point	LogY = 8.95255 + 16.5543*LogX	21	0.0000	3.74	0.91	0.83

Figure 9. Age vs. length regressions for largemouth bass.



Cottage Grove
Dorena
Dexter
Green Peter
Hills Creek
Lookout Point
Lookout Point
Dorena
Cottage Grove
Dexter
Green Peter
Hills Creek
Length (cm)
Age (Years)

Figure 9.

indicate there may be a greater abundance and better recruitment through older age classes of largemouth bass in Cottage Grove, Dorena, and Lookout Point Reservoirs. However, the representation in more age classes provides better reliability for the age vs. length regressions for largemouth bass in these reservoirs.

Age vs. length regression lines for each reservoir were compared to each other using the same statistical regression line comparison technique used for length vs. weight (Table 32). No significant differences in slope were found. However, intercept values were significantly different at $P = 0.0000$.

Largemouth bass age classes represented in the littoral zones sampled at each reservoir as well as across reservoirs were determined in order to assess the age class compositions of these assemblages (Table 36). Length at age groups was determined by establishing a length category criteria which ranged from the upper quartile of a lower age category through the upper quartile of the next upper age class. Quartiles are determined by the upper and lower boundaries of the middle 50% of the data (Ramsey and Schafer 1997). The range between these boundaries is referred to as the interquartile range. Across reservoirs 93% of the largemouth bass sampled were age 2^+ or less with 83% being age 1^+ (Table 36). Length frequency analysis results (not shown) substantiated these findings and provided further evidence that the majority of largemouth bass sampled across habitats were young individuals, although the habitats with wood and the large boulder substrate were found to have large ranges in size.

The results of otolith age determination at each reservoir were pooled and length at age data were compared for each reservoir (Table 37). At $P \leq 0.05$ the first three age groups with mean lengths of 12.13 cm, 15.49 cm, and 25.97 cm, respectively, were significantly different from each other. Also ages 4, 5, 6, and 7 with mean lengths of 34.40 cm, 37.63 cm, 39.07 cm, and 44.60 cm, respectively, were significantly different from ages 1, 2, and 3 fish. Additionally, age 4 fish were significantly different from age 7 fish. For all reservoirs, except Cottage Grove and Dorena, very few or no largemouth bass older than 3 years were collected in the littoral zone habitats.

Table 36. Number (N) and proportion (%) of largemouth bass represented by different age groups at each reservoir and across reservoirs.

Age	Reservoir														All Reservoirs	
	Cottage Grove		Dorena		Dexter		Foster		Green Peter		Hills Creek		Lookout Point			
	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%
$0\text{-}1^+$	83	56	619	86	1	17	6	86	66	92	243	78	299	93	1318	83
2^+	28	18	61	8	0	0	0	0	5	7	55	18	11	3	160	10
3^+	20	13	32	4	4	67	1	14	1	1	14	4	12	3	84	5
4^+	9	6	1	0.3	1	16							1	1	12	0.7
5^+	5	3	6	1											11	0.7
6^+	5	3	3	0.5											8	0.4
7^+	2	1	2	0.2											4	0.2
Total	152	100	724	100	6	100	7	100	72	100	312	100	323	100	1597	100

Table 37. Mean length (cm) of largemouth bass age groups sampled across all reservoirs during 1995-1996. Superscript ($^{1,2,3,\ ect.}$) numbers indicate significant differences at $P \leq 0.05$ (Tukey HSD) between ages of fish.

Age	N	Mean Length (cm)	SE	Range	Lower Quartile	Upper Quartile
1^{+}	31	$12.13^{2,3,4,5,6,7}$	0.29	8.8-15.4	11.10	13.10
2^{+}	61	$15.49^{1,3,4,5,6,7}$	0.41	10.0-22.3	12.70	17.90
3^{+}	12	$25.97^{1,2,4,5,6,7}$	1.68	16.2-34.5	20.55	30.00
4^{+}	2	$34.40^{1,2,3,7}$	1.10	33.3-35.5	33.30	35.50
5^{+}	4	$37.63^{1,2,3}$	0.64	36.0-39.0	36.65	38.60
6^{+}	7	$39.07^{1,2,3}$	0.82	36.8-43.2	37.00	40.20
7^{+}	2	$44.60^{1,2,3,4}$	2.40	42.2-47.0	42.20	47.00

Otolith age determination was also performed for representative black crappie, white crappie, and smallmouth bass size groups. Due to small number of age groups represented and/ or heavy grouping towards one age group it was felt that regression line analysis would be impractical for these species.

Black crappie sampled in the littoral zone across reservoirs in 1995-1996 were determined to be all two years old or younger with 88% of these being one year old while white crappie sampled were all four years old or younger with 94% of these being one to two years old (47% one year old and 53% two years old). The large differences in proportions of ages randomly sampled across reservoirs for black and white crappie may indicate that white crappie may have a higher adaptability to the shallower, warmer waters of reservoir littoral zones, when compared to black crappie.

Dexter Reservoir and Foster Reservoir were the only two reservoirs where smallmouth bass were found. However, Dexter was the only reservoir where larger individuals were sampled making age determination practical. Otolith age determination showed these fish to be four to five years old. No younger smallmouth bass were sampled suggesting successful spawning may be only periodic, the individuals sampled in this study were introduced, or younger individuals were in other areas of the reservoir not sampled.

Nonpiscivorous (Prey) vs. Piscivorous (Predator) Fish Representation

Predation is known to be a powerful force shaping fish communities. Jackson et al. (1992) suggests habitat related differences and predation rather than competition structure fish communities. Predation effects may be direct as in the elimination of individuals or species. Many indirect results of predation have also been reported including changes in the life history and decreased condition or growth of prey species as they modify their choice of or movements between habitats and foraging behavior, reduced fecundity as prey mature at smaller sizes, as well as increased competition with other prey species, and increased mortality due to stress (Jackson et al., 2000). The basic change is one of size structure. Predation can prevent recruitment by removing the preferred prey species.

Various tools have been devised to assess and monitor these dynamics including the use of ratios of piscivore species numbers to prey species numbers (Matthews 1998) and Y/C and F/C ratios (Swingle, 1950). The ratio of nonpiscivore (forage (F) or prey) fish species weight to piscivorous (carnivore (C) or predator) fish species weight has been used extensively (Swingle, 1950; Fletcher 1993) and was utilized in this study. This ratio is known to be a measure of "balance" as described by Swingle (1950). Desirable reported ratios are 3.0 to 6.0 (Swingle,1950) and 5.0 (Moehle and Davies, 1993). Fletcher (1993) elaborated on these optimal ranges to suggest that 2-10 should be an acceptable range, 0-2 an indication of overcrowded piscivorous species, and values in excess of 10 indicate an overcrowded nonpiscivorous species condition. While balance is an oversimplification of predator-prey dynamics (Bennett, 1971), the measurement of proportions of size groups and species is important. In general terms, balanced fish populations 1) reproduce periodically, 2) rates of recruitment are adequate to provide a reasonable harvest, and 3) consist of a combination of species with at least one piscivore representative (Moehle and Davies, 1993; Fletcher, 1993). Moehl and Davies (1993) also found standing crops in balanced warmwater fish populations would consist of about 12% largemouth bass.

Swingle (1950) concluded from his research that F/C ratios in balanced populations generally occur in a narrow range from 1.4 to 6.8, whereas, in unbalanced populations the range is much wider from 0.06 to 65.1. He further observed that F/C ratios in the ranges of 0.06 to 2.7 only occurred with unbalanced populations. Older aquatic systems exhibited low F/C ratios in the range of 1.9 to 3.5. However, due to the overlap of F/C ratios for balanced and unbalanced populations, Swingle (1950) and Bennett (1971) advised that the F/C ratio is not a definitive tool to describe fish populations, and other criteria need to be addressed as well in making management decisions. For example, the effects of cover, proportions of shallow and deep water habitat, as well as efficiency of predation, along with others could affect the F/C ratio.

The probability of balancing fish predators and prey in western reservoirs is low, due to lack of knowledge of species responses to these highly unstable habitats with low biodiversity (Wydoski and Bennett, 1981). Additionally, the F/C ratios addressed in this study are specific to littoral zone fish assemblage sampling rather than an all reservoir population sampling.

Forage (F) fish feed primarily on plants, plankton, and insects but may occasionally eat small fish (Swingle 1950). Swingle found that the principal forage (F) fish species present in both natural and impounded waters of Alabama were bluegills, suckers, and shiners. He further noted that bullheads compete with bluegills, not largemouth bass, substantiating their designation as a forage fish species.

The principal predator species encountered during the sampling for this study were the largemouth bass, smallmouth bass, northern pikeminnow, and black and white crappie. Although largemouth bass feeds at times throughout its life on invertebrates they have been generally found to have a fish diet (Swingle, 1950; Keast and Webb, 1966; Hall and Werner, 1977; Werner et al., 1977; Wydoski and Bennett, 1981) and are classified as piscivorous for this study. All sizes of largemouth bass are lumped together as a predator fish species for this analysis as well (recommended by Swingle, 1950). Black and white crappie up to 101 mm are considered to be largely insectivorous and to compete directly with bluegill (Swingle, 1950). Black and white crappie greater than 101 mm become largely piscivorous competing more directly with largemouth bass (Swingle, 1950; Markham et al., 1991).

The percent composition of predator and prey fish were compared across reservoirs by habitat type (Table 38) and at the reservoir scale (Table 39). Significant differences were found between reservoirs but not between habitat types. Although not significant, habitats with wood consistently showed the greatest piscivorous fish percentage by number and weight for the fine and gravel to small boulder substrates while only minimal differences were observed for bedrock.

When individual reservoir means for percent predator and percent prey fish were determined from the combination of all habitat types represented in each system, significant differences were found (Table 39) for both mean percent by numbers and mean percent by weight. Utilizing the mean percent predator fish numbers, Lookout Point (13.10%) and Dexter (14.57%) showed the lowest mean composition of piscivorous fish, and were significantly different from Cottage Grove (57.49%), Dorena (82.22%), Foster (56.45%), Green Peter (81.19%), and Hills Creek (54.87%) Reservoirs (Table 39). Additionally, the mean composition of piscivorous fish in Dorena Reservoir samples was significantly different from samples from Hills Creek Reservoir. The low values for Dexter Reservor samples are due to high numbers of redside shiners present during the 1996 sampling process, while the low values for Lookout Point Reservoir are attributable to the high numbers of largescale suckers sampled. Lookout Point (14.81%) and Dexter

Table 38. Percent of piscivorous (predator) and nonpiscivorous (prey) fish by number and weight for each habitat type across reservoirs. N represents numbers of samples compared.

Habitat Type	Percent Predator and Prey Fish by Number				Percent Predator and Prey Fish by Weight (g)			
	Predator		Prey		Predator		Prey	
	Mean	SE/ N	Mean	SE/ N	Mean	SE/ N	Mean	SE/ N
BR/None	65.09	10.60/ 9	34.67	10.32/ 9	63.24	11.43/ 9	36.77	11.43/ 9
BR/Wood	51.39	13.33/ 6	47.54	12.98/ 6	53.70	14.38/ 6	46.31	14.37/ 6
F/None	42.45	13.54/ 6	56.40	13.19/ 6	42.21	14.61/ 6	57.80	14.61/ 6
F/Veg	44.08	8.45/ 14	55.92	8.23/ 14	51.27	9.11/ 14	48.78	9.11/ 14
F/Wood	59.96	12.27/ 7	38.98	11.95/ 7	57.48	13.24/ 7	42.53	13.23/ 7
G-SB/None	54.27	8.78/ 13	45.82	8.56/ 13	57.17	9.48/ 13	42.83	9.48/ 13
G-SB/Veg	48.68	8.45/ 14	46.37	8.23/ 14	58.01	9.11/ 14	41.99	9.11/ 14
G-SB/Wood	64.05	10.18/ 10	34.84	9.92/ 10	62.43	10.99/ 10	37.58	10.99/ 10
LB/None	39.80	9.25/ 12	60.42	9.01/ 12	37.23	9.98/ 12	62.77	9.98/ 12

Table 39. Percent of piscivorous (predator) and nonpiscivorous (prey) fish by number and weight at each reservoir. Superscript ([1,2,3]) numbers indicate significant differences. N represents numbers of samples compared.

Reservoir	Percent Prey and Predator Fish Sampled by Number						Percent Prey and Predator Fish Sampled by Weight					
	Prey Fish			Predator Fish			Prey Fish			Predator Fish		
	Mean	SE	N	Mean	SE	N	Mean	SE	N	Mean	SE	N
1 Cottage Grove	34.81 [3,7]	11.02	9	57.49 [3,7]	13.09	9	36.49 [3,7]	13.28	9	63.57 [3,7]	13.30	9
2 Dorena	17.78 [3,4,6,7]	5.38	17	82.22 [3,6,7]	5.38	17	12.28 [3,6,7]	5.07	17	87.72 [3,6,7]	5.07	17
3 Dexter	85.43 [1,2,4,5,6]	7.16	11	14.57 [1,2,4,5,6]	7.16	11	82.17 [1,2,4,5]	9.36	11	17.83 [1,2,4,5]	9.36	11
4 Foster	43.55 [2,3,7]	11.21	12	56.45 [3,7]	11.21	12	36.35 [3,7]	9.29	12	63.65 [3,7]	9.29	12
5 Green Peter	18.81 [3,7]	7.32	16	81.19 [3,7]	7.82	16	20.55 [3,7]	8.75	16	79.45 [3,7]	8.75	16
6 Hills Creek	45.13 [2,3,7]	10.42	12	54.87 [2,3,7]	10.42	12	50.86 [2]	12.08	12	49.14 [2]	12.08	12
7 Lookout Point	86.91 [1,2,4,5,6]	7.85	14	13.10 [1,2,4,5,6]	7.85	14	85.19 [1,2,4,5]	9.43	14	14.81 [1,2,4,5]	9.43	14
Total	45.46	4.22	91	53.78	4.26	91	44.06	4.45	91	55.95	4.45	91

(17.83%) were again composed of less piscivorous fish by weight than other reservoirs and were significantly different than samples collected from Cottage Grove (63.57%), Dorena (87.72%), Foster (63.65%), and Green Peter (79.45%) Reservoirs. Percent by weight of piscivorous fish in Hills Creek Reservoir at 49.14% was also significantly less from those in Dorena Reservoir at 87.72%. Only Lookout Point and Dexter Reservoirs had resaonable values for prey fish, which correlates to the steepest condition regressions (length vs. weight) observed in these systems (discussed previously), and suggests other prey may be available for piscivorous fish in the other study reservoirs.

Prey/Predator fish ratios at the habitat scale were not significantly different at $P<0.10$ (Tukey HSD) (Table 40). Due to the few fish sampled in many BR/Wood and F/None habitat type replicates across reservoirs, these habitat types were not included in this analysis. Although no significant differences were found among habitat types, the ratio values ranged from a low of 1.34 with F/Veg to 11.82 for G-SB/Wood and the habitat types that included wood consistently showed the highest prey/predator ratios for their respective substrate categories with the exception of bedrock. Also, while there was a general increase in Prey/Predator values with increasing substrate size from fines to gravel to small boulder, values were very similar for the bedrock habitat types and LB/None.

Table 40. Mean Nonpiscivorous (Prey)/ Piscivorous (Predator) ratios (±SE) across reservoirs for habitat types. N = number of samples compared.

Habitat Type	Prey/Predator Mean	N
BR/None	3.49 (±3.23)	3
F/Veg	1.34 (±1.61)	11
F/Wood	1.73 (±3.15)	3
G-SB/None	4.85 (±2.03)	8
G-SB/Veg	2.81 (±1.80)	10
G-SB/Wood	11.82 (±3.83)	2
LB/None	3.75 (±2.48)	5

Benthic vs. Pelagic Fish Composition

The mean percentage (by number), of benthic fish, i.e., sculpin species, largescale suckers, and bullhead species, were compared to the mean percentage (by number), of pelagic (all other fish species) fish across reservoirs by habitat type (Table 41). No significant differences were found at $P \leq 0.10$ (Tukey HSD), although the percent of benthic fish was consistently low across habitat types with a range of 16.03% (G-SB/Veg) to 31.47% (F/Wood). Conversely, the mean percent of pelagic fish was consistently high across habitat types with a range of 68.53% (F/Wood) to 83.97% (G-SB/Veg). These data indicate that the reservoir systems studied are dominated by pelagic fish species as would be expected. However, a certain bias towards pelagic fish with electrofishing sampling is likely.

Table 41. Percent of benthic and pelagic fish sampled by habitat type.

Habitat Type	Percent Benthic Fish Numbers Sampled		Percent Pelagic Fish Numbers Sampled	
	Mean	SE	Mean	SE
BR/None	16.81	7.66	83.21	7.66
BR/Wood	17.40	9.63	82.62	9.63
F/Nine	18.91	9.79	81.13	9.79
F/Veg	23.92	6.10	76.08	6.11
F/Wood	31.47	8.86	68.53	8.87
G-SG/None	22.47	6.35	77.53	6.35
G-SB/Veg	16.03	6.10	83.97	6.11
G-SB/Wood	28.21	7.36	71.80	7.36
LB/None	16.16	6.68	82.62	6.68

At the individual reservoir scale (analysis by one way ANOVA utilizing pooled habitat type data by reservoir) significant differences in these ratios were found at $P \leq 0.05$ (Tukey HSD) (Table 42). Samples from Dexter Reservoir, with a mean percentage of benthic fish at 38.85% and a mean percentage of pelagic fish at 61.15% (38.85%/ 61.15%) was significantly different from samples from Cottage Grove (1.39%/ 98.61%), Dorena (2.19%/ 97.81%), Foster (4.35%/ 95.65%), Hills Creek (6.63%/ 93.37%) and Lookout Point (77.48%/ 22.52%) Reservoirs. Fish in Lookout Point Reservoir were significantly different from the same reservoirs with the addition of Dexter (38.85%/ 61.15%) and Green Peter (16.31%/ 83.69%) Reservoirs.

At the individual reservoir scale the values for the mean percentage of benthic vs. pelagic fish was consistently low (range 1.39-16.31%) except for Dexter (38.85%/ 61.15%) and Lookout Point (77.48%/ 22.52%) Reservoirs.

The high percentage of benthic fish in Dexter reservoir was due to high numbers of sculpin species sampled in 1996 while the high percentage of benthic fish in Lookout Point reservoir was attributed to the large numbers of largescale suckers sampled in 1996. The combined reservoir mean percentage (analysis by one way ANOVA utilizing pooled habitat type data from all study reservoirs) of benthic vs. pelagic fish was 21.48% (Table 42).

Table 42. Percent of benthic and pelagic fish sampled in 1996 by reservoir. Superscript ($^{1,2,3,\text{ ect.}}$) numbers indicate significant differences at $P \leq 0.05$ (Tukey HSD) between reservoirs. N represents number of samples compared.

Reservoir	Percent Benthic Fish Numbers Sampled		Percent Pelagic Fish Numbers Sampled		N
	Mean	SE	Mean	SE	
1 Cottage Grove	$1.39^{3,7}$	1.39	$98.61^{3,7}$	1.39	9
2 Dorena	$2.19^{3,7}$	0.81	$97.81^{3,7}$	0.81	7
3 Dexter	$38.85^{1,2,4,6,7}$	11.34	$61.15^{1,2,4,6,7}$	11.34	11
4 Foster	$4.35^{3,7}$	2.54	$95.65^{3,7}$	2.54	12
5 Green Peter	16.31^{7}	7.32	83.69^{7}	7.32	16
6 Hills Creek	$6.63^{3,7}$	3.38	$93.37^{3,7}$	3.38	12
7 Lookout Point	$77.48^{1,2,3,4,5,6}$	8.19	$22.52^{1,2,3,4,5,6}$	8.19	14
Total	21.48	3.59	78.72	3.59	91

Water Quality

Alkalinity, Secchi Disk Depth, and pH measurements were recorded at least once at all study reservoirs between 08/13/96 and 08/15/96 (Table 2). Alkalinity and pH measurements in these seven reservoirs were narrow in range at 22-24 mg/l and 7.40-7.81, respectively. Secchi disk depths ranged from 3.66 m at Dexter Reservoir to 6.32 m at Foster Reservoir, both reregulating reservoirs. Secchi depths were used to calculate the trophic state index (Carlson, 1977) of each study reservoir (Table 43). Data were available from this study and a study conducted by the COE in 1980. Using this secchi disk data alone, the COE determined Hills Creek and Dexter Reservoirs to be mesotrophic with eutrophic tendencies and all other study reservoirs to be mesotrophic, whereas, the current

Table 43. Trophic state index (Carlson, 1977) of study reservoirs as determined by current study and U.S. Army Corps of Engineers (1980).

Reservoir	Current Study			U.S. Army Corps of Engineers		
	Secchi Depth (m)	Trophic State Index	Date	Secchi Depth (m)	Trophic State Index	Date
Cottage Grove	5.5	35	08/14/96	4.4	39	08/05/80
Dorena	4.9	37	08/14/96	5.2	36	08/05/80
Dexter	3.6	42	08/13/96	1.8	51	08/18/80
Foster	6.3	34	08/15/96	6.4	33	08/26/80
Green Peter	4.9	37	08/15/96	2.7	45	08/26/80
Hills Creek	6.0	34	08/13/96	1.8	51	08/13/80
Lookout Point	3.9	40	08/13/96	7.6	31	08/13/80

study secchi disc data by itself indicate all study reservoirs to be mesotrophic. Dissolvedoxygen and temperature profiles were also recorded at all study reservoirs during this time period (Figures 10-13) and were used to determine whether eutrophic or oligotrophic tendencies appeared to exist within these reservoir systems. The COE also performed temperature and dissolved oxygen profiles in these reservoirs at comparable areas and time periods. Their results are included as well, except for Hills Creek Reservoir, where COE profiles were very erratic and extremely hard to read. These profiles suggest the samples were taken too close to the dam (conversation with Jim Britton, COE). The temperature profiles for this study and the COE indicates

Figure 10. Cottage Grove and Dorena Reservoirs water temperature (A,C) and dissolved oxygen (B,D) profiles.

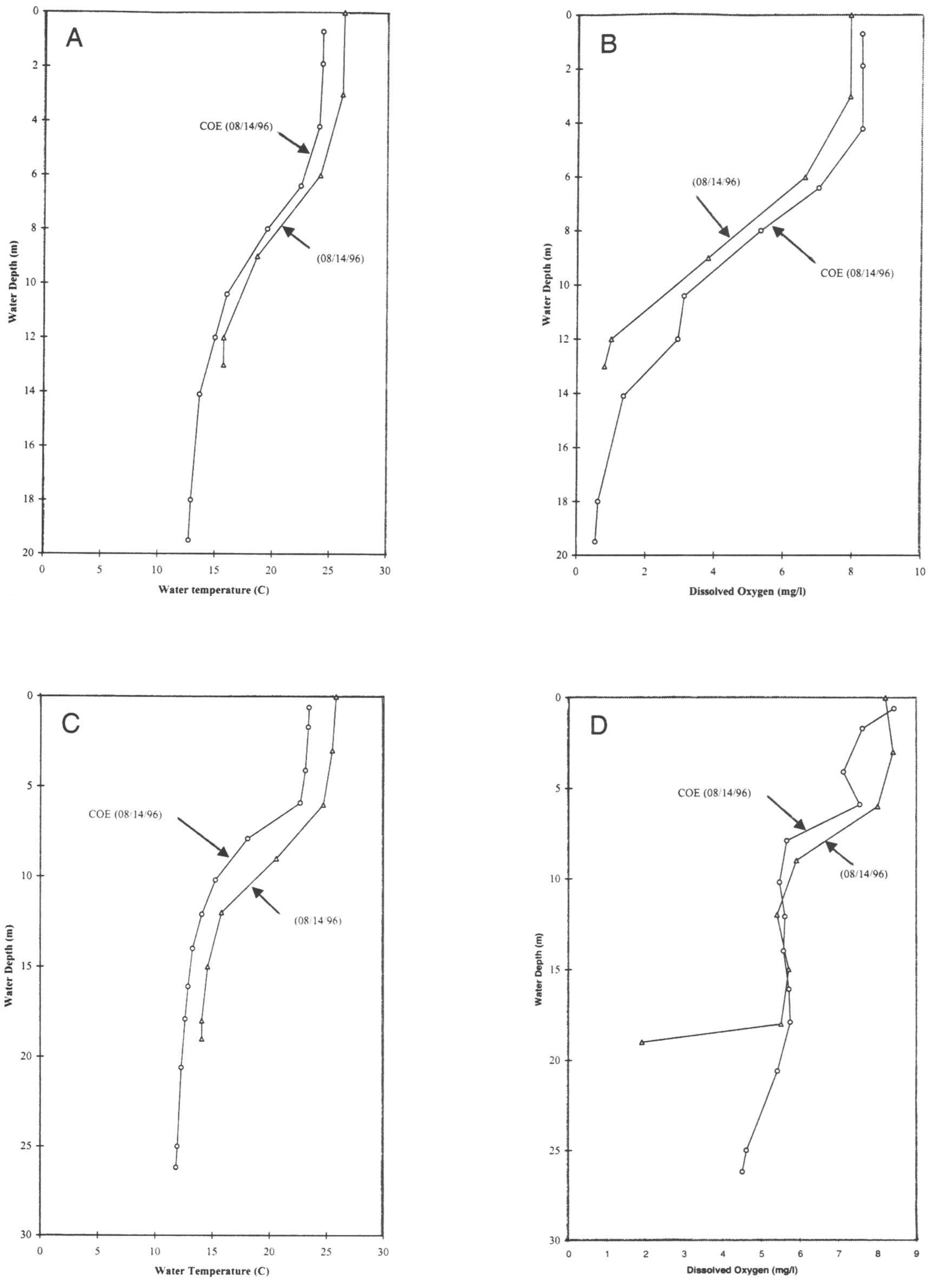

A
COE (08/14/96)
(08/14/96)
Water Depth (m)
Water temperature (C)
B
(08/14/96)
COE (08/14/96)
Water Depth (m)
Dissolved Oxygen (mg/l)
C
COE (08/14/96)
(08/14/96)
Water Depth (m)
Water Temperature (C)
D
COE (08/14/96)
(08/14/96)
Water Depth (m)
Dissolved Oxygen (mg/l)

Figure 10.

Figure 11. Dexter and Foster Reservoirs water temperature (A,C) and dissolved oxygen (B,D) profiles.

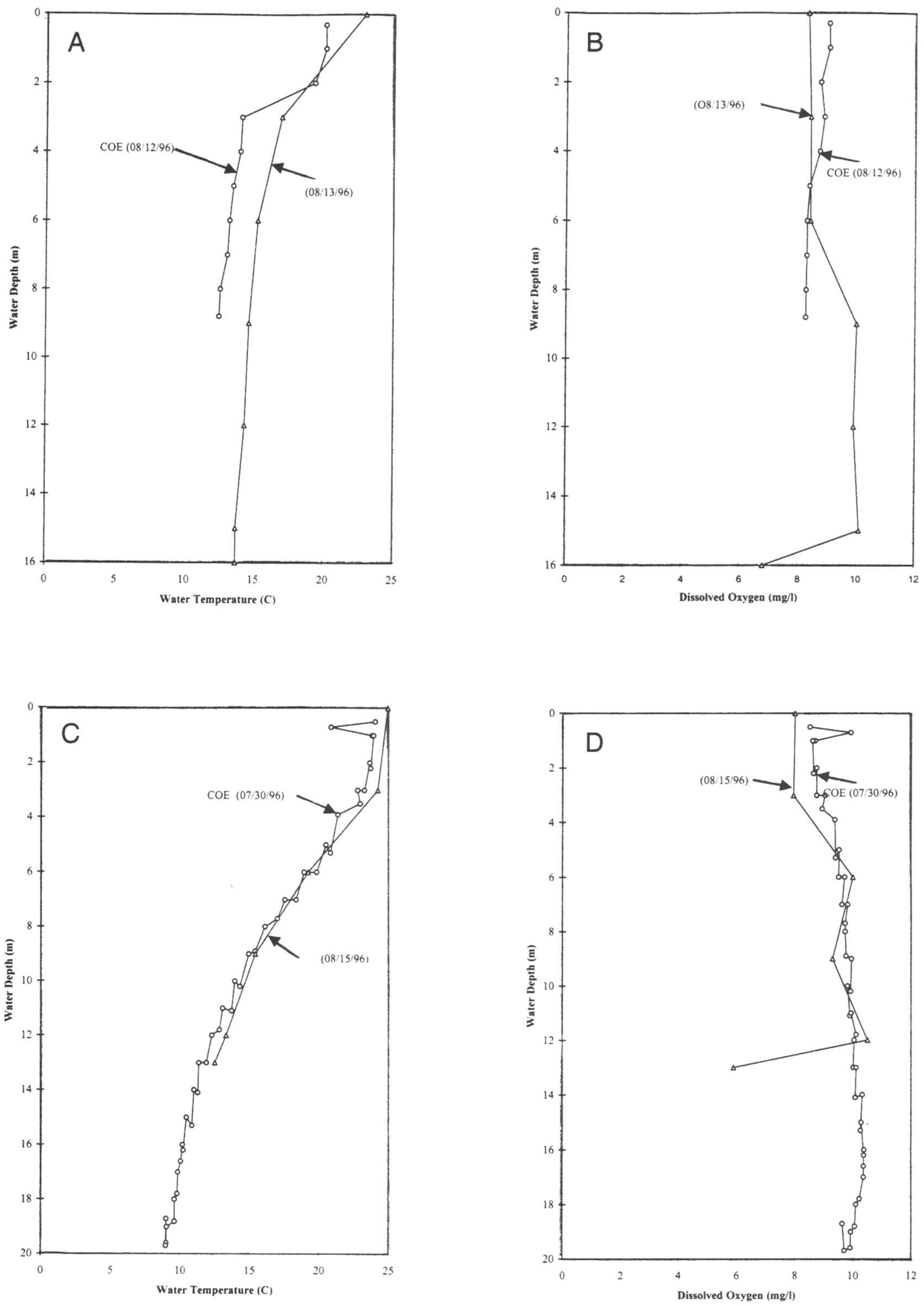

A
COE (08/12/96)
(08/13/96)
Water Depth (m)
Water Temperature (C)
B
(08/13/96)
COE (08/12/96)
Water Depth (m)
Dissolved Oxygen (mg/l)
C
COE (07/30/96)
(08/15/96)
Water Depth (m)
Water Temperature (C)
D
(08/15/96)
COE (07/30/96)
Water Depth (m)
Dissolved Oxygen (mg/l)

Figure 11.

Figure 12. Lookout Point and Green Peter Reservoirs water temperature (A,C) and dissolved oxygen (B,D) profiles.

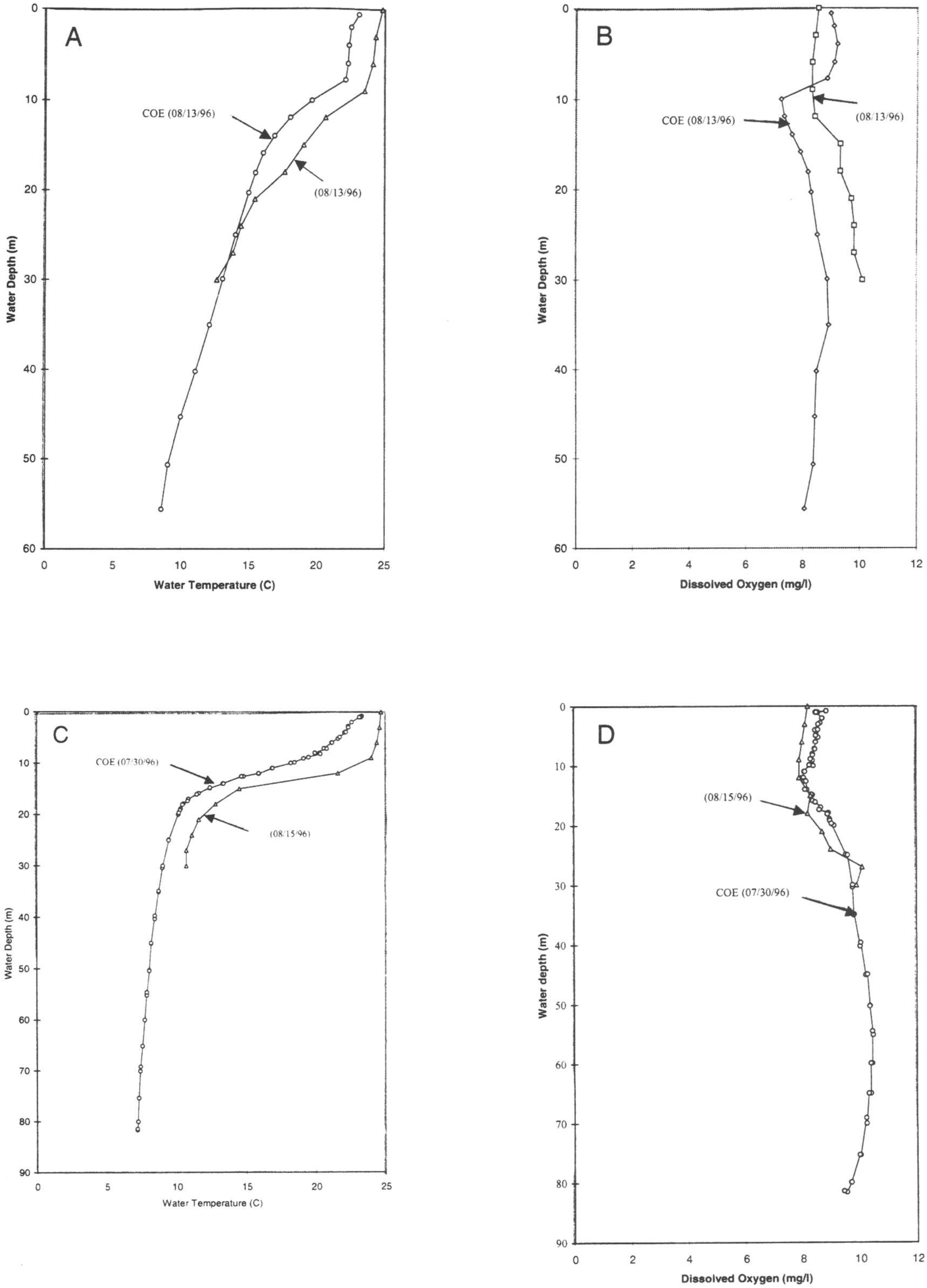
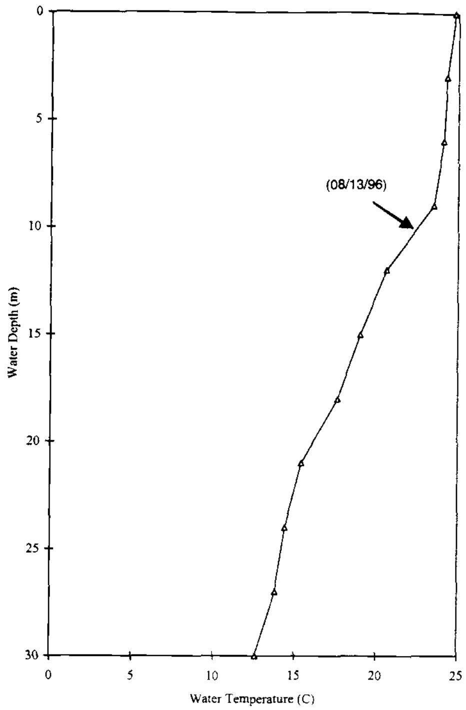

A
COE (08/13/96)
(08/13/96)
Water Depth (m)
Water Temperature (C)
B
COE (08/13/96)
(08/13/96)
Water Depth (m)
Dissolved Oxygen (mg/l)
C
COE (07/30/96)
(08/15/96)
Water Depth (m)
Water Temperature (C)
D
(08/15/96)
COE (07/30/96)
Water depth (m)
Dissolved Oxygen (mg/l)

Figure 12.



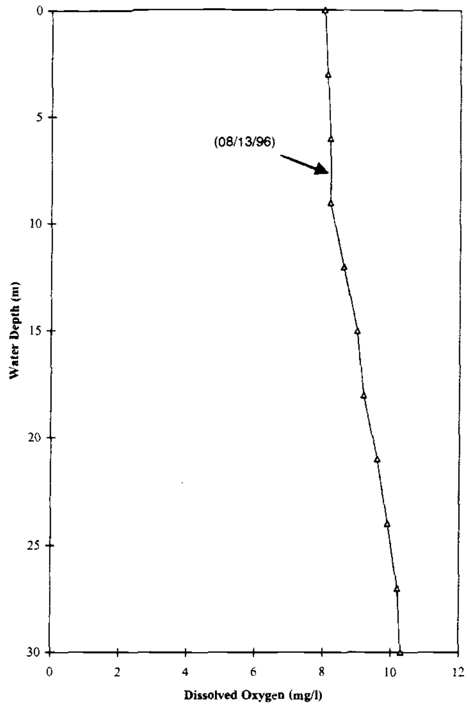


Figure 18. Hills Creek Reservoir water temperature and dissolved oxygen profiles.

all study reservoirs were stratified (Table 44) during field investigations. While the temperature and oxygen profiles for either study may shift due to the exact location and time readings taken at each reservoir, it is important to note that the shapes and positions of the profiles remain similar for purposes of assessing whether reservoirs were stratified and assess the general character of oxygen and thermal regimes. The COE data is not only important as a comparative study, but also the readings were taken at much greater depths in the deeper reservoirs. The oxygen and temperature profiles for this study were limited to 30 m.

The oxygen profiles for the three largest reservoirs, i.e., Lookout Point, Hills Creek, and Green Peter (Figures 12 and 13), reveal some characteristics of an oligotrophic system, although not a classical representation as described by Wetzel (1983). Similarities include: 1) a general increase in oxygen concentrations coincides with lowered temperatures at increased depths; and 2) oxygen concentrations are close to saturation levels throughout the water column (Table 44). In classical oligotrophic systems, organic production is low with low nutrient inputs from external sources. With summer stratification, the concentration of oxygen at increasing depths is primarily regulated by physical influences, such as temperature and wind (Wetzel 1983). Oxygen concentration in such systems increases with decreasing temperatures associated with greater depth, resulting in 100% saturation from the epilimnion down through the hypolimnion. However, because algae blooms have been recorded in these three largest study reservoir systems, and isolated beds of macrophytes do occur in the littoral zones, and oxygen profiles do not quite show the classical orthograde (oligotrophic profile) appearance, an intermediate designation of mesotrophic is probably a more appropriate designation, with a tendency more towards oligotrophy than eutrophy. Wetzel (1983) summarized that waterbodies large in size, long in length, and deep (like Lookout Point, Hills Creek, and Green Peter) with high ratios of hypolimnion to epilimnion volumes, as well as the presence of a rock dominated morphology, are common characteristics of oligotrophic systems.

Table 44. Important water temperature and dissolved oxygen profile characteristics.

Reservoir	Epilimnion Depth (m)	Metalimnion Depth (m)	Mean Percent Oxygen Saturation (±SE)	Percent Oxygen Saturation Range
Cottage Grove	6	9	65.00 (±7.14)	10-98
Dorena	6	12	68.00 (±5.65)	18-100
Dexter	2	3	93.17 (±6.52)	83-98
Foster	3	9	97.00 (±7.14)	94-100
Green Peter	9	18	89.18 (±4.82)	78-99
Hills Creek	9	12	95.27 (±4.82)	95-97
Lookout Point	9	13	98.55(±4.82)	92-100

In contrast to the three largest study reservoirs mentioned previously, the oxygen profiles for Cottage Grove and Dorena Reservoirs (Figure 10) exhibit classical eutrophic characteristics and substantial decreases in oxygen concentrations are observed with depth. Eutrophic systems exhibit high organic production and high external nutrient inputs. Respiration (primarily by bacteria and secondarily by plants and animals), associated with decomposition of organic material is high just below the thermocline in eutrophic systems, resulting in lowered oxygen in the metalimnion and anaerobic conditions in the hypolimnion, especially at the sediment/water interface where organic material accumulation and decomposition is often the heaviest in eutrophic systems. The oxygen profile commonly associated with this eutrophic condition is termed a clinograde. Macrophytes and algae are important components of these systems. Cottage Grove and Dorena reservoirs not only have the highest percent of shoreline with the best substrate for macrophyte plant growth, fines, at 81% and 57% (Table 10), respectively, of any study reservoir, but virtually all of this substrate is covered by this macrophyte growth at these reservoirs, specifically, 99% at Cottage Grove and 97% at Dorena (Table 45). The reservoir with the next highest percent of vegetated fines is Lookout Point at 74%. Also, eutrophic systems are shallow in depth and commonly located in fertile lowland regions, similar to the environments of Cottage Grove and Dorena Reservoirs. Cottage Grove and Dorena have the 1) highest shoal area at 17% and 15%, 2) lowest mean depth of 9.0 m and 12.9 m, and 3) lowest maximum depth at 22.3 m and 29.6 m, respectively, of any study reservoir except Dexter (Table 1). Dexter's' shoal area is 21.6%, with a mean depth of 8.2 m and maximum depth of 17.1 m (Table 1). However, only 36% of Dexters' shoreline length is fine substrate and only 59% of this fine substrate is vegetated with macrophytes (Table 45). Secchi disk readings indicate that Cottage Grove and Dorena are mesotrophic but other indicators discussed above show significant eutrophic tendencies. A more consistent trophic designation of these two reservoir systems is mesotrophic with eutrophic tendencies.

Table 45. Percent of fine substrate habitat types along entire reservoir shoreline.

Reservoir	Fine Substrate Habitat Type		
	F/None	F/Veg	F/Wood
Cottage Grove	<1	>99	0
Dorena	2	97	1
Dexter	41	59	0
Foster	19	64	18
Green Peter	66	9	25
Hills Creek	83 1/	17	--
Lookout Point	0	74	26

1/ Includes F/None and F/Wood habitat types.

Oxygen profiles from the two reregulating reservoirs, Dexter and Foster were orthograde rather than clinograde, with oxygen concentrations approaching saturation at depth (Figure 11). However, like Lookout Point, Hills Creek, and Green Peter Reservoirs, the profiles are not in classical form. Both reservoirs are characterized by short water retention times due to their relatively shallow depth and management as reregulating reservoirs. Both reservoirs, especially Dexter Reservoir, would likely demonstrate much higher eutrophic tendencies if water retention times were longer, due to their general shallow nature with extensive flats, abundant macrophyte growth, and algae blooms. However, without a change in water retention time, a designation of mesotrophic for Dexter and Foster Reservoirs is probably appropriate.

Habitat Regression Analysis

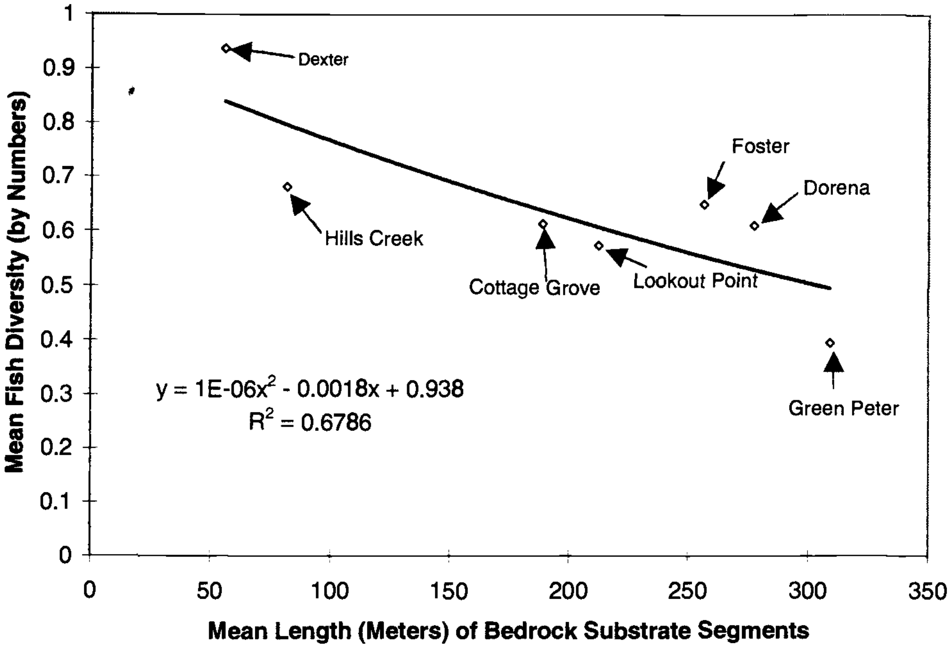
The relationship of several quantifiable substrate characteristics to mean fish species diversity expressed by numbers and weight, and to mean and total fish species richness (number of species) were analyzed with polynomial regression ($y = c_1x^2 + c_2x + b$, where c and b are constants). There are no strict guidelines regarding the spatial scale at which an organisms response to habitat fragmentation or patchiness should be measured (Hart and Horwitz, 1991). This analysis was at the scale of the reservoirs utilizing the shoreline inventory data for each reservoir. Characteristics of substrate categories analyzed in this study were: 1) mean segment length; 2) the percent of total shoreline length represented by each substrate type; 3) number of segments per kilometer; 4) mean distance between segments of a given substrate type; 5) the percent fine substrates that are vegetated, and 6) percent of segments longer than 152 m (see Appendix). Relationships with weak correlations were determined to exist when $R^2 = 0.30\text{-}0.45$. Moderately strong correlations were assumed to exist when $R^2 = 0.46\text{-}0.63$ while correlations were considered strong if $R^2 \geq 0.64$. Substrate correlations with $R^2 \geq 0.64$ are included as figures for succeeding discussions. Also references to fish species H' and richness in this section are for the combined habitat fish samples, unless otherwise noted.

Moderate to strong correlations of the bedrock substrate were found for the mean ($R^2 = 0.68$) segment lengths to fish H' (by numbers) and the number of segments per kilometer to total ($R^2 = 0.64$) (Figure 14). Additionally, one weak correlation were observed for bedrock substrate regressions.

Relatively short bedrock segments seem to provide a more diverse fishery, because increases in mean length of bedrock segments, over the length of segment lengths observed in this study, were found to result in decreased H' (by numbers) (Figure 14).

Fish assemblages in bedrock exhibited low H' and richness (Table 22, 23).

Figure 14. Relationship of the mean length (meters) of bedrock substrate segments to mean fish diversity (by numbers) and the relationship of the shoreline percent of gravel to small boulder substrate to total fish richness in each reservoir.


Mean Fish Diversity (by Numbers)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Dexter
Foster
Dorena
Hills Creek
Cottage Grove
Lookout Point
Green Peter
y = 1E-06x2 - 0.0018x + 0.938
R2 = 0.6786
0
50
100
150
200
250
300
350
Mean Length (Meters) of Bedrock Substrate Segments

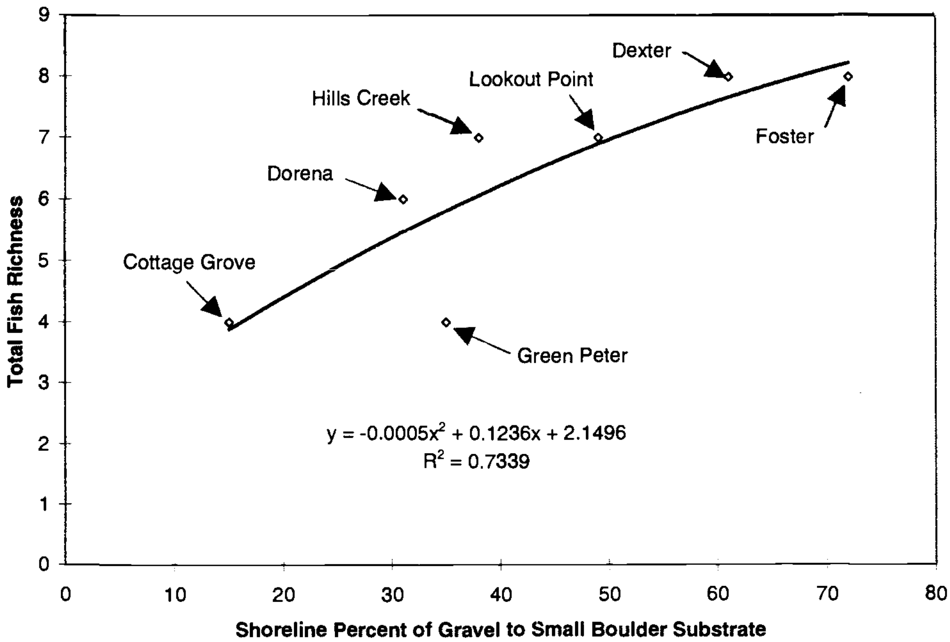

Total Fish Richness
9
8
7
6
5
4
3
2
1
0
Dexter
Lookout Point
Hills Creek
Foster
Dorena
Cottage Grove
Green Peter
y = -0.0005x2 + 0.1236x + 2.1496
R2 = 0.7339
0
10
20
30
40
50
60
70
80
Shoreline Percent of Gravel to Small Boulder Substrate

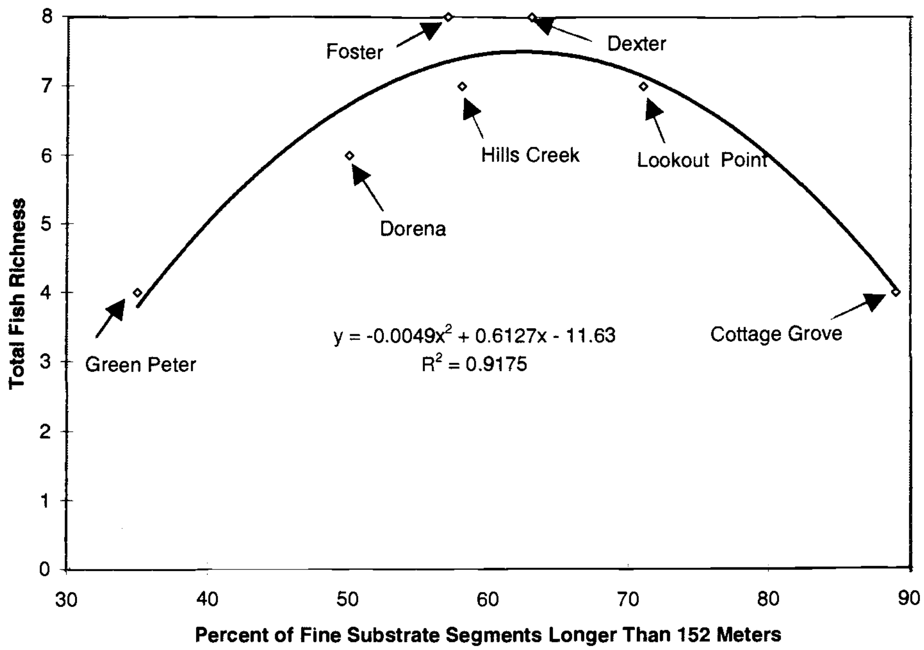
Figure 14.

Mean lengths of bedrock segments greater than 50 m (minimum bedrock mean length observed across range of study reservoirs) negatively influence fish diversity and richness (Figure 14). High density of bedrock substrates creates extensive areas of habitat that supports fewer species than other habitats. At lower densities and shorter lengths, bedrock segments may contribute to overall reservoir littoral zone habitat diversity without substantially reducing overall habitat quality. Reservoirs where bedrock is prevalent also tend to have steeper slopes and fewer productive shoal areas than reservoirs with more moderate amounts of bedrock. But reservoirs with very little bedrock, prevalent shoal areas, and low slope also had fewer fish species than reservoirs with moderate amounts of bedrock.

Contrary to the bedrock substrate regressions, the gravel to small boulder substrate showed all positive, nearly linear relationships throughout the range of variables associated with fish richness or H'. The regression of the percent of gravel to small boulder segments greater than 152 m provides a good example of this observed trend (Figure 14).

The percent of the total shoreline represented by the gravel to small boulder substrate was positively correlated to total richness ($R^2 = 0.73$) and H' (by weight) ($R^2 = 0.61$). The gravel to small boulder mean segment length was also positively correlated to total richness ($R^2 = 0.49$) and H' (by weight) ($R^2 = 0.53$), as well as mean fish richness ($R^2 = 0.54$) Additionally, the number of gravel to small boulder segments was positively

Figure 15. Relationship of the percent of fine substrate segments longer than 152 meters to total fish richness and the relationship of the percent of fine substrates that are vegetated to the total fish richness, by reservoir.


Total Fish Richness
Percent of Fine Substrate Segments Longer Than 152 Meters
0
1
2
3
4
5
6
7
8
30
40
50
60
70
80
90
Foster
Dexter
Hills Creek
Lookout Point
Dorena
Green Peter
Cottage Grove
y = -0.0049x^2 + 0.6127x - 11.63
R^2 = 0.9175

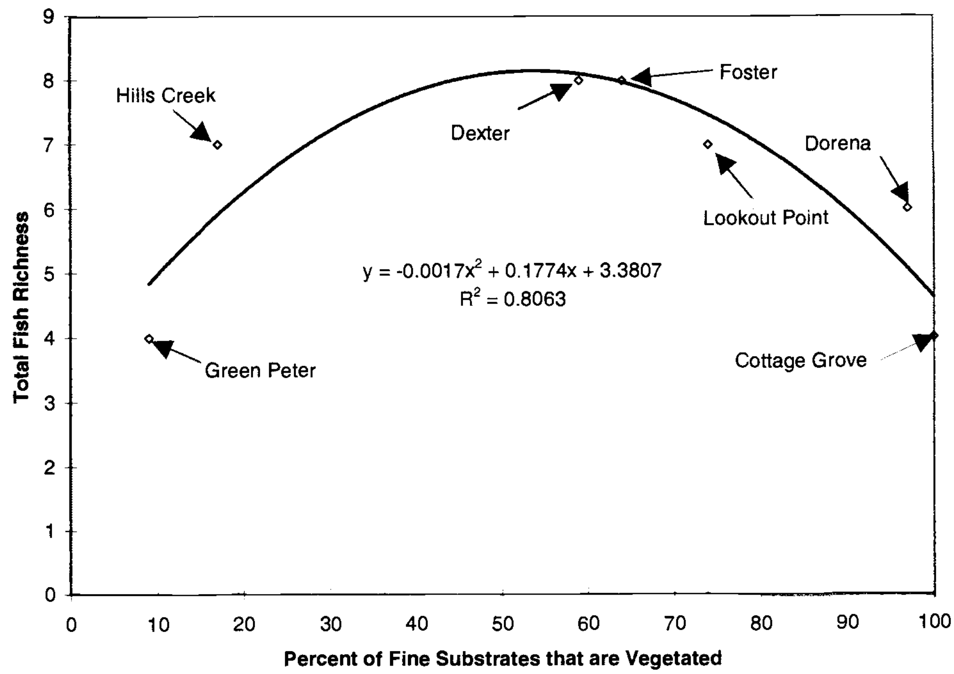

Total Fish Richness
Percent of Fine Substrates that are Vegetated
0
1
2
3
4
5
6
7
8
9
0
10
20
30
40
50
60
70
80
90
100
Hills Creek
Dexter
Foster
Dorena
Lookout Point
Green Peter
Cottage Grove
y = -0.0017x^2 + 0.1774x + 3.3807
R^2 = 0.8063

Figure 15.

correlated to total richness (R^2 = 0.48) and the percent of gravel to small boulder segments greater than 152 m was positively correlated to H' (by weight) (R^2 = 0.51).

Two moderate to strong correlations were found for fine substrate regressions between the percent of segments longer than 152 m to total fish richness (R^2 = 0.92) and mean fish H' (by numbers) (R^2 = 0.53). All fine substrate correlations (including percent vegetated fines) showed similar humped curve shapes. For example, total fish richness was found to increase until the percent of fine substrate segments longer than 152 m reached a level of about 62% (Figure 15). Further increases in this percentage appear to negatively impact fish richness. However, even though fine substrates, especially those with vegetation, appear to benefit fish species diversity and richness, an excessive amount of one habitat type can also lead to reduced diversity and richness by virtue of increased habitat redundancy.

Vegetated fine substrates appeared to be very important habitats in reservoir systems. The percent of fine substrates that are vegetated were strongly correlated to total fish species richness (R^2 = 0.81) (Figure 15). Total fish richness increased with an increase in the percent of fine substrates that are vegetated up to a level of about 55%. Further increases appear to negatively impact total fish richness. When fine substrates are found in a vegetated state in greater abundance this may lead to excessive habitat redundancy resulting in decreased fish species diversity and fish species richness. Davies (1991) found ponds with aquatic plants over more than 15% of the area had fewer adult largemouth bass compared to ponds with less than 15% area coverage. Davies suggested predator success declined with excessive area of refuge for prey fish. Other species may also be favored where vegetated areas of fines are more dispersed.

Although R^2 values were often high, the regressions of large boulder substrate parameters to richness and H' indicated neither a strong positive or negative influence. While the CPUE, richness, and size range demonstrate that the fish assemblages found in this substrate tended to be diverse, the relatively small abundance in the reservoir systems studied appear to prevent the observation of a strong correlation to fish richness and diversity at the reservoir scale.

Fish species H' and richness were not correlated with mean distance between nearest substrate segments.

Habitat H' was calculated by five different methods to determine potential relationships between habitat H' and fish species H' (by number), fish species H' (by weight), and fish species total and mean richness (see Appendix). Habitat H' was calculated by: 1) kilometers of each substrate type per kilometer of shoreline; 2) total kilometers of each substrate type; 3) total number of segments of each substrate type per reservoir; 4) number of segments of each substrate type per reservoir, weighted by reservoir size; and 5) substrate size categories (0-152 m, 152-305 m, 305-457 m, >457 m). This last approach provides only an index of habitat H' because the "species" are selected size categories.

Only the regression of habitat H' as calculated using substrate size categories was strongly (R^2>0.64) correlated to fish richness, and H' (both by numbers and weight), whereas, habitat H' as determined by the total length of each substrate type (R^2 = 0.79) and by the kilometers of each substrate type per kilometer of shoreline (R^2 = 0.84) were both only correlated to H' (by weight). Habitat H' as calculated by the total number (R^2 = 0.77) and weighted total number (R^2 = 0.77) of segments of each substrate type per reservoir were both only correlated to H'(by numbers) (see Appendix). These relationships were hump-shaped, with habitat H' highest at some intermediate level. This relationship is unexpected in light of long-standing ecological theory (MacArthur and MacArthur, 1961; Gorman and Karr, 1978). No clear explanation of this curve shape is apparent with this data set that would be consistent with ecological theory. Further study is warranted.

DISCUSSION

Fish assemblages associated with specific littoral zone habitats within seven reservoirs of the Willamette River Basin were examined in this study. Significant differences in these assemblages allow a rejection of the null hypothesis that fish were distributed randomly across habitat types. Similarities in limnological data also suggest differences in assemblages were due to habitat, not water quality. This study directly examined the presence of fish in designated habitats without observations on how these fish were utilizing the habitats.

Also, the presence of fish in a given habitat may not indicate preference. Finger (1979) found that *Cottus perplexus* was found only in pools, while *Cottus beldingi* was found only in riffles of the Marys River in Oregon. When *C. perplexus* was introduced into a model stream environment, however, were overwhelmingly found in riffles. Adding *C. beldingi* caused an immediate movement of *C. perplexus* to the pools while *C. beldingi* exclusively occupied the riffles formerly used by *C. perplexus*. Thus, fish may not necessarily live where they prefer, but where they can fit in the community.

Habitat categories examined included both substrate particle size classes and also overlying wood or vegetative structure. The mean body length of combined species and largemouth bass, along with species richness, and CPUE tended to increase with substrate particle size, especially between the fine and large boulder substrates. While these trends were not necessarily significant in this study, it is anticipated that similar future studies employing higher statistical power with larger sample sizes may find such trends to be generally significant. Assemblages in bedrock habitat had some similar characteristics with assemblages in the F/None habitat and some characteristics similar to coarse substrates. The presence of overlying structure altered the fish assemblages associated with fine-grain substrates but did not appear to greatly influence assemblages associated with coarser substrates (gravel to small boulder). This was the clearest comparison as wood, but not vegetation was present with bedrock, and neither overlying structure type was found in large boulders in sufficient quantities across the study reservoirs to analyze. However, fish assemblages associated with large boulders, a highly structured substrate, were similar in H' and richness to those in finer substrates with overlying structure.

These results appears to be consistent with the existence of a saturation level of habitat structure. When the substrate itself contributes a sufficient structural complexity, further increases in complexity by overlying structure may not be influential. This hypothesis warrants further study.

The relationship of mean fish size and substrate coarseness, in this case particle size, appears to be a response to interstitial space size in relation to body size. Larger fish in this study were associated with deep water cover of bedrock, the coarse structured large boulder substrate, and fine substrates with either overlying wood or vegetation. The largest individual fish (>250 mm) were found in the BR/Wood and LB/None habitats. Smaller particle size fines and gravel to small boulder, with or without overlying cover, were used by successfully smaller individuals.

Large fish influence the distribution of smaller fish (Werner and Gilliam, 1984; Baltz et al., 1991; Kwak et al., 1992). Redside shiners, for instance, appeared to avoid woody structures preferred by large piscivorous fish in this study. Other studies show size or development stage has a paramount influence on an animals energetic requirements, its food and habitat use, and its susceptibility to natural enemies and physical factors (Keast and Webb, 1966; Hall and Werner, 1977; Werner et al. 1977; Mittlebach 1981; Werner and Gilliam, 1984; Keast, 1985). However, regardless of the mechanism, development stage or size-specific habitat use is common (Werner et. al. 1983a, 1983b; Werner and Gilliam, 1984; Keast, 1977, 1985). Habitat selection also works to reduce competition and partition scarce resources (Matthews 1998). Consequently, as fish grow, each size group may react to resources as if a separate species (Wanjala et al., 1986).

Exotic fish species dominated fish assemblages across all habitat types except F/None. The assemblages occurring in F/None were shown with this study to have low richness, diversity, and CPUE. In this habitat type, native fish are evidently able to successfully (88% representation) utilize a habitat that may be of low preference to exotic fish. Conversely, BR/Wood (0%), G-SB/Wood (9%) and LB/None (9%) were lowest in native fish representation. Wood and large boulder habitats appear to be utilized by large exotic piscivores which may be limiting native fish exploitation of these habitats.

Significant differences occurred in mean length and weight of fish found in differing habitat types. In a comparable lake study, Brown et al. (2000) found the mean length of smallmouth bass to be different in specified littoral zone habitats of Little Moose

Lake, New York, indicating size class segregation. In stream systems, Spina (2000) also reported size and age specific habitat use in the North Fork of the San Gabriel River of California. In the current study a general trend of increasing mean length were associated with increasing substrate size for all fish species combined and also for largemouth bass alone. Sammons and Bettoli (1999) is the only other study the author is aware of that addressed this specific correlation. Increasing substrate sizes is associated with both increasing substrate slope and water depth and increasing size of interstitial spaces, as well. However, Walters et al. (1991) were unable to verify a trend of increasing fish size with increasing size of interstices when they tested fish use of artificial structures within a narrow range of two interstice sizes (40 and 35 mm) in C.J. Brown Reservoir, Ohio. Sammons and Bettoli (1999) did concur that coarser than gravel habitats did support larger fish and greater abundance for three black bass species than finer substrates sampled in Normandy Reservoir, Tennessee. Brown et al. (2000) reported that adult smallmouth bass (<50 mm) were only observed in wood and cobble habitats, while juveniles were only observed on sand and silted rock, considered structureless substrates by the authors. Large fish susceptibility to terrestrial (Schlosser, 1987) and avian (Power, 1984) predation may limit their use of shallow areas associated with fines. They are also less mobile in shallower habitats (Willis and Magnuson, 2000).

Keast and Webb (1966) and Werner et al. (1977) reported that small (<8.0 cm) largemouth bass were almost totally restricted to densely vegetated shallows due to their vulnerability to predation while large largemouth bass occupied deeper and a greater variety of littoral zone habitats (Keast and Webb, 1966; Hall and Werner, 1977). Similar results were documented for bluegill (Keast, 1977). In stream systems, the deeper water or pool habitats are traditionally occupied by larger fish while the shallower run and riffle habitats are utilized by smaller species of fish or juveniles of larger species (Spina, 2000; Willis and Magnuson, 2000).

Across reservoirs the mean size at Age 1 for largemouth bass was about 12.13 cm. This data suggests that 83% of largemouth bass collected in the study reservoirs were 0-1^+. A comparison of the prevalent 1^+ group to other study results is summarized in Table 48. The prevalence of this age group in study reservoirs should be considered in the evaluation of apparent habitat selection.

Largemouth bass in the study reservoirs appear to show intermediate length at age, better than more northern study areas (Keast and Harker, 1977; Fletcher et al., 1993; and Post et al, 1998), but not as good as systems in the southeast (Gutreuter and Anderson, 1985; Wanjala et al., 1986; and Gilliland, 1991) (Table 48).

Minimum range values of fish size for all species remained nearly constant from smaller to larger substrate sizes across habitat types. In contrast, Sammons and Bettoli (1999) found that only gravel habitats supported the smallest and youngest individuals of all black bass species encountered in Normandy Reservoir, Tennessee. Walters et al. (1991) discuss several potential advantages of interstice size to fish. These spaces provide food attachment sites, shade, and refuge (Johnson et al., 1988). However, Johnson et al.

(1988) reported that in ponds with muck bottoms and gravel riprap, the interstitial spaces were too small to provide cover for fish.

Table 46. Mean length (cm) at age data for largemouth bass from other studies.

Age	Location							
	Alamo Lake, Arizona 1/	Lake Conroe Texas 2/	Paul Lake Mich. 3/	West Point Res. Georgia 4/	Lake Opinicon Ontario Canada 5/	Sooner Lake Arizona 6/	Lakes of Eastern Wash. 7/	Current Study
1^+	10-25	12.8-13.4	6.6-8.6	15	6.0-8.0	10.5	6.9	12.30
2^+	25-31					22.5	13.56	15.49
3^+	30-42					30.2	18.92	25.97
4^+	42^+					38.7	24.89	34.40

1/ Wanjala et al., 1986
2/ Bettoli et al., 1992
3/ Post et al., 1998
4/ Gutreuter and Anderson, 1985
5/ Keast and Harker, 1977
6/ Gilliland, 1991
7/ Fletcher et al., 1993

A wandering stage in centrarchids provides for juvenile dispersal (Gerking, 1959) which may encourage migration from nursery habitats with small interstitial spaces into habitats with ever increasing substrate and interstitial sizes. A greater range of fish sizes of all species tended to coexist as substrate size increased in this study.

In these studies, bedrock was the only substrate not to be designated by particle size. Other fish habitat studies utilizing bedrock in a substrate size classification system

(Bain et al., 1985; Aadland, 1993; Byron and Wurtsbaugh, 1994; and Hatzenbeler et al., 2000) have also not designated it by size, but rather analyze its ecological significance as a habitat type. A lack of size determination prevents a more quantitative use of data on fish associated with bedrock. Based on the results of my study, substrate smoothness could be used to quantify texture while also addressing interstice size, a standardized approach for quantifying texture would be useful.

A third variable, substrate slope, appears to further separate relatively smooth surfaced substrates such as silt sand, clay, and bedrock by ecological roles. Slope determines rate of change of water depth and thus these two factors may impact habitat utilization by fish in generally the same way. Although interstitial spaces that can be used by small fish may be nearly absent in bedrock (and sand, silt, and clay), bedrock ledges appear to provide important cover for larger fish. Further work needs to be undertaken to quantify texture and interstitial size across substrate size categories for further inference about relationships between rock structure and fish distribution.

The smooth and fine particle sizes (bedrock and fines) in the absence of additional structure were found to have the lowest CPUE (by numbers and weight). A smooth surface with few interstitial spaces for smaller species or early life stages of fish tend to limit bedrock's use as fish habitat. Lane et al. (1996) found bedrock and hard pan clay to be utilized by few species in the Great Lakes, as well. Additionally, Barrett and Maughan (1995) showed that although juvenile fish selected a variety of habitats in two streams of central Arizona, preference was low for bedrock.

Fish utilization of the intermediate substrate size, gravel to small boulder, without additional structure, was generally intermediate in CPUE, richness and H', and size in comparison to either fine or coarser substrates.

The largest substrate size, large boulder, was associated with a fish assemblage similar to that associated with substrates with additional vegetation or wood structure. The large boulders used for dam riprap were perceived by Bettoli et al. (1992) to be intermediate in complexity between those littoral zone habitats with and without vegetation. My findings suggest that the fish assemblages found in large boulder and vegetated habitats were quite similar.

The largest particle size was also found to have nearly the same high CPUE by number value (289.31) as the vegetated habitats, F/Veg (312.24) and G-SB/Veg (291.05) Mean fish richness was not significantly different from F/Veg (4.00) at 2.96. These three habitat types were much higher in mean CPUE by number than the other habitat types studied. This suggests when the fines and gravel to small boulder substrates have vegetation as overlying structure these habitats appear to be as highly utilized as large boulder substrate. This may indicate all three habitats have comparable habitat complexities. The LB/None and BR/Wood habitat types were much higher in CPUE by weight than any other habitat types. Sammons and Bettoli (1999) and Beauchamp et al. (1994) also found littoral zone fish to be most abundant in large particle size habitats of riprap and cobble-boulder, respectively. The lengths and weights of fish found in large boulder habitat were only surpassed by those habitats with wood, while higher richness and diversity were principally observed with vegetated habitats. The total number of species found in large boulder substrates (10) was only surpassed by the F/Veg habitat type at 11.

The addition of wood and/or vegetation appears to significantly increase the habitat structural complexity for bare substrates, especially for fines and bedrock, the two smoothest substrate types. Those habitat types, with the additional structure of vegetation or wood, resulted in both higher CPUE and larger mean size. Increased richness and diversity occurred in fine substrates only. However, overlying structure appeared to positively affect fish size and CPUE of assemblages of the fine and bedrock substrates to a much higher degree than for gravel to small boulder. This is probably due to gravel to small boulder possessing more textured structure. In addition, those habitat types with vegetation were consistently higher for CPUE by numbers and for richness and H', but consistently lower in mean fish length when compared to those habitat types with wood. Overlying structure allows an even greater size range of fish to coexist as compared to those habitat types without this structure.

Productive habitats such as vegetation provide greater dietary specialization and increased habitat complexity to occur and consequently should support more fish species (MacArthur, 1972; Werner et al., 1978; Tonn and Magnuson, 1982; and Canfield and Hoyer, 1992) and a greater general abundance of fish (Strange et. al., 1982). In the current study, the habitat types with vegetation were highest for mean total fish species richness at 4.00 for F/Veg and 3.43 for G-SB/Veg. F/Veg was highest in mean fish species diversity at 1.17, G-SB/Veg was next highest at 0.86. However, the local density of vegetation and type of underlying substrate may be influential. The patchiness of macrophytes, in addition to their abundance, has been shown to produce increased fish abundance and diversity (Eadie and Keast, 1984; Engel, 1987; Weaver et al., 1997). CPUE (by number) for F/Veg was the greatest of any habitat (312.24/ hour) and much greater than for F/None, a substantially smaller influence of vegetation was observed for the gravel to small boulder substrate. Tonn and Magnuson (1982) found that vegetation diversity appeared to be the single most important component of habitat structure in the assemblages studied. Increased vegetation diversity resulted in increased richness.

While fish samples were too narrow in focus to compare entire reservoir communities they did provide a means to compare littoral zone communities between reservoirs. Regression analysis results suggest that fish richness and H' is not only dependent on the type of substrate available for use as habitat but also the size, distribution, abundance of those substrates. Regression analysis provided a powerful inference tool with which to understand the relationship of littoral zone habitat characteristics to the richness and H' of the fish assemblages encountered. Fish species richness and H' were responsive to many substrate parameters. The shape of regression curves appeared to be correlated to the substrate type.

Regressions of gravel to small boulder substrate parameters against richness and H' produced exclusively positive correlations. Fish species H' and/or richness were found to increase across the range of reservoirs with increases in mean segment length, segments per kilometer, percentage of total shoreline composed of gravel to small boulder substrate, and shoreline percentage of gravel to small boulder segments greater than 152 m in length. These results indicate the gravel to small boulder substrate, like large boulders, is important to fish assemblage dynamics. Regression results of the large boulder substrate was not useful because of its rarity in these systems. Large boulders are normally obtained from a rock quarry at a high cost, resulting in limited use.

Only for bedrock did richness and H' appear to consistently decline as bedrock increased in prevalence. Increases in mean segment lengths were found to result in decreased H' (by numbers) in the study reservoirs.

Regressions of fish H' and/or richness associated with reservoirs with very long segments of fines tended to show an increase to some point followed by a decline with further increases in fines. The percent vegetated fines to total richness also showed this hump-shaped regression curve. Vegetated fine substrates, as opposed to bedrock, are exceptional habitats for fish. However, these regression analysis results suggest that when the fine substrate type is in too great of an unbroken abundance or creates too large of a homogeneous habitat, habitat H' declines resulting in a concomitant reduction in fish species richness and H'.

A similar phenomenon may be operating for bedrock segments. While this study has shown bedrock to be a low quality habitat, bedrock may provide effective segregation between groups of fish or break up large blocks of homogeneous habitats and consequently promote fish richness and H', when segments are spaced adequately and not excessively long in length. However, at too great a size, bedrock may act as a boundary desert between more preferred habitats. The H' and abundance of fish in a habitat patch can be greatly affected by adjacent habitats and the difficulties associated in crossing boundaries between habitats (Weins et al., 1985; Schlosser, 1995). The transition from deep to shallow habitats may also prevent some species, such as large piscivores, from crossing, thereby creating a refuge from other species (Willis and Magnuson, 2000). Consequently, some spatial patterns can restrict access to preferred habitats thereby limiting species distribution (Matthews et al., 1994).

The seven reservoirs in this study shared similarities derived from their relatively close proximity within the Willamette River Basin. They are limnologically similar and share a common species pool. Introduction of non-native species altered this species pool, but a working assumption for this study is that all species in the overall system were at some time available to each reservoir. The particular environment of each system subsequently determined the present species composition.

This similarity provides a basis for examining how specific habitats, and distribution and abundance of habitats were utilized by the littoral zone fish assemblages. In addition, evidence suggests the habitats available in each reservoir influenced the species composition and H' of the fish assemblage.

Habitat H' calculated using five approaches was strongly associated to fish richness or diversity in seven of 20 possible realtionships (see Appendix). The hump-shaped relationship, with richness and H' highest at an intermediate level was not consistent with ecological theory. Data in this study did not clearly provide an answer, but apparently substrate type and the length of the segments, along with their spatial distribution across the littoral landscape are characteristics that are influencing these relationships in a complex manner. Doak et al. (1992) report that habitat fragmentation consists of two different spatial scales (i.e., the relative size of the habitat fragments or patches and the spatial scale at which the fragments are arranged).

In marine environments small rather than large patches appear to be more important, especially in terms of higher recruitment. Increasing density of organisms with decreasing patch size may be responding to an edge effect consisting of increased refugia and forage or a reaction to increased predation in larger patches (Eggleston et al., 1999). Conversely, in terrestrial systems there is a general trend of increasing H' and abundance with larger habitat patches. Large edge influence was detrimental (Saunders et al., 1991; Robinson et al., 1995). For those habitats of the reservoirs studied here, it appears intermediate sized habitat patches may be most influential for fine substrates.

Although broadly similar, three sub-groups could be discriminated within this set of reservoirs. The three subgroups were the long, deep reservoirs (Lookout Point, Hills Creek, and Green Peter), the reregulating reservoirs (Dexter and Foster) and the broad, shallow reservoirs (Cottage Grove and Dorena). In addition, each reservoir demonstrated some unique habitat characteristics. The morphological, geological, and limnological characteristics of the study reservoirs can be reviewed in Tables 1 and 2. These morphological and geological characteristics were the major apparent causal factor in the types and distribution of habitats, as well as vegetative features, within each group. The lowest mean slope (25%) was associated with fines, 45% for gravel to small boulder and 72% for large boulder. The mean slope for bedrock was 94%. Thus, except perhaps for bedrock, reservoir slope characteristics is a causal factor in the size and distribution of sediments.

The three largest reservoirs (Lookout Point, Green Peter, and Hills Creek) that form one logical grouping are long, deep, steep sloped upriver reservoir systems with relatively small shoal areas and limited macrophyte growth. As these reservoirs are upriver and in deep canyons, they have the highest percentage of bedrock found in the study reservoirs from 12-47%, whereas the percentage of shorelines represented by fines is low to moderate at 17-47% for the rangeof values observed across reservoirs. Despite sharing common morphological traits, each of these reservoirs was unique in a particular substrate abundance. Gravel to small boulder was the most common substrate, in terms of percent shoreline representation, at Lookout Point Reservoir (49%), whereas, fines was the most common substrate at Hills Creek Reservoir (47%) and bedrock was the most common at Green Peter Reservoir (46%).

In addition, these three reservoirs have the deepest drawdown zones or zone of fluctuating water levels. Grimas (1961) reported a 70% loss of benthic invertebrates in the littoral zone due to fluctuating water levels. Hale and Bayne (1982) found the benthic community of the fluctuating water zone in West Point Reservoir, Georgia took 4 months to recover after inundation. A similar situation probably exists in some of the study reservoirs. Continued annual fluctuation of water level may cause further deterioration in the soil composition of the exposed littoral area as fines are eroded away by wave action and redeposited in the unregulated areas of the reservoir, exposing more and more rocky substrate and resulting in a continued lowering of the production of benthic fish food organisms (Grimas, 1962; Hale and Bayne, 1982). Annual water fluctuations also limit the growth of aquatic and terrestrial vegetation (Hayle and Bayne, 1982).

The attainment of maximum conservation pool level and the duration, timing, and extent at this level are critical to year-class strength of fish. Sammons and Bettoli (2000) found the year-class strength of largemouth bass in Normandy Reservoir to be determined late in the year and dependent on the level of water held throughout the summer. When water levels dropped in late summer, survival and abundance of largemouth bass in this system decreased (Sammons and Bettoli, 1999). Jackson et al. (1991) also documented high mortality of age-0 largemouth bass in summer in when water levels fell below the maximum conservation pool level in Lake Jordan, North Carolina.

Conversely, high water levels in late winter to early spring have been shown to correlate to strong year classes of crappies (McDonough and Buchanan, 1991; Maceina and Stimpert, 1998; Sammons and Bettoli, 2000). High flows early in the year appear to be a spawning cue for crappie. Unlike largemouth bass, once the adults spawn strong year classes are predictable (Sammons and Bettoli, 2000).

Important information can be inferred about potential assemblage structure from aspects of morphometry. One simple but potentially important morphometry measures is "fetch". The maximum possible fetch is the longest open water-straight line distance that wind can move across a lake or reservoir. Fetch determines the maximum wave height realized along the shoreline due to a given wind strength. Consequently, it is one of the most critical factors determining littoral zone habitat quality (Matthews, 1998). The length of fetch and orientation of wind produce sharp contrast between inshore habitats. Wave action along the shoreline may be nearly as extreme as those found in the ocean, but minimal in protected areas such as coves, where fine substrate particles have a greater chance of being left undisturbed and available for colonization by macrophytes. All three of the largest reservoirs have very long fetch distances in comparison to the other study reservoirs.

Although the three largest reservoirs can be grouped together quite readily due to similar morphological traits and long fetch patterns, the cove shape and sinuosity in these systems appear to be the primary reasons, along with a high percentage of gravel to small boulder open water habitat of Lookout Point Reservoir, for the realized favorable differences in fish assemblage structure found for Lookout Point Reservoir vs. Green Peter and Hills Creek Reservoirs. In understanding the potential differences in these three large, generally unproductive reservoirs, it is critical to view cove areas as nursery areas for the exportation of recruits to less productive neighboring habitats. Green Peter and Hills Creek Reservoirs have large arms. Aggus et al. (1980) found that young fish are proportionately less abundant in arms of reservoirs versus coves in those arms. Based on this reasoning, the quantity and quality of cove habitat should be very important in long, deep, generally unproductive reservoirs such as Lookout Point, Green Peter, and Hills Creek Reservoirs.

Deep, cold, unproductive systems like the three largest reservoirs in this study generally provide conditions that result in poor first year growth (Carlander, 1977; Okeyo and Hassler, 1985). In addition, while the mean percent composition of benthic fish across reservoirs was generally less than 20%, the three larger reservoirs were found to have a much more even mix of benthic and pelagic fish with benthic fish percentages of between 44 to 60%. While the general abundance of fish in the three reservoirs was observed to be generally low and the percent of shoreline fines was low to moderate in comparison to the other reservoirs (17% at Green Peter, 47% at Hills Creek, and 30% at Lookout Point Reservoirs), Lookout Point Reservoir is unique among the three largest reservoirs in having virtually all (74%) littoral zone fine material vegetated. Green Peter and Hills Creek Reservoirs are much lower in percentages of vegetated fine substrates at 9 and 17%, respectively. In Lookout Point Reservoir, most fine substrates are in protected coves, where vegetation can be established.

These characteristics in Lookout Point Reservoir appear to provide for the greatest length at age for largemouth bass and highest condition (length vs. weight) for nine of ten species when comparisons were performed across the study reservoirs. Relative weight analysis showed largemouth bass and white crappie to be particularly robust with Lookout Point Reservoir. In contrast, Hills Creek and Green Peter Reservoirs were found to have the least length at age relationship for largemouth bass and lowest condition (length vs.

weight) of the seven reservoirs. However, mean relative weight analysis showed black crappie to be robust in this Hills Creek Reservoir at 117.91.

Much of the F/Veg habitat type in Lookout Point Reservoir is located in heavily vegetated cove areas. Due to the narrow and/ or convoluted nature of the coves in Lookout Point Reservoir they are generally well protected from the adverse effects of wind over a long fetch, as opposed to those in Green Peter and Hills Creek Reservoirs. Coves in these latter reservoir systems, which were accessible by boat from the main channel during sampling periods, especially Hills Creek, tended to be wide and/or deep, often taking on a horseshoe shape which was much more easily affected by wind action, and with less vegetative coverage, as compared to those coves in Lookout Point Reservoir.

While the abundance of fish may be less overall in large reservoirs with low to moderate amounts of fine habitat that is protected from influences of wind fetch, condition (length vs. weight) may actually be better than in the smaller, rounded reservoirs with extensive shoal areas due to reduced fish densities and reduced competition (Van Den Avyle and Carlander, 1977).

In addition to largemouth bass and bluegill, white crappie, largescale suckers, and redside shiners appear to be the dominant fish species residing in the littoral zones of the three largest reservoirs. The white crappie appears to be much better suited to the environmental conditions found in these systems than the black crappie. White crappie do not depend on rooted vegetation (Wydoski and Whitney, 1979), which is relatively rare in these large reservoirs, and are more tolerant of turbid waters (Wydoski and Whitney, 1979), also characteristic of these systems. While largescale suckers and redside shiners are generally found in shallow waters both are known to utilize deep water (Wydoski and Whitney, 1979), which is common to this group of reservoirs. Largescale suckers, in particular, have been found in waters 80 feet deep (Wydoski and Whitney, 1979). Redside shiners appear to prefer cooler temperatures and are more tolerant of cold water (to 44 F) when compared to the brown bullhead.

Longnose dace and mottled sculpin were only found in Lookout Point Reservoir. As adults, longnose dace utilize habitat with gravel and rock substrates, especially larger substrates such as boulders (Mullen and Burton, 1995, 1998). The need for rock and boulder substrates and vulnerability to predation (Wydoski and Whitney, 1979) may limit the success of longnose dace in many reservoir systems.

The mottled sculpin prefers the same basic temperature (13 to 18 °C), and utilizes the same general habitat as the reticulate sculpin (10 to 18 °C), and the prickly sculpin (10 to 18 °C) found in the other study reservoirs, however, its maximum documented habitat temperatue of 21 °C is 5 degrees cooler than the maximum temperature for reticulate sculpin and 7 degrees cooler than the maximum temperature for the prickly sculpin. Consequently, the mottled sculpin may be better adapted to the cooler temperatures of the large deep study reservoirs. The majority of mottled sculpins were found on rocky substrates (gravel and rubble sized material) known to be associated with this species (Table 17). However, this species was also found in bedrock and in habitats with fine particle size substrate (F/Veg), which is reported to be a rare occurrence in comparison to the prickly sculpin (Wydoski and Whitney, 1979).

The reregulating reservoirs comprise the second sub-grouping among the studied reservoirs. Distinctions from the other subgroups are primarily due to short water retention times, daily anthropogenic manipulations of flow, and extensive application of riprap habitat in both reservoirs. These reservoirs share similar morphological characteristics with Dorena and Cottage Grove Reservoirs. However, the rapid flushing of nutrients and the cooler water flowing through these systems prevents the development of large areas supporting macrophytes that are typical of Cottage Grove and Dorena Reservoirs.

Both Dexter and Foster Reservoirs are also unique in having extensive segments of shoreline reinforced with the addition of gravel to small boulder size material for protection of roadways adjacent to the reservoir high pool level along both sides of these reservoirs. Gravel to small boulder substrates comprise 61% and 72% total shoreline for Dexter and Foster Reservoirs, respectively; the largest values for this substrate in any study reservoir. This habitat is known to be highly utilized by smallmouth bass which are only present in these two systems. Smallmouth bass are more abundant in Dexter than Foster Reservoir. Conversely the largemouth bass in Dexter and Foster Reservoirs comprised only 1.95 and 5.43% of the combined 1995-1996 sample which was unusual for the study reservoirs.

The smallmouth bass is an opportunistic piscivore, which is known to feed on a variety of prey species found in the reregulating reservoirs such as sculpins, sandrollers, juvenile salmonids, juvenile suckers, and juvenile cyprinids (Poe et al., 1994). Sandrollers were documented at Dexter Reservoir previous to this study (Personal sampling, Hasselman and Garrison, 1957). The strong preference of smallmouth bass for rocky reefs (Okeyo and Hassler, 1985; Sammons and Bettoli, 1999), which are present in Dexter Reservoir in the highest abundance of any reservoir, may add to the success of smallmouth bass in these systems.

In addition to smallmouth bass, largemouth bass and bluegill, redside shiners and northern pikeminnow also reside in the littoral zones of Dexter and Foster Reservoirs. Smallmouth bass are known to utilize rocky substrates, that are prevalent in these reservoirs. Like smallmouth bass, northern pikeminnow also prefer shallows with rubble and gravel, but have been reported in mud and sand bottoms (Wydoski and Whitney, 1979), of which the reregulating reservoirs have a moderate percentage. The principal food items of this piscivorous fish are reported to be crayfish, sculpins, and sandrollers (Buchanan et al., 1981; Poe et al., 1993, 1994). However, salmon (Beauchamp et al., 1995) (a fishery for kokanee exists in Green Peter Reservoir, although no individuals were found in samples for this study), trout (Jeppson and Platts, 1959), suckers, other northern pikeminnow, and redside shiners are also known to be important prey items (Wydoski and Whitney, 1979). Representatives of at least one of these preferred prey species are found in each of the reservoirs where the northern pikeminnow were found.

Smallmouth bass are known to compete with northern pikeminnow (Poe et al., 1994). The reasons for the segregation between smallmouth bass and northern pikeminnow in Dexter and Foster Reservoirs are not apparent, but the northern pikeminnow and smallmouth bass may be partitioning available habitats, avoiding competition for prey. Smallmouth bass in Dexter and Foster Reservoir may be displacing the northern pikeminnow as the major predator fish in those habitats.

Similar to the three largest reservoirs, the reregulating reservoirs provide redside shiners cooler and deeper water for night use, while also providing some vegetated shallows for day use. Redside shiners are an important prey species (Weisel and Neuman, 1951; Wydoski and Bennett, 1981) for piscivorous fish. They are known to be thermal generalists, thriving in both coldwater and warmwater littoral habitats of reservoirs (Wydoski and Bennett, 1981; Bond et al., 1988). Population densities are mainly influenced by unstable or fluctuating water levels and predation. For example, in systems with fluctuating water levels during the spawning season, and heavy predation, redside shiner densities are generally low. Consequently, the high numbers of redside shiners in Dexter Reservoir may be due to low seasonal change in water levels and abundant cover from predation due to abundant macrophyte level, while the low observed abundance of redside shiners in Dorena and Cottage Grove Reservoirs is probably due to a much deeper zone of seasonal change in water levels and a high abundance of piscivores, especially largemouth bass and black crappie. The importance of predation to the survival of this species is suggested by its utilization of all habitat types except those with wood. Redside shiners may avoid woody structure to limit their exposure to the large piscivores that are associated with wood structure.

The third sub-group of reservoirs, Cottage Grove and Dorena Reservoirs, have the most extensive coverage of the shoreline by fine substrate (81 and 57%, respectively), and greatest (>95%) percent of vegetated fine substrates of any study reservoir. The importance of vegetation to y-o-y and older fish is well established, although excessive plant coverage may also have a negative impact on piscivorous fish (Savino and Stein, 1982; Lowery et al., 1994; Olson et al., 1995; Wrenn et al., 1995; Post et al., 1998) and community structure (Weaver et al., 1997). The threshold level at which vegetation abundance is generally believed to produce this negative impact is approximately 15-20% of the water surface area (Anderson et al., 1978; Durocher et al., 1984; and Moehle and Davies, 1993) or 20-40% of the littoral zone (Fletcher, 1993). Both Cottage Grove and Dorena Reservoirs exceed these criteria.

. In addition to largemouth bass and bluegill, black crappie and brown bullhead appear to be the dominant fish species residing in the littoral zone of Cottage Grove and Dorena Reservoirs. Shallow lakes with large littoral zones are known to contain many brown bullheads, while lakes with relatively deeper and smaller littoral zones have few or no brown bullheads (Hinch et al., 1991). Brown bullheads are also known to be tolerant of high temperatures (up to 97° F) and low dissolved oxygen (0.2 part per million) (Wydoski and Whitney, 1979). Black crappie are also dependent on rooted vegetation and relatively intolerant, as compared to white crappie, to turbid water condition. The littoral zones of both Dorena and Cottage Grove are highly vegetated and relatively free of turbid water.

Finger (1982) reported the reticulate sculpin to be on all substrates of the Marys River in Oregon. This species can be considered a substrate generalist (Bond et al., 1988) and may be more able to utilize the abundant smaller substrate sizes found at Dorena Reservoir better than the other species of sculpins which are known to prefer larger rocky substrates (Wydoski and Whitney, 1979).

A pattern of decreasing growth rate with increasing density of fish has been demonstrated for many fish species including black and white crappie (Maceina et al., 1991), and bluegill (Belk, 1993). Density-dependent growth can also impact fish survival and recruitment (Houde, 1989). Consequently, a combination of high vegetation coverage and high density of fish may account for the somewhat depressed size at age and length vs. weight relationships observed in these systems in comparison to Lookout Point and Dexter Reservoirs, for example.

Moyle and Herbolt (1987) reported that fish assemblages west of the continental divide of North America commonly contain less than 10 species (Friesen and Ward, 1996) while those east of the continental divide are generally much more diverse, often with more than 20 species (Werner et al., 1978; Foltz , 1982; Tonn and Magnuson, 1982). Reservoirs in this study tended to agree with this regional pattern described by Moyle and Herbolt (1987) (Table 15). Friesen and Ward (1996) documented a species richness at 5 to 15 fish species per stream in the lower Tualatin Basin of Oregon. However, a latitudinal influence is evidenced by increased fish assemblage species richness in the more southern latitudes. For example, in the east, 43 species were reported in West Point Reservoir, Alabama-Georgia (Timmons et al., 1977) while Brown and Moyle (1993) reported 34 fish species in the San Joaquin drainage of south central California and Brown and Moyle (1997) documented 30 species in the Eel River of northern California in the west.

There did not appear to be a correlation of reservoir age to richness or H' of the littoral zone fish assemblages among the reservoirs studied, as is observed in some other studies.

Studies have shown that in most animal assemblages there will be a few abundant species and many rare ones represented by one to only a few individuals, especially where closely related taxonomically species coexist (Sheldon, 1987; Brown, 1995). In this study largemouth bass, bluegill, and largescale suckers were most abundant species found to inhabit the littoral zones of the study reservoirs, although a total of 16 other less abundant species were also documented across the reservoirs. Largemouth bass and bluegill are among the most flexible fish species with regards to habitat use and exploit a wide variety of small and large bodied prey types (Werner and Mall, 1976; Werner, 1977). Consequently, largemouth bass and bluegill are found to occupy similar spatial distributions but segregate by food sizes (Werner, 1977; Werner et al., 1977). Werner (1977) showed largemouth bass and bluegill to monopolize a broad range of the food sizes available, suggesting that any other coexisting centrarchids such as black crappie and white crappie should possess strong niche complimentarity (Schoener, 1974) with largemouth bass and bluegill. For example, observations of Werner et al. (1977) suggest an offshore movement of black crappie for food in the evening. This could mean the food of black crappie may be obtained in a different habitat than that of largemouth bass or bluegill while the midday distribution of these three species are similar.

The white crappie appears to be much better suited to the environmental conditions found in the large, deep reservoirs (i.e., Hills Creek, Lookout Point, and Green Peter Reservoirs) than the black crappie for a variety of reasons. Markam et al. (1991) found white crappie usually located over steep bottom gradients (6-22 degrees) and utilizing structure in the form of large rocks (which are also common in the large reservoirs) along with tree stumps and logs. For these reasons, in those reservoirs where white and black crappie were both sampled, Dexter and Hills Creek Reservoirs, white crappie will likely remain the dominant crappie species.

Speckled dace occur in a variety of habitat conditions and are considered habitat generalists (Bond et al., 1988; Seals and Gorman, 1994). Bond et al. (1988) found the speckled dace to be the most frequently collected species in the state of Oregon, occurring in almost all drainages of the state. The speckled dace also appears to be quite general in its diet. While the speckled and longnose dace both feed on insects, only the speckled dace is known to eat plant material in significant quantities (Carlander, 1969). This flexible feeding pattern may contribute to the persistence of this species in a variety of reservoir types and its preference for vegetated habitats.

The samples of fish analyzed with this study were collected using a boat electroshocker which injected some unmeasured amount of bias into the results. However, electrofishing has some advantages in this environment.

Daytime boat electroshocking has been found to an appropriate sampling method for a variety of fish, including largemouth bass, smallmouth bass, bluegill, black crappie, white crappie, and bullhead species (Hall,1986; Fletcher et al., 1993). Hughes et al. (1993) considered boat electroshocking to be the most effective and least time consuming method for sampling littoral fishes. Electroshocking also provides a way to sample fish in complex structure and at depths which would be difficult (if not impossible) to sample with seining or gillnetting (Gelwick and Matthews, 1990). The depth (1.3-1.9 m) at which the maximum fish density in a lake littoral zones has been found to exist (Keast and Harker, 1977) is effectively sampled with electrofishing which reaches fish to approximately 3 m depth (Mesa et al., 1990). Largemouth bass, in particular, usually inhabit depths of less than 5 m (Heidinger, 1975; Carlander, 1977), which roughly corresponds to the littoral area of a lake (less than 4.6 m deep).

Many factors influence electroshocking efficiency and certain biases are inherent in the sampling effort. However, all sampling results in some collection bias (Malley and Reynolds, 1979). These factors can be placed in three categories (Reynolds, 1983): 1) fish characteristics, 2) habitat characteristics, and 3) operating conditions. Reynolds (1996) determined important variables to be fish size and species, water clarity and conductivity, and reservoir substrate and morphometry (surface area, shoreline slope and development).

In a study of fish capture efficiency by boat electrofishing in several midwestern lakes, Bayley (2002) reported the catch rates of inshore fish by electrofishing to be heavily dependent on fish species and length as well as the mean water depth of the sample site and surface macrophyte cover. For example, Bayley determined that an increase in macrophyte cover of up to 50% could result in a 2.3 factor of decrease in the catch efficiency of 30 cm largemouth bass in his study area. This phenomenon is primarily due to the ability of macrophyte beds to trap small fish. Bayley (2002) reports that catch efficiency decreases in deeper water, especially for larger fish as this is a habitat where they often reside . Steeper shoreline slopes also provide more limited habitat for sampling (Reynolds, 1996). Although this study by Bayley provides important insights into bias associated with boat electroshocking equipment, Bayleys method of boat operation and fish retrieval is different than the protocal used in this study. Bayley used a boat moving parallel to the shoreline with a fish netter onshore to sample fish, whereas I operated my boat in concentric perpendicular arcs to the shoreline with the fish netter being onboard.

Large fish are more susceptible to collection by electrofishing than are small fish. Visibility is one of the primary reasons for this well known bias (Reynolds, 1983). Conversely, Rider et al. (1994) found electroshocking to be reliable in comparison to cove rotenone for estimating the abundance of the small age-0 largemouth bass, and when Gelwick and Matthews (1990) conducted a study at Lake Texoma, Oklahoma-Texas, they found few if any differences in species found between electroshocking and shoreline seining. Bayley (2002) concurs on the applicability of this concept of electrofishing gear being more effective on larger fish only up to intermediate sized fish. Bayley hypothesizes that large fish experience greater escapement from boat electrofish sampling due to a fright response elicited from either the boat motor or generator noise or from contact with the weak peripheral electrical field at the lead of the boat. Fast swimming speed allows for enhanced escapement when compared to smaller individuals of a particular species. This is counter to the theory put forth by Sternin et al. (1972) that the probability of capturing a larger fish in a specific electrical field is greater since larger fish are exposed to a greater voltage difference.

Other factors pertinent to the generator type, crew makeup, and mean inshore width were not found to be significant influences on catch efficiency. The results from sampling in coves versus shoreline sites, changing densities of fish, and varying water temperature and conductivity also did not produce significant difference in catch efficiency with this study by Bayley. Conversely, McInerny and Cross (2000) found changes of temperature, conductivity, and densities of fish to affect fish catch per hour in lakes of Minnesota, along with different substrate types, morphometry, and secchi depths.

As described previously, Bayley (2002) emphasizes the need to calibrate the catch efficiencies of sampling gears so that catch-per-unit effort and other sampling data can be accurately adjusted for bias. However, this is not always possible. Bayley (2002) suggests that the feasibility and universality of using such calibrations may be accomplished in one of three ways: 1) once the sampling effort has been completed follow it with a calibrated high efficiency method such as rotenone or draining of the water body,

2) perform a standard mark and recapture study with a lowered efficiency, 3) derive catch efficiency from a recently stocked fish population whose behavior related to capture can be used to model a resident population. All such methodologies described are not feasible in the habitats investigated in this study because of legal restrictions on numbers of fish killed, the multiple habitats sampled, and unavailability of a recently stocked population of each species encountered. Consequently, the applicability of results from this study may be somewhat limited. However, the approach used was to reduce these biases by standardizing the sampling equipment and its use whenever possible. Reynolds (1996) reports that electrofishing sampling variance can only be minimized when such measures are implemented.

CONCLUSIONS

Results of this study indicate that wood structure in bare substrates provides habitat for the largest and oldest fish in reservoir littoral zones and for the highest occupancy by piscivorous fish compared to other habitats. These habitats provide coarse structure and large interstitial spaces. Presence of vegetative structure in a given substrate, especially fines, provide habitat for the greatest numbers, richness, and diversity of fish. Overall, the F/Veg habitat seemed to provide the best habitat for small to moderate-sized fish. Conversely, fish associated with bedrock had the lowest numbers, richness, and diversity, with the exception of F/None. Substrate and overlying structure influence both individuals within a fish species and the composition of fish assemblages. Overlying structure associated with fine substrates tended to increase richness and diversity, but this was not observed for coarse substrates.

The mean length of fish tends to increase with increasing substrate size, but the lower range of fish size remains relatively constant, with or without overlying structure. Consequently, increases in substrate size result in a greater range of fish sizes to coexist.

Certain substrates such as bedrock are generally a negative influence on fish richness and H' while other habitats such as cobble to small boulder are positive. The influence of fine substrates appears to be dependent on segment size. Large blocks in a reservoir resulted in depressed richness and diversity while smaller segments had a positive effect. Large boulder habitat was very rare in the reservoirs ($\leq$4% shoreline representation) but fish assemblages associated with this substrate were high in richness, diversity, CPUE, and range of fish sizes. Reservoir littoral zone richness and diversity appear to be dependent not only on the type of habitats available but the size and distribution of those habitats. Results suggest habitat modification by adding structure would be effective in fine but not coarse substrates. Vegetation and wood added to fines would probably increase fish richness and diversity. Adding large boulders, especially to in wind protected areas would likely benefit fish richness and diversity.

Although there is a general ratio of 3 to 1 exotic to native fish representaion across reservoir littoral zone habitats, the large boulder habitats and those habitats with wood as overlying structure appear to be especially detrimental to the native fish component in fish assemblages. Fine substrates, without overlying structure, were unique in being the only habitat where native fish dominated the composition.

Future research is recommended to quantify substrate texture and to pursue the concept of a saturation level of structure beyond which additional structure is not influential.

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APPENDIX

Table A1. Days required for completion of field work components.

Reservoir	1995 Sampling	1996 Littoral Zone Substrate Mapping	1996 Sampling Site Layout	1996 Sampling	1996 Water Quality Analysis	Reservoir Totals
Cottage Grove	3	1	1	2	1	8
Dorena	3	1	2	2	1	9
Dexter	3	1	2	2	1	9
Foster	-----------	1	1	2	1	5
Green Peter	-----------	3	2	2	1	8
Hills Creek	8	2	3	3	1	17
Lookout Point	5	2	2	2	1	12
Total	22	11	13	15	7	68

Table A2. Electroshock time (pedal down time in minutes) by sampling year.

Sample Year	Reservoir							Total
	Cottage Grove	Dorena	Dexter	Foster	Green Peter	Hills Creek	Look-out Point	
1995	60.45 1/	115.18 1/	143.48			312.28	302.02	933.41
1996	39.43	44.62	40.52	60.03	71.63	70.27	65.63	392.13
1996 Mean (±SE) Per Sampling Replicate	3.95 (±0.23)	2.62 (±0.18)	3.38 (±0.21)	3.75 (±0.18)	3.98 (±0.17)	3.90 (±0.17)	3.93 (±0.18)	

1/ Shocking time documented for only one of two days sampling time

Table A3. Regression analysis results (R^2) for relationships of substrate characteristics to (mean) fish species diversity (div.), by numbers and weight, and fish species total and (mean) richness (rich.).

Substrate Characteristic	Substrate Size Category												Total Corre-lations/ %
	Bedrock			Fine			Gravel-Small Boulder			Large Boulder			
	Rich.	Div. (No.)	Div. (Wt.)	Rich.	Div. (No.)	Div. (Wt.)	Rich.	Div. (No.)	Div. (Wt.)	Rich.	Div. (No.)	Div. (Wt.)	
Mean Segment-ment Length	NC (NC)	(0.68)	(NC)	NC (NC)	(NC)	(NC)	0.49 (0.54)	(NC)	(0.52)	0.89 (NC)	(NC)	(NC)	5/31
Percent of Total Shoreline Length	NC (NC)	(NC)	(NC)	NC (NC)	(NC)	(NC)	0.73 (NC)	(NC)	(0.61)	0.45 (0.85)	(NC)	(NC)	4/25
Number of Segments per Kilometer	0.64 (0.40)	(NC)	(NC)	NC (NC)	(NC)	(NC)	0.48 (NC)	(NC)	(NC)	NC (NC)	(0.86)	(0.51)	5/31
Mean Distance Between Segments	NC (NC)	(NC)	(NC)	NC (NC)	(NC)	(NC)	NC (NC)	(NC)	(NC)	NC (NC)	(NC)	(NC)	0/0
% of Seg-ments > 152 m	NC (NC)	(NC)	(NC)	0.92 (NC)	(0.53)	(NC)	NC (NC)	(NC)	(0.51)	NC (0.91)	(0.46)	(0.49)	6/38
Total Correlations/ %	2/20	1/10	0/0	1/10	1/10	0/0	4/40	0/0	3/30	4/40	2/20	2/20	

NC = No correlation (R^2<0.30).

Table A4. Regression analysis results (R^2) for relationships between specified habitat parameters to fish species total and (mean) richness, and (mean) fish species diversity, by numbers and weight.

Habitat Parameter	Richness	Diversity (numbers)	Diversity (weight)
Habitat Diversity (kilometers of substrate to kilometers of shoreline)	NC (NC)	(NC)	(0.84)
Habitat Diversity (total length of each substrate type)	NC (NC)	(NC)	(0.79)
Habitat Diversity (total number of segments of each substrate type per reservoir)	NC (NC)	(0.77)	(NC)
Habitat Diversity (weighted total number of segments of each substrate type per reservoir)	NC (NC)	(0.77)	(NC)
Habitat Diversity (substrate size categories)	0.73 (NC)	(0.65)	(0.66)
Percent Vegetated Fines	0.81 (NC)	(NC)	(NC)
Number of Habitat Types in Each Reservoir	NC (NC)	(NC)	(NC)

NC = No correlation (R^2<0.30).