HABITAT USE, MOVEMENTS, AND EXPLOITATION OF STRIPED BASS AND HYBRID STRIPED BASS IN CLAYTOR LAKE, VIRGINIA

By

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ABSTRACT

The comparative performance of striped bass *Morone saxatilis* (STB) and hybrid striped bass *M. saxatilis x M. chrysops* (HSB) was evaluated in Claytor Lake, Virginia. This study assessed: 1) habitat use versus habitat availability for STB and HSB; 2) seasonal movement patterns, movement rates, and emigration rates of STB and HSB; and 3) angler catch rates of STB and HSB in Claytor Lake.

In general, STB and HSB used similar habitats throughout this study. However, HSB used warmer (2-3°C) water than STB during spring of 2001 and 2002. During the summer months, fish selected the coolest water temperature available that contained adequate (> 2.0 mg/L) dissolved oxygen. Striped bass habitat was more degraded than HSB habitat during summer stratification of both years.

Both moronids exhibited similar seasonal movement patterns. Upstream spawning migrations took place in March at 9-10°C. Summer habitat was restricted to the lower 1/3 of Claytor Lake, whereas fish used the entire reservoir during other seasons. Minimum daily movement rates were similar between species and seasons (0.2-0.5 km/h). Hourly movement rates were also similar between species (0.2-0.3 km/h). One tagged fish from the reservoir was recovered below the dam, suggesting low rates of emigration.

Poor tag return rates by anglers limited confidence in estimation of exploitation rates. However, based on estimated natural and handling mortality rates and tag-reporting rates,

estimated annual fishing mortality was 26% for STB and 14% for HSB, lower than rates found in Virginia's Lake Gaston and Smith Mountain Lake.

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INTRODUCTION

The striped bass *Morone saxatilis* (STB) is native to the Atlantic slope from southern Canada to Florida, and on the Gulf slope from Florida to eastern Texas (Jenkins and Burkhead 1993). In their native environments, STB are anadromous fish that spawn in many Atlantic and Gulf rivers (McLaren et al. 1981). The Santee River in South Carolina was one of these (Braschler et al. 1988), and the first inland landlocked population was established by the impoundment of Santee-Cooper reservoir in 1942 and the subsequent trapping of migrating STB (Bailey 1979). These fish subsequently reproduced and carried out their entire life cycles within freshwater (Scruggs 1957), leading to the stocking of striped bass in other inland reservoirs (Jenkins and Burkhead 1993). The objectives for stocking striped bass have included establishment of a recreational fishery, development of a trophy fishery, and the control of undesirable forage fishes, primarily clupeid species (Bailey 1979; Combs and Peltz 1982; Axon and Whitehurst 1985; Harper and Namminga 1986).

Hybrid striped bass (*M. saxatilis x M. chrysops*) (HSB) were first produced in 1965 by crossing a female STB with a male white bass *M. chrysops* (Bishop 1967). While not achieving the size often obtained by STB, HSB often have higher survival rates (Bishop 1967; Bayless 1972; Ware 1974) grow faster (Bayless 1972; Ware 1974), may be more sedentary (J. R. Copeland, Virginia Department of Game and Inland Fisheries (VDGIF), personal communication) have higher temperature tolerance (Coutant 1985; Moss 1985; Muncy et al. 1990), and may have higher benefit/cost ratios (in terms of angler satisfaction vs. hatchery production costs) than their STB counterparts (Crandall 1978). Hybrid striped bass have also been stocked into United States reservoirs to provide sport-fishing opportunities and to utilize pelagic forage-fish populations (primarily Clupeidae spp.) (Ott and Malvestuto 1981; Axon and

Whitehurst 1985; Coutant 1985; Murphy and Valentine 1985; Austin and Hurley 1987; Neal et al. 1999). As of 1985, 34 state agencies had stocked STB or HSB into lakes or streams (Axon and Whitehurst 1985), and the advent of many tournaments and clubs dedicated to their pursuit is testament to their popularity.

Striped bass and HSB have been stocked together in some reservoirs, (e.g., Norfolk Reservoir, AR, Cherokee Reservoir, TN, and Claytor Lake, VA). However, there are no published reports as to movement and habitat use of sympatric populations of STB and HSB. Food habits have been found to overlap between STB and HSB (Bonds 2000) providing evidence for potential competition. However, the amount of interference competition is unknown. If, for example, STB and HSB eat similar food items but inhabit different areas of the reservoir, then interference competition would be minimized.

Claytor Lake, an 1,810-ha reservoir located in southwestern Virginia, has been stocked with both STB and HSB since 1993, and fisheries for both have become well established. This dual stocking provided an opportunity to research the degree of habitat overlap between STB and HSB. Striped bass have been stocked in Claytor Lake since 1969, but they have not reached the sizes (> 15 kg) that they do in nearby Smith Mountain Lake, VA and they may emigrate from Claytor Lake through the dam at a higher rate than HSB. To both diversify the fishery and because of a belief that HSB were less susceptible to emigration from Claytor Lake, HSB have been stocked regularly since 1993 in Claytor Lake. Because the habitat overlap between STB and HSB is unknown in Claytor Lake, it will be useful to managers to estimate the degree of compatibility. In particular, it will be useful to identify whether these species are complementary to one another, thus both diversifying the fishery and increasing potential moronid biomass available to anglers.

Movements

Striped bass

The STB is a pelagic fish that is almost constantly moving (Coutant and Carroll 1980), but generally, in inland populations, moves in association with the reservoir's river channel (Brashler et al. 1988). Striped bass minimum daily movement rates are variable, but are generally between 0.5 and 3.0 km/day when measured from successive locations by telemetry studies (Cheek et al. 1985; Hampton et al. 1988; Lamprecht and Shelton 1986; Henley 1991; Wilkerson and Fisher 1997; Brashler et al. 1998). Minimum hourly movement rates of STB have been reported to average between 0.05 and 0.2 km/h, also from successive locations by telemetry studies (Wilkerson and Fisher 1997; Schaffler et al. 2002). Movement rates are often slightly higher at night (Koo and Wilson 1972; Lamprecht and Shelton 1986; Wilkerson and Fisher 1997). Striped bass appear to be most active during crepuscular periods (Stooksbury 1977).

In their native environments, the STB are anadromous, living most of its life in the ocean or tidal river habitats but migrating annually upstream to spawn (Jenkins and Burkhead 1993). Landlocked STB also typically exhibit a spring spawning migration (Combs and Peltz 1982; Cheek et al. 1985; Brashler et al. 1988; Carmichael et al. 1988; Young and Isely 2002; Schaffler et al. 2002). The spawning migrations most often take place from early April to late May, beginning when water temperature is about 13-18°C, most often 17-18°C (Combs and Peltz 1982; Braschler et al. 1988; Carmichael et al. 1998; Bjorgo et al. 2000). While the timing of the upstream migration is often attributed to increased water temperatures, it may also be in response to increased springtime flows (Brashler et al. 1988). However, if river flows are low, STB may abandon spawning runs (Farquhar and Gutreuter 1989), and some segments of the population may remain in the reservoir throughout the entire year (Poarch 1989).

Following the springtime up-river migration, eggs are deposited pelagically in the water column (Coutant 1985). The semibouyant STB eggs require fairly long stretches of river to successfully hatch; eggs often settle to the bottom and die when they reach the reservoir and current is insufficient to keep eggs suspended (Coutant 1985). Consequently, there are few self sustaining STB populations, although STB in most reservoirs attempt to reproduce. Following spawning, landlocked STB usually remain in upstream shallow areas from 8-22 d and then migrate back downstream into main reservoir bodies (Combs and Peltz 1982; Cheek et al. 1985; Brashler et al. 1988; Carmichael et al. 1988; Young and Isely 2002; Schaffler et al. 2002), where they seek cool (16-25°C) oxygenated water (Matthews et al. 1989). Striped bass do not, however, always necessarily return quickly to reservoirs. If thermal refuges are available, STB may stay in riverine environments throughout the summer (Cheek et al. 1985; Wilkerson and Fisher 1997; Lamprecht and Shelton 1988).

An interesting aspect of STB movement is the occurrence of emigration from reservoirs. They have been observed to pass through dams or over spillways, usually during spring following spawning, during high water flows, or as a flight response following handling (Scruggs 1957; Bishop 1968; Higginbotham 1979; Cheek 1982; Matthews et al. 1985; Jackson and Hightower 2000). Passage through hydroelectric dams often results in STB mortality (Coutant 1987; DuBois and Gloss 1993). Passage mortality has been positively correlated with STB total length (TL) and negatively correlated with larger spacing of turbine blades (DuBois and Gloss 1993).

Within reservoirs, landlocked STB have been found to move more during spring and fall than during summer and winter (Dudley et al. 1977; Cheek et al. 1985; Farquhar and Gutreuter 1989; Poarch 1989; Schaffler et al. 2002). Low summer movement rates are often attributed to STB being restricted to refuge areas (Cheek et al. 1985; Coutant 1985; Benson 1988; Brashler et al. 1988). In some cases, radio-tracked STB demonstrated no difference in movement between any seasons (Jackson and Hightower 2001). Differences in movement patterns within certain reservoirs are also probably attributable to differences in reservoir morphometry and availability of thermal refuges (Wilkerson and Fisher 1997). However, movement of forage fish may also strongly influence STB movement (Hatfield 1982; Oklahoma Department of Wildlife Conservation 1982; Brashler et al. 1988; Bettoli 2000).

A home range can be defined as "the area to which an animal usually confines its daily activities" (Merriam-Webster 2001). Because of their pelagic nature, inland STB may not have true home ranges (Hampton et al. 1988). For example, if movements of an individual STB range over the entire length of a reservoir, any true home range is simply within the bounds of the reservoir. The term "biological center of activity", however, has been used instead of home ranges (Hampton et al. 1988). These are simply areas where a fish is often found, but is not indicative of a true home range. Striped bass may utilize biological centers of activity (BAC) following spawning and throughout the summer months (Lamprecht and Shelton 1986; Hampton et al. 1988; Jackson and Hightower 2001).

Hybrid striped bass

Less research has been directed toward the movement of HSB than for STB. Hybrid striped bass also have extreme mobility, ranging as much as 4.4 km/day (Jones and Rogers 1998). Hybrid striped bass usually have higher movement rates before summer stratification, when fish become restricted to temperature refugia (Douglas and Jahn 1987), although movement may be greatest during spawning and summer and lowest during fall and winter (Prophet et al. 1991). When neither temperature nor DO is limiting, HSB movement and distribution is influenced by prey availability (Jones and Rogers 1998). Most diel movement by HSB likely occurs during crepuscular periods (Ebert et al. 1987; Jones and Rogers 1998; Prophet et al. 1991). Similar to STB, HSB show no true home range establishment (Prophet et al. 1991), but may also establish activity centers (Muncy and Phalen 1987; Jones and Rogers 1998; DeMauro 1990; Muncy et al. 1990). Hybrid striped bass are also susceptible to emigration from reservoirs through dams (Jahn et al. 1987; Muncy and Phalen 1987; DeMauro 1990).

Like their parental STB, HSB also often exhibit a springtime spawning migration followed by movements back to deeper main-lake habitats (Phalen et al. 1988; DeMauro 1990; Muncy et al. 1990). Similar to STB, they may also exhibit upstream movement in response to increased flow rates (Phalen et al. 1988; Muncy et al. 1990). Not all HSB appear to participate in this migration; some remain in the main reservoir throughout the year (Muncy et al. 1990; Prophet et al. 1991).

Hybrid striped bass migrate at about 15-16°C, intermediate between the parental white bass (about 13-15°C), and STB (usually 17-18°C) (Adornato 1986; Jenkins and Burkhead 1993). The actual timing of HSB spawning is close to three weeks prior to the spawning of STB (Bayless 1972). Although HSB are not 100% sterile, reproduction between HSB and STB or white bass is generally considered rare (Bonn et al. 1976; Forshage et al. 1986).

Habitat

Striped bass

Given the opportunity, fish will select a combination of conditions of temperature, dissolved oxygen (DO), food availability, and physical habitat that optimizes both survival and growth (Baltz et al. 1987). If optimal conditions do not exist, fish will occupy the best available habitat, which comes at the sacrifice of metabolic efficiency (Coutant 1990). Because this pelagic species does not strongly associate with substrate or cover, physical habitat conditions considered for inland populations of STB are most often simply the combination of temperature and DO (Coutant and Benson 1990).

Dissolved oxygen is often a non-renewable resource in the cooler and deeper sections of reservoirs during summer (Coutant 1987). Declines in summertime DO have been attributed to biochemical oxygen demand (which causes 15-20% of the depletion), phytoplankton respiration (60-80%), zooplankton respiration (5-10%), and fish respiration (1-10%) (Gordon and Nichols 1977). Optimal DO level for STB is usually considered at or above 5 mg/L, while tolerable or suboptimal levels are from 2 or 3 mg/L to 5 mg/L (Waddle 1979; Coutant 1985; Coutant 1990). Levels of DO less than 2 mg/L are considered as poor or uninhabitable (Crance 1984).

Temperature preference for STB varies with size, with larger fish occupying cooler temperatures if available (Schaich and Coutant 1980). Exact temperature preferences have been found to be variable, but adult STB prefer cooler water temperatures than do juveniles (Coutant 1985). However, preferred temperature for adult STB is most often cited between 18 and 24°C (Coutant and Carroll 1980; Crance 1984; Cheek et al. 1985), but may be as low as 15°-16°C (Shaich and Coutant 1980). In spite of temperatures exceeding 27-28°C, STB may survive if DO remains above 2 to 3 mg/L (Brashler et al. 1988; Van Horn et al. 1996). Coutant and Carroll (1980) predicted that a realized thermal niche (that part of the fundamental niche actually occupied by the species) of 20-24°C closely represented a fundamental niche (the total range of environmental conditions that are suitable for existence without the influence of interspecific competition or predation from other species) for STB. However, the fundamental niche for STB may actually be only 19-23°C (Coutant and Carroll 1980). Laboratory studies to determine temperature preference of large pelagic fish such as STB prove difficult at best, so for adult STB, field studies may provide the best evidence for a fundamental niche. However, Bettoli (2000) suggested that many previous studies have been conducted in stratified reservoirs, where cool, oxygenated waters may not have been available, thus skewing the perceived temperature preference of STB to be higher than what it actually is. During summer stratification, STB may simply select the coolest water available with DO levels above 2-3 mg/L (Coutant and Benson 1990).

During the winter, STB will, when available, seek warm-water discharges (Cheek et al. 1985; Benson, 1988; Poarch 1989). This may be to avoid cold water stress or simply a response to forage fish movements.

Habitat selection by STB often confines them to thermal refuges during the summer (Moss 1985). The term "summer squeeze" was coined by Cheek (1985), who observed that inland populations of STB are often confined to a small band of water during summer stratification, where fish are in the coolest possible water that still contains enough DO to survive. The utilization of summertime temperature refugia has subsequently been documented by many authors (Waddle 1979; Schaich and Coutant 1980; Bjorgo et al. 2000; Schaffler et al. 2002; Young and Isely 2002).

Thermal refuges may actually control the STB carrying capacity of reservoir systems (Shaich and Coutant 1980; Crance 1984; Coutant 1985; Moss 1985; Coutant 1987; Brashler et al. 1988; Matthews et al. 1989; Coutant and Benson 1990). Summer die-offs can occur when these thermal refuges do not contain sufficient oxygen and/or food supply (Coutant 1985). While horizontal movements may be attributed to prey densities, residence in summertime refuge habitat is seemingly not affected by the presence or absence of prey (Coutant 1985). While thermal refuges are important, they may lead to crowding and increases in both natural and fishing mortalities (Schaich and Coutant 1980; Waddle et al. 1980; Coutant 1987). The problem of marginal summertime habitat may be further exacerbated by catch-and-release mortality. Release of angler-caught STB has resulted in mortality estimated to range from 15-67%, with highest mortality among larger fish in warmer months (Harrell 1987; Hysmith et al. 1992; Osborne 1995; Tomasso et al. 1996; Nelson 1998).

Even for adult, sexually mature STB, it has been known for some time that smaller (<500 mm TL) STB perform much better in warmer (24-30°C) water temperatures than larger STB, an aspect important consideration for trophy STB management (Coutant 1985; Coutant 1987). Most reported mortalities of STB in southeastern reservoirs occur from July through September, and are most often reported for larger fish (>6 kg; Matthews 1985). For example, Coutant (1985) pointed out that the scarcity of larger fish (>6 kg) observed by Kohler (1980), coupled with the temperature-DO squeeze identified by Boaze (1972), was evidence of marginal habitat for STB in Claytor Lake, VA. However, in nearby Smith Mountain Lake, cool-water refuge exists and larger fish have historically been caught (D. Wilson, VDGIF, personal communication). Summertime die-offs of fish larger than 5kg occur periodically if appropriate habitat is not maintained (Coutant 1985). Striped bass energy demands under suboptimal conditions are often high (Coutant and Benson 1990). If food is plentiful, then individuals may be able to meet increased demands. If, however, food is absent or depleted after fish congregate in thermal refuge areas, the fish may experience an energy deficit and less energy will be available for growth. Because of summer stratification, growth rate potential for STB is often restricted to a small portion of lake volume (Brandt and Kirsch 1993).

Habitat Suitability Indices (HSI) are simple tools for managers to use to measure habitat quality. An HSI was created in the early 1980s for inland populations of STB from existing laboratory and telemetry studies (Crance 1984). This information has been used to predict both habitat suitability and selection of either temperature or DO (Schaffler et al. 2002; Young and Isely 2002). The STB HSI was developed by assigning different temperatures and DO levels a value from 0 to 1, where 0 represented poor habitat, 0<HSI score<1 was suboptimal, and HSI values of 1 represented optimal habitat. The specific temperature criteria for STB was poor habitat at <12°C or >30°C, suboptimal habitat between 12-18°C or 24-30°C, and optimal habitat at 18-24°C. The field methods for measuring these criteria were described by Crance (1984) as "average mean temperature at mid-afternoon; lacustrine habitats during warmest months" and "minimum dissolved oxygen near surface, lacustrine habitat throughout year." This methodology does not state the depth at which temperature should be measured nor does it address habitat actually used by fish (DO). Since the early 1980s, there have been significant technological improvements in radio-telemetry equipment, and temperature-sensitive tags are now readily available, helping managers to identify more specific fish habitats.

Hybrid striped bass

Habitat needs and preferences for HSB are not as well defined as for STB, but HSB are believed to be better able to tolerate warm summertime conditions in warm, eutrophic reservoirs (Coutant 1985; Moss 1985; Muncy et al. 1990). While no HSI exists for HSB, the combination of temperature and dissolved oxygen is often reported as the two most limiting factors (DeMauro 1990).

The exact temperature preferences for HSB are unknown, but may be intermediate to the parental STB (20-24°C) and white bass (28-30°C) (Barans and Tubb 1973; Gammon 1973).

Based on findings from telemetry studies, HSB seem to prefer 21-27°C water with dissolved oxygen >4.5 mg/L (Douglas and Jahn 1987; Muncy et al. 1990). Like STB, they are intolerant to low (<2 mg/L) levels of DO. For example, Piner (1993) found HSB in Fairfield Reservoir, TX to inhabit water up to 32°C in well-oxygenated water (>5mg/L) even though cooler water with DO of 2-4 mg/L was available. Anecdotal evidence for differences in summertime habitat selection between STB and HSB indicates that HSB may only rarely found in close proximity with adult STB (Coutant 1985; Moss 1985). Also similar to STB, HSB condition seems to decline when preferred habitat is not available (Muncy et al. 1990). Carrying capacity for HSB is also likely limited by summertime habitat for the same reasons as proposed for STB (Coutant and Benson 1990).

Study Rationale

The purpose of this study is to evaluate the comparative performance of STB and HSB as pelagic sport fishes in Claytor Lake. Although there is an abundance of literature on landlocked STB, and to a lesser degree HSB, their behavior when coexistent has not been described.

Seasonal and diel movements, as well as habitat usage, are currently unknown for Claytor Lake STB and HSB populations. Although Bonds (2000) reported the two species to be trophic equivalents in Claytor Lake, seasonal and diel interactions between them are unknown. While both STB and HSB utilize gizzard shad *Dorosoma cepedianum* and alewife *Alosa pseudoharengus* as primary forage, spatial overlap may heighten or lessen competitive overlaps between them. According to VDGIF catch rates from gillnet sampling, STB numbers have declined by 79% since the introduction of the HSB (Bonds 2000). Documentation of habitat use and movements that STB and HSB make with the associated available habitat and the description of the quality of available habitat will provide VDGIF with information to evaluate different management options.

Claytor Lake has the reputation of producing small STB (compared to nearby Smith Mountain Lake). Because STB in Claytor Lake do not reach trophy sizes found in nearby Smith Mountain Lake and because many anglers seek trophy fish, it is important to determine if limited suitable habitat exists in Claytor Lake. Striped bass often experience a summer habitat squeeze in southeastern reservoirs, which can cause an increase in potentially lethal diseases and promote overfishing upon easily located schools of fish (Coutant 1985). If habitat is limiting in Claytor Lake, then managers may want to explore alternative options such as increased bag limits, decreased stocking rates, or decreased size limits to better utilize smaller fish. If "summer-squeezed" fish experience additional stress due to overcrowding in limited habitat space, the creeling of additional fish may benefit remaining STB by restricting their numbers and allowing remaining fish to achieve faster growth.

Estimation of angler catch and harvest rates for STB and HSB will also be useful for future management of the reservoir. Following the introduction of gizzard shad and the program of stocking HSB into Claytor Lake, the relative abundance of STB declined, while numbers of sampled HSB has remained relatively high (J. R. Copeland, VDGIF, personal communication). Quantification of these rates is important to determine whether there has been an actual decline in harvest rate of STB and that this is not just due to limitations of VDGIF sampling techniques (limited sampling days and sample sizes of gillnetted moronids). Catch-and-release fishing and resulting mortality may also contribute to a decline in STB abundance. Fishing effort may have increased in Claytor Lake over the past decade (J. R. Copeland, VDGIF, personal communication), and catch-and-release mortality has been documented to be high (12-67%)

during summer months and size-dependent (Bettoli and Osborne 1998). Future stocking rates of STB and possibly harvest regulation for STB and HSB may be adjusted according to these findings. Calculation of these rates will also prove useful for the development of future Claytor Lake stocking models.

The degree to which STB and HSB emigrate from Claytor Lake is also unknown. Emigration of STB from Claytor Lake has been documented for some time (Kohler 1980), but both STB and HSB have been caught by anglers in the tailwater below Claytor Lake, despite the belief that hybrids are sedentary. Numbers of STB bass large enough to noticeably reduce angling success on Lake Texoma, Texas-Oklahoma have also been lost through the dam following storm events (Matthews et al. 1985). This phenomenon may be especially pronounced in reservoirs with low retention times (Crance 1984). This same phenomenon may also occur in HSB, but has not been documented. The penstock location and the intake gates of Claytor dam leave all but the largest moronids susceptible to emigration.

Study Area

Claytor Lake (Figure 1) has a surface area of 1,810 ha (4,500 acres) at normal pool and is 34 km long with a 35 m maximum depth (Table 1). The average retention time is a relatively short 30 days (Copeland 1999). The reservoir is maintains a relatively stable depth, only fluctuating about 1.6 m annually. Claytor dam was designed to operate four 18,750-kW generators, which have a cumulative yearly average output of 222 million kW hours. The gate openings for each of the four penstocks are located from 6.4 m (21 ft) to 20.4 m (67 ft) (midline at 13.4 m) below the headwater level at full pond (Claytor Lake dam blueprint, American Electric Power). Dam dimensions are also listed in Table 1. The actual penstock openings are square and measure about 13.7 m (45 ft) on each side, the penstocks measure 4.9 m (16 ft) in diameter, and the bars blocking the penstocks are spaced 10 cm (4 in) apart.

Claytor Lake: Prior Management

Claytor Lake (Figure 1), located in the New River Valley in southwest Virginia, was impounded in 1939 by the Appalachian Power Company (Rosebery 1951). Although piscivores such as the smallmouth bass *Micropterus dolomieu*, flathead catfish *Pylodictis olivaris*, and walleye *Stizostedion vitreum* inhabited the New River at the time of impoundment, Claytor Lake has been the subject of at least 16 species introductions and two hybrid species intended to diversify and expand the sport fishery (Kohler et al. 1986; Bonds 2000). Introductions of pelagic predators such as the striped bass (STB), white bass *M. chrysops*, the hybrid striped bass (HSB), white crappie *Pomoxis annularis,* and black crappie *P. nigromaculatus* have been followed by the introductions of pelagic prey such as the threadfin shad *Dorosoma petenense* (a failure due to extreme winter conditions in Claytor Lake), gizzard shad, and alewife.

Striped bass were first introduced into Claytor Lake in 1969 (J. R. Copeland, VDGIF, personal communication). The STB was a good candidate for stocking, as Claytor is limited in littoral habitat (Kohler1983) and has mostly open-water habitat for fish. Striped bass were stocked at a rate of about 70,000 fingerlings per year (37 fingerlings/ha) from 1969 until 1993, when stocking rates were halved to about 35,000 fingerlings per year (18.5 fingerlings/ha). Stockings were reduced to allow for HSB stockings (which began in 1993). However, in 1998 and 2001 until present, the stocking rate was again doubled to 70,000 per year. This is being done in an attempt to boost STB abundance because their numbers have apparently declined precipitously since the introduction of the HSB (Bonds 2000).

Table 1. Claytor Lake impoundment and dam characteristics

Claytor Lake		Claytor Dam	
Characteristic	Value	Characteristic	Value
Surface Area	1810 ha	Length	350 m
Elevation	562 m	Height	40 m
Watershed to surface area ratio	212:1	Penstock openings	13.7 x 13.7 m^2
Mean depth	15 m	Penstocks	4.9 m diameter
Max depth	35 m		
Length	33.8 km		
Annual storage ratio	0.09		
Retention time	30 days		
Annual fluctuation	1.6 m		
Volume	2.8 x 10^8 m^3		
Shoreline length	163 km		
Shoreline development index	10.8		

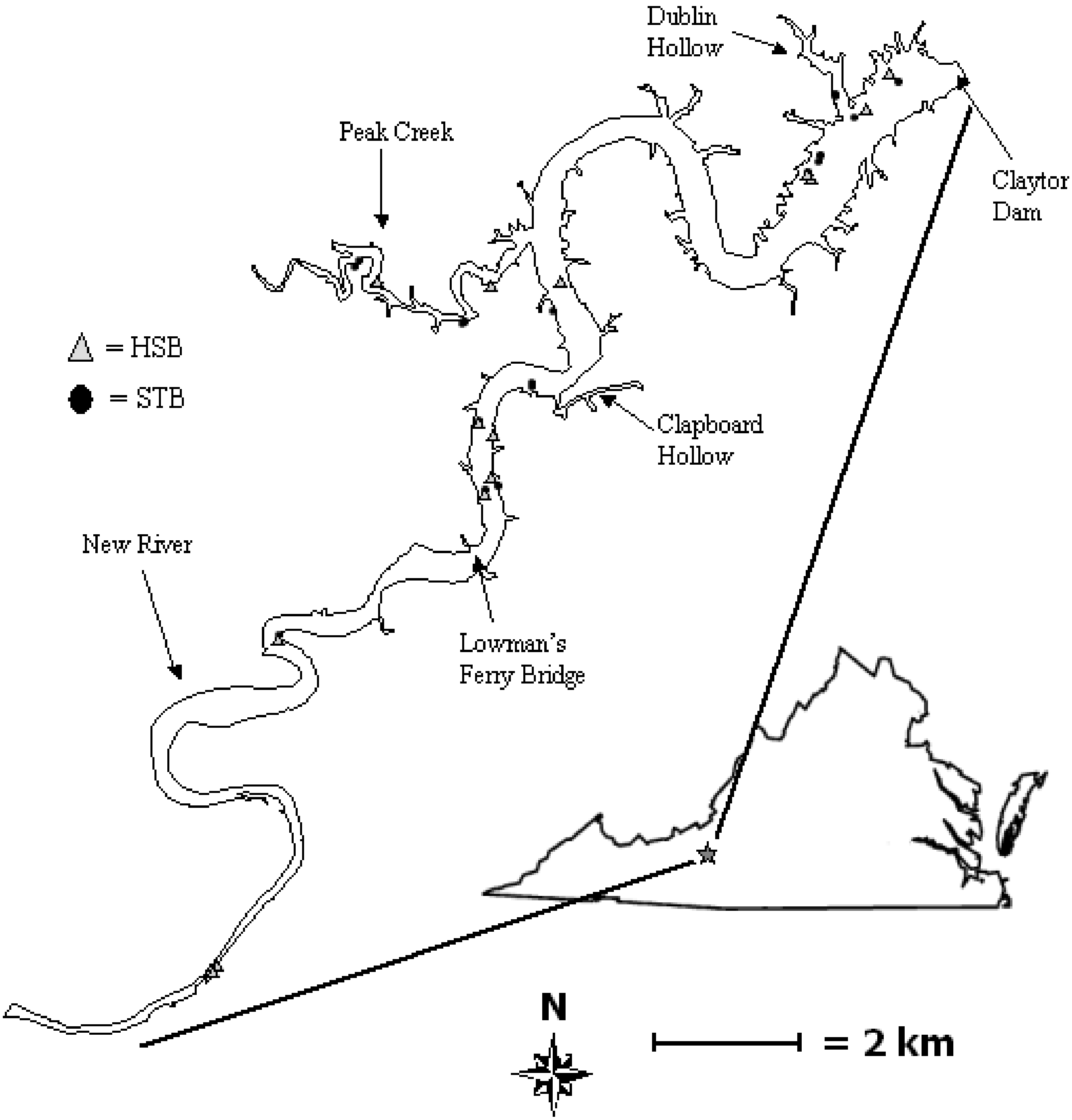


Figure 1. Claytor Lake, Virginia. Collection sites for radio-tagged STB and HSB from spring 2001 through spring 2002 are shown. Points may represent multiple captures at one location.

Hybrid striped bass have been stocked at about 35,000 fingerlings per year (18.5 fingerlings/ha) from 1993 until present. As STB were believed to emigrate from the lake fairly readily (Kohler 1986), HSB were stocked because they were believed by VDGIF biologists to be more sedentary and less susceptible to losses through Claytor Dam. They were also stocked because of supposedly warmer temperature tolerances and to diversify the fishery (J. R. Copeland, VDGIF, personal communication).

Kohler (1986) reported that STB > 6 kg (13.2 pounds) were rarely creeled from Claytor Lake. Research by Boaze (1972), who found that cooler water (<24°C) in Claytor Lake during the summer rarely contained oxygen, likely identified a limiting factor for growth of STB. This would be an effect identical to the temperature-dissolved oxygen summertime squeeze believed to impact striped bass fisheries in many southern reservoirs by limiting their growth and survival (Coutant 1985).

Recent trends (late 1990s) have suggested that growth rates of STB in Claytor Lake have improved, possibly due to the introduction of gizzard shad in the late 1980s (Bonds 2000). Personal communication with anglers at Claytor Lake suggest that fish > 6 kg may not be as rare as they once were. Bonds (2000) also observed that, in spite of STB and HSB being considered trophic equivalents, STB growth rates have actually increased while their relative abundance has decreased since the introduction of HSB. One theory (being addressed in a concurrent research project on Claytor Lake) is that interference competition among juvenile STB and HSB may lead to reduced numbers of STB, but the remaining fish have higher growth rates from the consumption of gizzard shad. However, relatively low harvest rates of trophy fish persist and few STB >6 kg are caught by VDGIF gillnet sampling. The apparent lack of larger fish has contributed to this investigation into the availability of suitable habitat for adult STB and HSB in Claytor Lake.

Available Habitat

Claytor Lake is dimictic, experiencing both a summer and winter stratification (Kohler et al. 1986). Summer stratification in Claytor Lake results in the hypolimnion becoming anoxic (Kohler et al. 1986). The Virginia Department of Environmental Quality (DEQ) has periodically sampled the reservoir during summer stratification to quantify lake conditions. Stratification is variable, however, and habitat conditions may be considerably different between years. For example, stratification of Claytor Lake during August of 1999 and August of 2001 was drastically different (Figure 2). Both years exhibit negative heterograde oxygen profiles (Cole 1994), where there exists a metalimnetic oxygen deficit. However, oxygenated thermal refuges persisted in 2001, but not in 1999. This metalimnetic oxygen deficit phenomenon is believed to be due to respiration of nonmigrating animals, DO consumption by decaying seston, or density currents of water with low DO being trapped between two well-oxygenated layers (Cole 1994).

When considering the profile by the dam, it is apparent that in the summer of 2001, a large stratum (10-20 m) of water was available as oxygenated (>5.0 mg/L) thermal refuge (<25°C). In 2001, almost the entire oxygen-containing metalimnion was susceptible to loss through the dam, due to the location of the upper and lower bounds of the penstock openings. Thermal refuge also existed in the summer of 1999, although as a much smaller water stratum (26-30 m) where DO was 2.5-5.0 mg/L. However, in 1999, the thermal refuge was not within the upper and lower bounds of the dam intake, and oxygenated thermal refuge habitat was not likely lost or drawn out by dam operations. Stratification patterns may be linked to reservoir inflow. For example, flows were well below average in 1999, where flows were greater in 2001

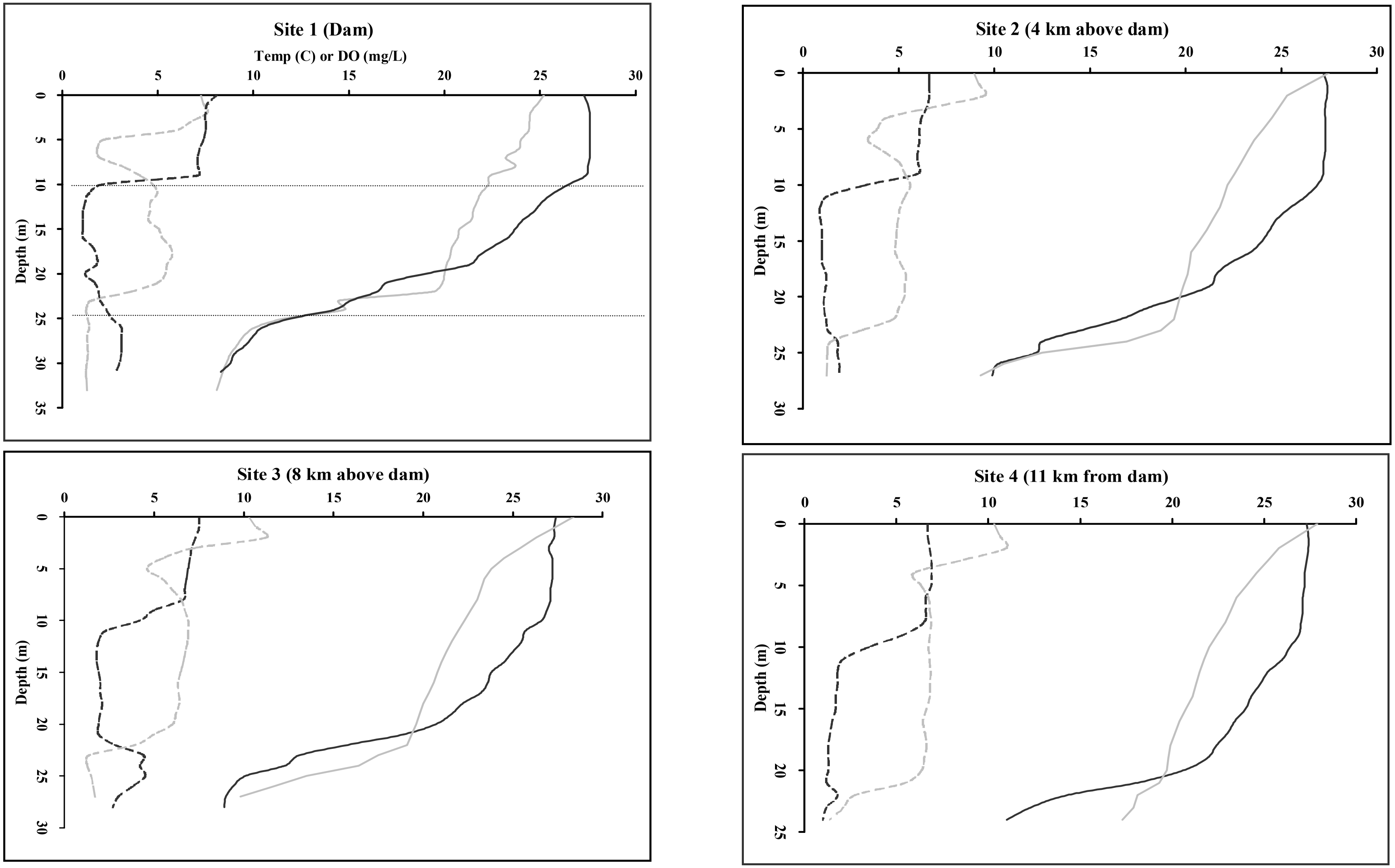


Figure 2. Claytor Lake Profiles, August 1999 (black lines) and August 2001 (gray lines) at upstream distances from Claytor dam. Vertical solid lines represent temperature (°C) vertical dashed lines represent DO (mg/L). Horizontal dashed lines (site 1 graph) represent upper and lower bounds of dam intakes.

(Figure 3).

When comparing longitudinal habitat, it is apparent that, as the lake becomes more shallow (further from the dam), summer refuge habitat is susceptible to loss (Figure 2). For example, by 11 km from the dam, the oxygenated thermal refuge in 1999 was almost gone, while in 2001, some thermal refuge still existed. Further from the dam, as the reservoir becomes even less deep, thermal refuge completely disappears. This loss of habitat may restrict STB and even HSB to habitat in the lower end of Claytor Lake during summer stratification.

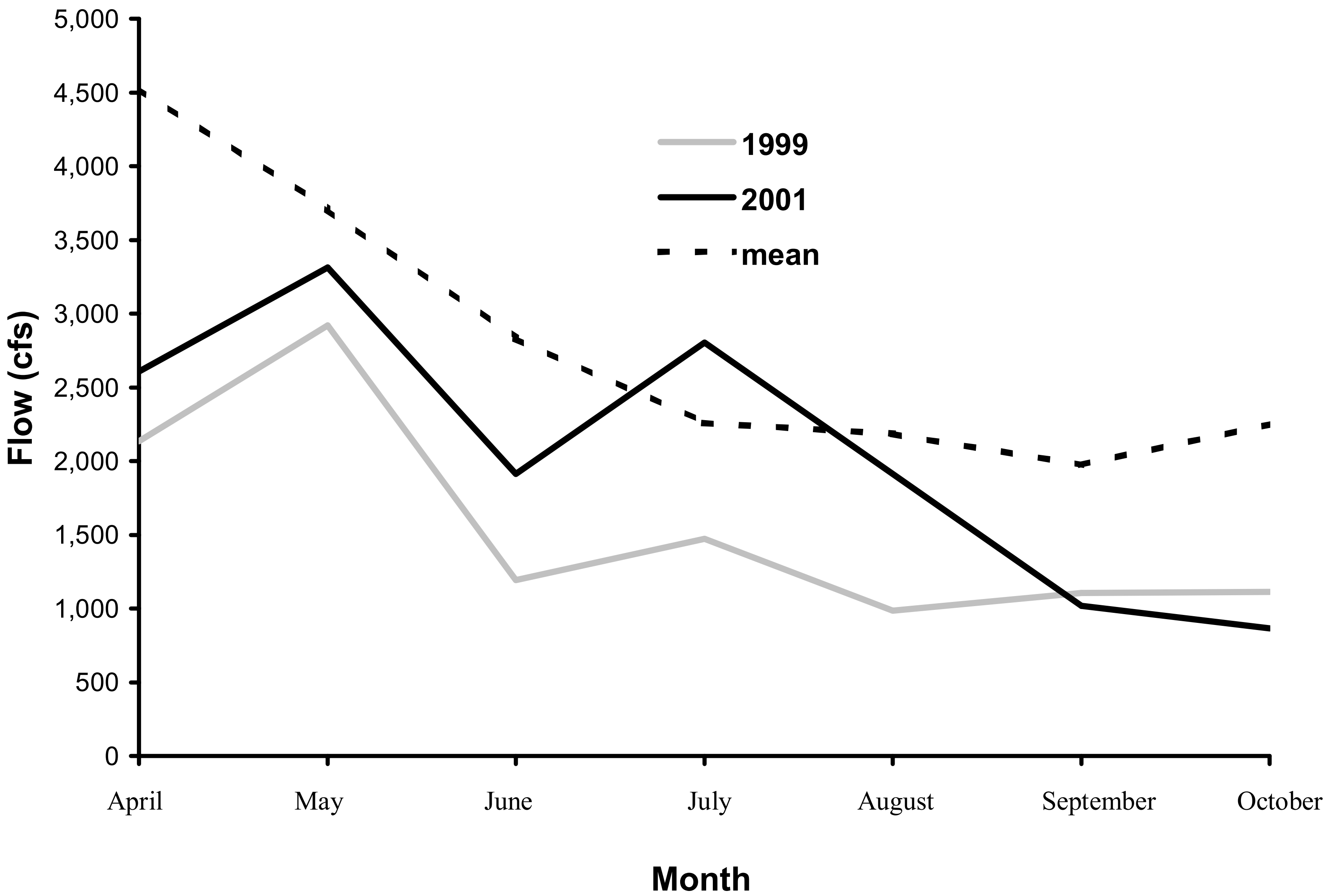


Figure 3. Mean monthly flows into Claytor Lake during 1999 and 2001. Seventy-year average monthly flow is also shown for reference.

Goals and Objectives

The goal of this study is to evaluate the comparative performance of STB and HSB as pelagic sport fishes in Claytor Lake. Specific objectives are to:

1. Determine seasonal habitat utilization versus habitat availability for STB and HSB in Claytor Lake;
2. Describe seasonal and diel movement patterns for STB and HSB in Claytor Lake;
3. Quantify exploitation rates for STB and HSB in Claytor Lake; and
4. Estimate STB and HSB emigration rates from Claytor Lake.

METHODS

Habitat Use

Laboratory study

To practice surgical procedures and determine best fish handling methods, I initiated a laboratory study before field collections began. On March 17, 2000, I collected three striped bass (584, 635, and 711 mm TL) and two hybrid striped bass (559 and 610 mm TL) from Claytor Lake via hook and line. Fish were transported back to Virginia Tech Aquaculture Center where they were acclimated and placed into two 190-L living stream tanks with water chillers. Water temperature was maintained at 8-10°C.

On March 22, 2000, I surgically implanted each fish with internal radio-transmitters (Advanced Telemetry Systems, Isanti, MN) and internal anchor tags (Hallprint, LTD., South Australia). Radio transmitters were to be used to monitor fish movement and habitat use, while internal anchor tags were to be used for exploitation estimations. Each cylindrical, trailing-whip transmitter measured 17 mm diameter, 51mm in length, had an approximately 25-cm antenna, and weighed 20 g. The internal anchor tags (i.e., internal anchor with external spaghetti-type tag) measured approximately 100 mm in length and had an anchor of approximately 19 mm. Internal anchor tags were used because of their superior retention times, when compared to dorsal or other tags (Dunning et al. 1987).

Radio-tagging procedure for each fish was as follows (Hart and Summerfelt 1975; K. Hughes, Virginia Tech University Aquatic Medicine Laboratory, personal communication):

1. Each fish was placed securely in a surgery table with the ventral surface facing up and the fish's head to the left.

2. Three to four scales were removed at the incision site, approximately halfway between the vent and the distal tip of the depressed pelvic fins and slightly off-center (1-2 scale rows) of the mid-ventral line.

3. An approximately 25-mm long incision was made through the body musculature with a scalpel. The peritoneum was only slightly incised, and I used a finger to gently open the incision only to the length needed to insert the radio transmitter into the body cavity. Slight force was used to put the transmitter into the body cavity, but care was taken not to jam the transmitter into the internal organs.

4. Each incision was closed with three evenly spaced absorbable sutures. Only one layer of suture was used, through both the peritoneum and musculature. The transmitter antenna wire was external to the body cavity and exited posterior to the suture.

Internal anchor tagging procedure was as follows (as adapted from STB tagging procedures developed by Normandeau Associates, Bedford, New Hampshire).

1. The fish was secured in the surgery table with the ventral surface facing up and the fish's head to the left.

2. One to two scales were removed at the tag insertion site, approximately mid-way between the vent and the distal tips of the depressed pelvic fins and slightly off-center (3-4 scale rows) of the mid-ventral line.

3. A 1-2 mm puncture was made through the body musculature with a scalpel. Depth of puncture was to, but not quite through, the peritoneum. The peritoneum was gently punctured with the anchor of the tag as it was inserted through the incision, and the tag was set with a gentle pull on the streamer. The external streamer was rotated so that the tag anchor aligned with the long axis of the fish.

The first fish that I tagged was anesthetized with tricaine methanesulfonate (MS-222). The entire procedure for the insertion of both tags, from introducing the striped bass to anesthetic to releasing it back into its tank, lasted approximately 5 minutes. In an attempt to increase fish survival by reducing total handling time, subsequent fish were handled and tagged without the use of anesthetics (Muncy et al. 1990), which reduced the entire handling time to 100-200 s.

After 15 days at the Virginia Tech Aquaculture Center, all of the STB and HSB were alive and no radio or internal anchor tags were lost. Fish were in apparent good health and were subsequently re-released into Claytor Lake. Examination of the fish revealed approximately 60% closure of wounds, although no sutures had been absorbed yet. No infections were observed at incision sites and all radio tags were firmly in place. Surgical removal of the radio tags revealed partial surrounding of the tag by peritoneal tissue. All anchor tags were still securely in place and incision sites were approximately 60% healed. Fish were released following removal of the radio tags, re-suturing of the wound, and removal of the internal anchor tags.

Field study

I assessed fish habitat use and movements by tagging adult (> 457 mm total length) STB (n = 26) and HSB (n = 33) with implanted radio tags (Table 2). Twenty fish were tagged in the spring of 2001 and an additional 39 fish were tagged from fall 2001 to spring 2002 (Table 3). Because

Table 2. Striped bass and hybrid striped bass caught and tagged with internal implant radio tags by season.

Season	Striped bass	Hybrid striped bass
Spring 01	9	11
Fall 01	7	9
Winter 02	5	0
Spring 02	5	13
Total	26	33

Table 3. Summary information for striped bass and hybrid striped bass with internal radio transmitters monitored in Claytor Lake, Virginia.

Fish ID (freq.)	Species	Tagging date	Capture method[1]	Total length (mm)	Status[2]	Days observed	Number times located
48.011	STB	6/5/01	A	855	M	14	2
48.021	HSB	4/23/02	A	556	D	91	7
48.031	STB	4/11/01	E	565	M	0	0
48.051	HSB	4/5/01	E	492	M	42	6
48.071	HSB	10/31/01	A	524	M	199	21
48.081	HSB	4/5/01	A	460	M	515	43
48.091	STB	3/27/02	E	940	D	50	4
48.101	HSB	4/11/01	E	502	M	403	30
48.131	HSB	4/25/02	A	535	D	11	1
48.141	HSB	6/14/01	A	521	D	18	4
48.151	HSB	4/17/02	G	559	A	242	16
48.161	HSB	5/2/01	E	629	M	28	4
48.171	STB	4/18/02	G	673	A	228	15
48.181	HSB	4/13/02	A	483	M	480	36
48.191	STB	4/18/02	A	673	A	228	14
48.201	HSB	4/5/01	A	508	M	417	35
48.222	STB	5/9/01	A	565	D	35	4
48.231	HSB	4/29/01	G	540	M	258	15
48.241	HSB	4/29/01	E	641	M	495	31
48.251	HSB	4/19/02	E	533	A	214	13
48.461	STB	11/9/02	A	749	M	258	14
48.481	STB	10/31/01	A	692	M	22	1
48.491	STB	6/6/01	A	533	M	305	20
48.501	STB	4/8/02	A	702	A	228	16
48.511	STB	5/14/01	E	559	D	16	3
48.521	STB	10/31/01	A	641	M	338	11
48.531	STB	6/5/01	A	740	M	287	20
48.541	HSB	4/17/02	G	638	M	0	0
48.561	STB	11/9/01	A	759	A	395	21
48.581	STB	11/9/01	A	683	A	395	21
48.601	HSB	4/17/02	G	533	M	0	0
48.621	HSB	11/13/01	G	533	M	121	7
48.659	HSB	4/17/02	G	559	A	228	16
48.681	HSB	4/25/02	A	635	A	214	12

[1]A=angling, E=electrofishing, G=gillnet
[2]Status at conclusion of study (December, 2002): A=Alive, D=dead, M=missing

Table 3 (cont). Summary information for striped bass and hybrid striped bass with internal radio transmitters monitored in Claytor Lake, Virginia.

Fish ID (frequency)	Species	Tagging Date	Capture method[1]	Total length (mm)	Status[2]	Days observed	Number times located
48.701	HSB	4/17/02	G	454	D	22	3
48.791	HSB	11/31/01	G	525	A	395	21
48.801	STB	4/18/02	G	899	M	0	0
48.841	HSB	11/6/01	A	679	M	176	9
48.871	HSB	4/11/01	A	470	M	68	10
48.881	STB	3/27/02	E	813	A	256	12
48.892	STB	4/25/01	A	778	M	299	20
48.902	HSB	11/9/01	G	552	A	395	24
48.911	STB	5/9/01	A	575	M	404	27
48.921	HSB	4/24/02	A	559	D	5	1
48.931	HSB	5/23/01	E	648	M	390	26
48.942	STB	4/18/02	A	740	D	24	1
48.951	STB	5/3/01	A	864	M	523	20
48.961	STB	12/4/01	A	711	A	274	6
48.972	HSB	4/25/01	A	527	M	495	38
48.981	STB	11/6/01	A	714	A	395	21
49.004	STB	3/15/02	A	743	M	6	1
49.015	STB	11/9/01	A	775	D	176	9
49.015	HSB	5/20/02	E	540	A	206	13
49.024	HSB	11/14/01	G	521	A	395	24
49.034	HSB	11/9/01	G	565	A	411	17
49.045	HSB	4/17/02	G	591	A	214	16
49.054	HSB	10/30/01	A	543	A	411	22
49.065	STB	3/27/02	A	686	A	279	19
49.075	STB	4/18/02	A	743	A	274	14
49.085	STB	3/15/02	A	645	A	260	15
49.095	HSB	11/14/01	G	505	M	113	4

[1]A=angling, E=electrofishing, G=gillnet
[2]Status at conclusion of study (December, 2002): A=Alive, D=dead, M=missing

high water temperature has been shown to increase skin irritations, infections, and mortality to tagged fish (Walsh et al. 2000), fish collections were made when surface temperature was below 21.1°C (70°F). Both STB and HSB were captured by shoreline electrofishing, angling, or gillnets from various locations throughout the reservoir (Figure 1). Shoreline electrofishing was conducted using a boom electrofisher with pulsed-DC current during spring of 2001 and 2002. Angling was conducted during all seasons. Lake-caught live bait (gizzard shad and alewives) and artificial lures were used. To try to minimize hooking mortality, only circle hooks were used for live bait fishing, and baits were not fished below 12.2 m (40 ft). Artificial baits included bucktail jigs, topwater twitch baits, and crankbaits. Gillnets were used during the winter of 2001-2002, when surface water temperature was below 10°C (50°F). Sinking nets, measuring from 30.5 to 61 m (100-200 ft) in length and 2.4 to 3.0 m (8-10 ft) in height were used in bar-mesh sizes of 64 to 114 mm (2.5-4.5 in). Nets were set in locations where fish were located using boat-mounted 200 kHz sonar equipment (Lowrance LCX-15 MT) with a 12°-cone-angle transducer. Nets were fished no longer than 20 minutes, and fish were immediately cut out and placed into a 379-L (100 gallon) tub upon pulling nets. Approximately 250 g of rock salt was added to every 100 L of water in the holding tub to minimize osmotic stress (Cech et al. 1996). Fish were only held long enough to tag and release all subjects.

Following capture, a temperature-sensitive internal radio tag (Advanced Telemetry Systems, Inc., model 5955) was surgically implanted into the fish using the same techniques as in the laboratory study. In addition, the scalpel blade was changed frequently (every 1-2 fish) to avoid tearing of fish tissue when making the tag incision. A 10% Betadine solution was used to disinfect both tags and the scalpel to avoid infection (K. Hughes, Virginia Tech University Aquatic Medicine Laboratory, personal communication). The use of anesthetics was deemed not necessary, because fish were immobilized in the surgery table (Cheek 1982). Fish were also fitted with yellow internal anchor tags (IAT) (Hallprint, LTD, South Australia). Each IAT had a unique number and the name and phone number for Virginia Tech Department of Fisheries and Wildlife. Approximately 105-150 s were needed for the entire radio-tagging procedure, from placement into the surgery table until release of the fish back into the water. Internal anchor tags required only about 10-15 s to implant into fish. Fish were resuscitated gently in the water prior to outright release to ensure health and equilibrium. Each transmitter was identical in dimensions to the transmitters used in the laboratory test. The radio-tags had the following features:

1. one size 2/3 AA lithium battery
2. individually coded radio-frequency
3. magnetic ON/OFF switch
4. microprocessor program controlled
    a. duty cycle (4 days on / 3 days off)
    b. 0°– 40°C temperature sensor with pulse indicator

To attempt to quickly detect fish mortality, radio tags used in the fall 2001-Spring 2002 had an additional mortality switch feature with a duty cycle override. Fish mortality could be determined by rapid pulses of radio tags that remained motionless for more than 24 hours. Each transmitter was temperature-calibrated per Advanced Telemetry Systems (ATS) instructions prior to use.

Survival of captured fish decreases with increasing water temperature (Harrell 1987). Therefore, I stopped all collection and tagging of fish when surface water temperature reached 21°C (70°F). Although a subjective determination, I classified fish to be in “poor condition” if they never regained equilibrium, or never gained enough strength to swim from my hand as I lightly grasped the tail. I observed fish to be in poor condition immediately following tagging only rarely, although more so at temperatures approaching 21°C. Over the course of this study, only 5 fish were ever in very poor condition and were recovered after release for tag reclamation. I resuscitated all fish prior to release by holding the fish gently by the bottom jaw and slowly swimming them in a figure-8 motion to allow water flow over the gills.

Fish tracking

Beginning in May, 2001 and continuing until December 2002, I attempted to locate fish at least twice per week throughout the period of thermal stratification (May-October) and at least once monthly otherwise. Fish were tracked via a boat-mounted loop-style antenna and a scanning radio receiver (ATS, Isanti, Minnesota). The entire reservoir was searched in a loop fashion, so that both sides and each cove were searched each tracking event. Boat speeds while radio-tracking ranged from 3 mph (when most tags were yet to be found) to 10-12 mph (when only a few tags were left to be found). Tracking was done both during daylight and nighttime hours, and took anywhere from 8 to 20 hrs to complete.

To determine fish location, I tracked fish until the radio signal was strongest. I also attempted to find all fish with the boat-mounted sonar. Most often, large schooling fish (presumably STB or HSB) would be located in the vicinity of the radio-tagged fish so the boat-mounted sonar was used to verify fish location (Figure 4). Data recorded included estimated fish

depth, temperature at fish depth, dissolved oxygen at fish depth, UTM coordinates (WGS 84), and notes as to the nearest landmark (e.g., just above Mallard Point). Fish depth was estimated by applying each individual tag timed pulse rate to individual temperature curves to determine fish temperature. A temperature probe was lowered to depth at which temperature

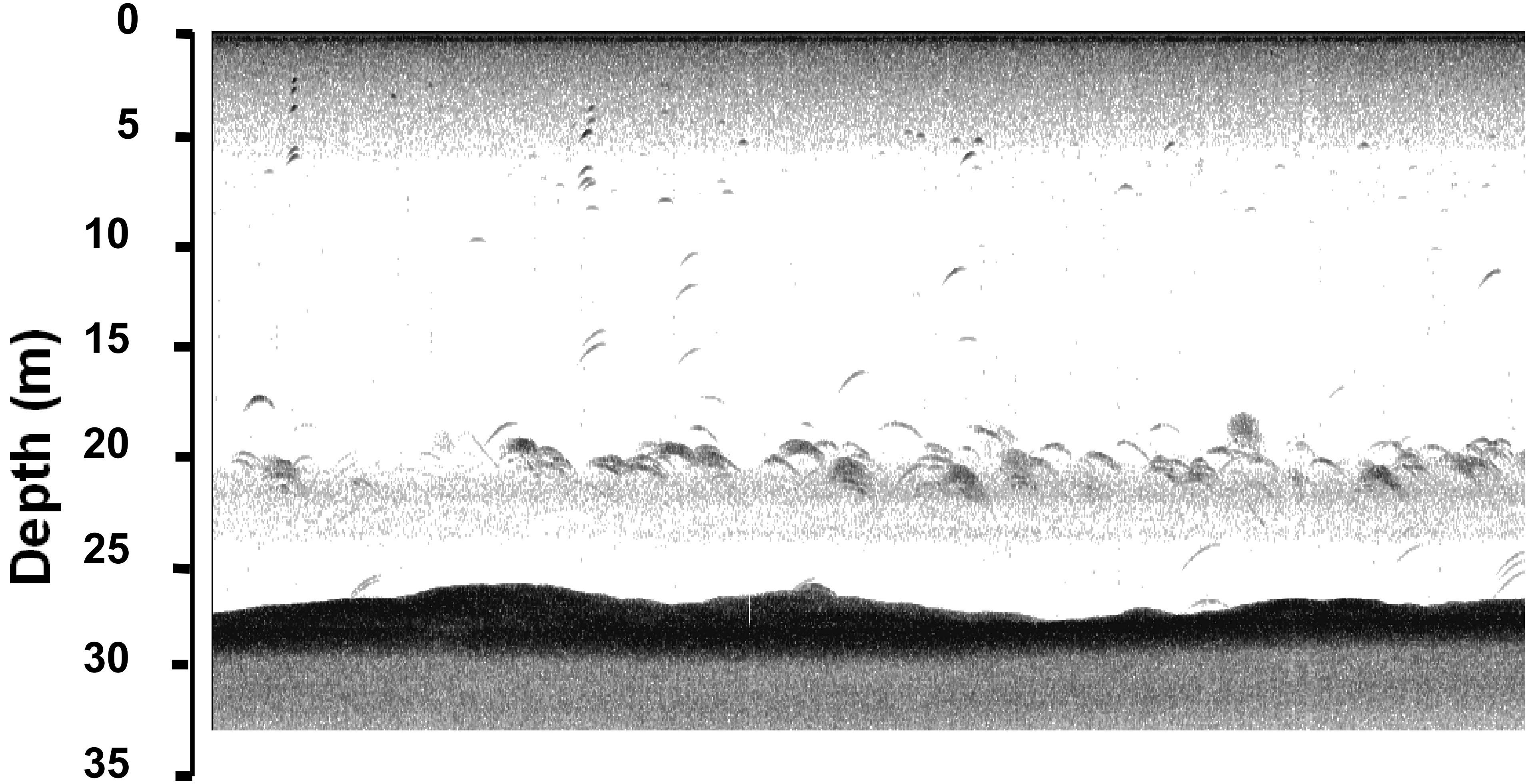


Figure 4. Sonar reading from Claytor Lake, August 2002. Larger fish at around 20 m represent schooling STB. Fish were often in fairly narrow bands of water, thus demonstrating typical “summer squeeze”.

was located and DO use at that depth strata was recorded.

To describe general diel movement patterns, I tracked 3 STB and 2 HSB each on a separate date. Each fish was tracked during a 24-hour period, and hourly location data were recorded. Analysis of variance was used (α= 0.05) to test if hourly movement rates differed between HSB and STB, and to test whether movement rates differed between day and nighttime periods and between crepuscular periods and all others times.

Movement

Movement data were analyzed using the Geographic Information System (GIS) program ArcView (Version 3.2, Environmental Systems Research Institute, Inc., Redlands, California). Point locations were used to determine minimum linear distance moved (shortest straight line swimming distance between successive dates for each fish) and to calculate utilization distributions. Minimum distance moved was determined between each tracking event and for each fish by using the measure tool in ArcView.

Utilization distribution areas for individual fish were calculated using the kernel home range estimator in the ArcView extension animal movement (Hooge and Eichenlaub 1997). For true calculation of home ranges, a minimum of 30 points should be used (Seaman et al. 1999). Because I evaluated utilization distributions within seasons by tracking every other week, my sample sizes are small (n=3-6) and do not represent true home range estimates, but rather give a general idea of how much area each fish used in each season. For analysis, seasons were considered as follows: spring was April-June, summer was July- September, fall was October-December, and winter was January-March.

A utilization distribution is the name given to the distribution of an animal' position in a plane (Worton 1989). Different tools exist in which to estimate 2-dimensional areas used by animals (i.e., minimum convex polygon, grid cell), although they do not account for animal densities (intensity of use for a particular area). However, the densities used by animals are useful; a simple measure of the total area of habitat used may be misleading if the animal uses a space at either higher or lower intensity (Seaman and Powell 1996). Furthermore, weighting areas by actual usage gives a better picture of the probability of interaction between animals (Seaman and Powell 1996). Biological centers of activity are simply specific areas within a reservoir that a fish returns to on a frequent basis (Hampton 1988).

A tool to obtain this density distribution is the kernel density estimator (or utilization distribution), which uses a non-parametric statistical procedure to calculate probabilities of an animal being in various locations (Worton 1989). For analysis of area occupied by individual fish, I used the 95% adaptive kernel estimate with least-squares cross-validation (Silverman 1986; Worton 1989), as limited by the boundaries of the reservoir. This simply provided a model to estimate areas used by individual fish with 95% confidence (i.e., 95% of the time).

Seasonal movement comparisons of minimum mean distances moved per season and 95% utilization distributions were calculated for striped bass and HSB. I used the mixed model procedure (SAS) with subsamples on individual fish to determine species differences in minimum daily movement ($\alpha = 0.05$). Analysis of Variance was used to determine significant differences ($\alpha = 0.05$) in utilization distribution use between seasons for both STB and HSB, to determine if individual fish within species expressed different utilization areas and to determine whether seasonal HSB and STB utilization areas were different. If significant differences were found using ANOVA, Fisher's Least Significant Difference (LSD) test was used to identify differences between seasons. Potential biological centers of activities were investigated by plotting 95% utilization distributions for individual fish.

Habitat use

Each time a telemetered fish was located, temperature at fish depth was determined by the timed interval of the temperature-sensitive tags (tag pulse rate varied linearly with temperature). Once temperature was determined and recorded, a temp/DO probe (YSI model 58) was lowered to the depth at which that temperature was found. Thus, both depth and DO at that depth could be recorded when the reservoir was thermally stratified. I used new membranes and calibrated the instrument prior to each day's use. Temperature of each fish was estimated from the temperature-pulse rate calibrated from each radio-tag.

Because some of the radio-tag temperatures were not possible given lake conditions (e.g., radio-tags indicated the fish were at temperatures that were not present in the reservoir), it became apparent that the radio-tags were not completely reliable for determining fish depth and temperature use. This was especially problematic given that small errors in temperature could result in large errors in estimated DO habitat occupied, because DO sometimes varied sharply over 1-2 m depth. Boat-mounted sonar provided a second method for estimating depth, and thus temperature and DO usage for each fish. Therefore, in cases where temperature differed by more than 1°C or DO differed by more than 1 mg/L between radio-tag and sonar-predicted estimates, I used the sonar-predicted values because they could be supported by the locations of other fish. Because the positive vertical identification of a specific temperature was only possible when the reservoir was stratified, the boat-mounted sonar was used for estimating fish depth during isothermal conditions.

I used ANOVA to test for differences (α=0.05) in the temperature, DO, and depth selection both between species in each season (Spring 01-Fall 02) and within each species over seasons. Fisher's LSD was used to highlight differences where they occurred.

Available habitat

I determined parameters of available habitat by taking temperature and dissolved oxygen vertical profiles every 2 m from surface to bottom at 3.2-km (2-mile) intervals along the main channel of the impounded New River and along Peak Creek (Figure 5). Profiles were taken within 1-2 days of each tracking event. From July through September, 2001, I only conducted habitat readings within 17.7 km above the dam (11 miles), because I knew this was heavily used habitat for both STB and HSB. However, as it became apparent from telemetry observations that fish used the entire reservoir, I expanded my breadth of readings to include the entire reservoir and Peak Creek. Beginning in September 2001, I took measurements along the entire river channel (mile 0-20), and in November of 2001 I expanded this further to include Claytor's only major tributary arm, Peak Creek. This resulted in 13 sites, for each of which one profile was taken to represent each 3.2 km stretch. I took measurements from the center of the reservoir or at the deepest spot within each transect, and usually between the hours of 1000 and 1400. A YSI model 58 dissolved oxygen meter was used for all measurements. The instrument was calibrated and the oxygen membrane was changed prior to each day's use. Readings were usually taken twice monthly, from July 2001 through December 2002, usually within one day of each tracking event. Temperature and DO were recorded to the nearest 0.1°C and 0.1 mg/L.

Because I only took one vertical profile from the deepest part of each transect, I tested if this "longitudinal habitat" could be applied to "transverse habitat" as well. To do this, I took vertical profiles on 7/16/02 at either 4 transverse positions (at dam and mile 2) or at 3 transverse

Figure 5. Water quality stations, at which vertical profiles (temperature, DO) were taken to evaluate available Claytor Lake habitat.

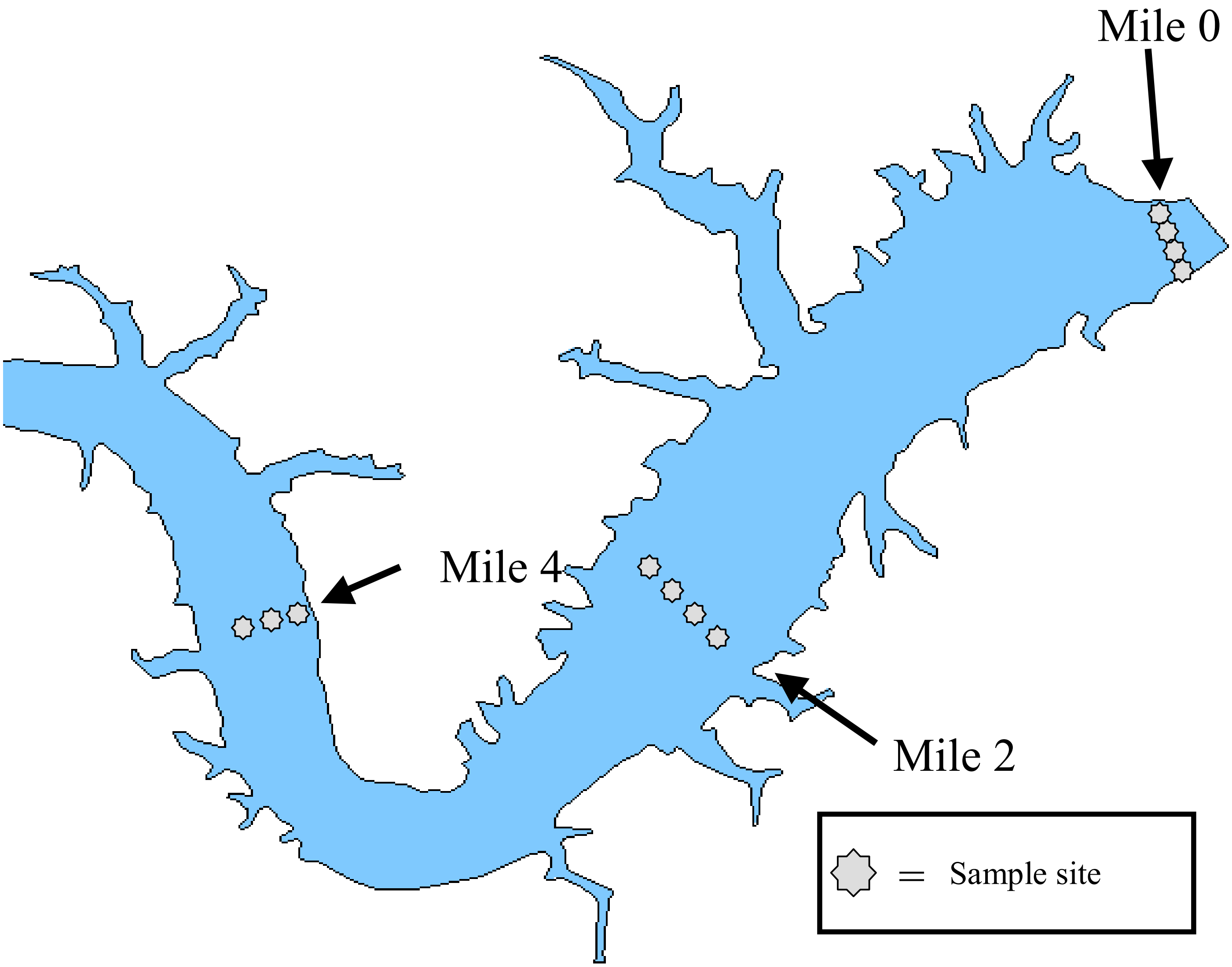


Figure 6. Profile locations for testing whether there is a position effect on temperature/dissolved oxygen profiles by depth at transverse sampling locations. Transverse sample sites were compared on 7/16/02 for depth-specific differences at miles 0, 2, and 4. The sample site at mile 2 was used on 7/26/02 to evaluate whether depth specific temperature and dissolved oxygen habitat changed throughout a single day.

positions (mile 4). Location for each transect was determined by measuring approximately across the inundated river channel and spacing transects equidistant from one edge of the river channel to the other (Figure 6). I tested the null hypothesis that there was no transverse position effect on vertical profiles (temperature and DO) at each depth and location by using multivariate analysis of variance (MANOVA). Of the four MANOVA statistic outputs, (Pillai's trace, Wilk's lambda, Hotelling-Lawley trace, and Tory's Maximum Root), Pillai's trace statistic is the best for general use and is considered the most conservative (Zar 1999). Therefore, Pillai's trace statistic was used to interpret MANOVA outputs. Each set of profiles was used to test if a profile taken at any position laterally to the reservoir flow describes the profile at any other position at that river mile and that depth.

Because profiles were also taken at different times of the day throughout this study, I tested to see if time of day influenced data. To do this, I took vertical profiles during three time periods on 26 July 2002, all from the centerline of the reservoir at mile 2 from Claytor dam. I took five samples at random times within each of the blocked time periods of 0900-1000, 1300-1400, and 1700-1800. I used MANOVA with Pillai's trace statistic to test the hypothesis that no time effect (morning, mid-day, and evening) exists when taking vertical profiles at one position in the reservoir.

I calculated habitat for the entire reservoir for each season by taking readings for each variable (temperature and DO) and weighting them by lake volume at each depth strata. Weighting measurements by lake volume is important for determining amount of fish habitat available in different seasons. For analysis of lake volume, I divided the reservoir into 14 cells, each cell being bound by each 2-mile transect established from water quality sites (Figure 7). Each cell was 3.2 km (2 miles) long, except for the cells at the upper end of the lake (from mile

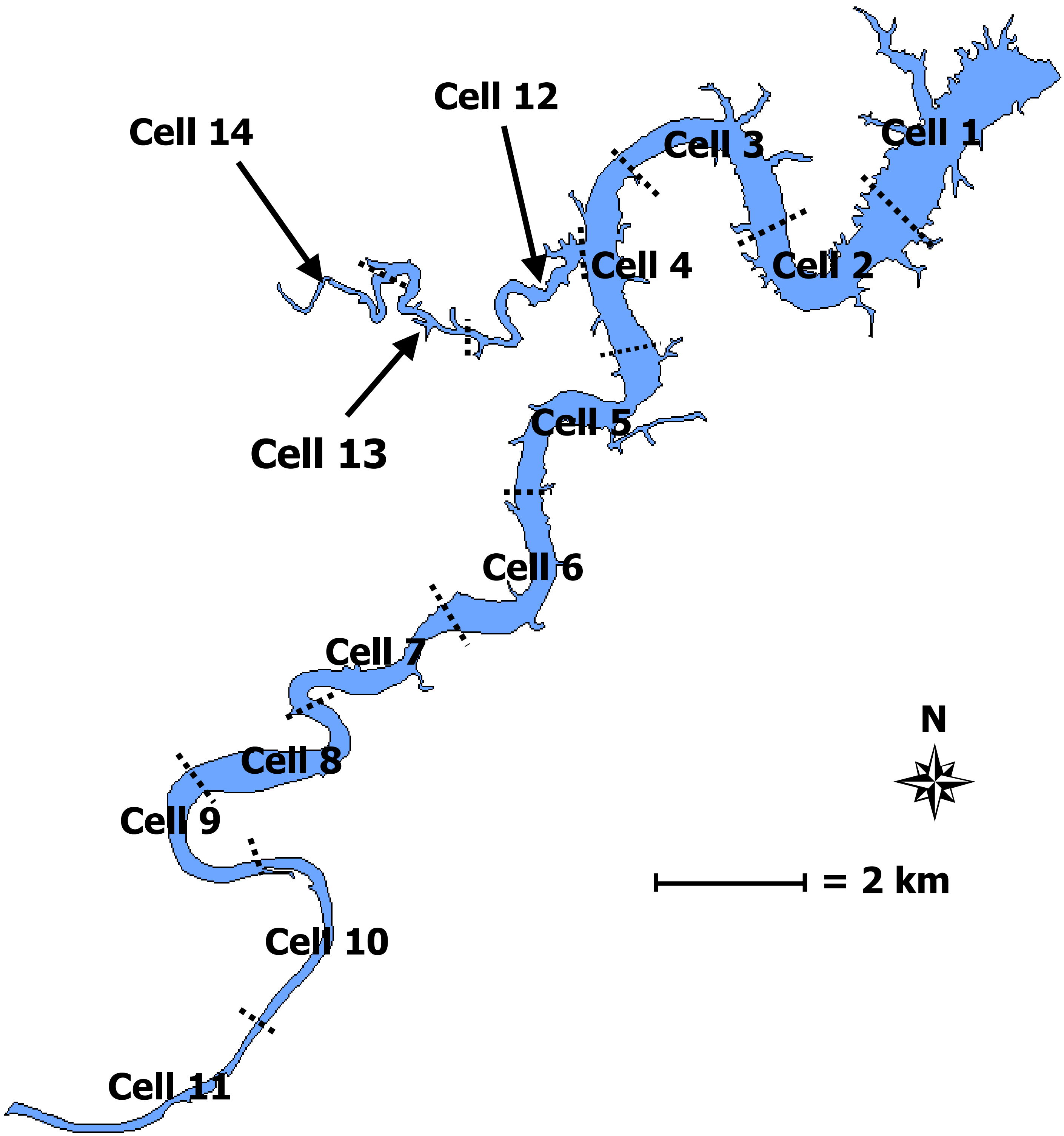


Figure 7. Claytor Lake "cells" for lake volume determination. Volume was determined within each cell to compare habitat volume for different areas of the reservoir.

20 to 21) and the upper stretch of Peak Creek that is still considered a part of Claytor Lake (approximately 1 mile). I calculated volumes for each cell from a depth contour map, provided by American Electric Power (AEP). I used a polar planimeter (Tamaya digital, model Planix 6) to calculate areas for each 2-m depth stratum and then I constructed hypsographs for each cell to determine volumes for each stratum (Cole 1994). I calculated the strata volumes as the first being depth contour 0-1 m and thereafter every 2 m. For each stratum, within each cell, I assigned a temperature and DO value. These data were then used to calculate by-volume (m^3) percentages of poor, suboptimum, and optimum habitats available during stratification.

Lake conditions vs. habitat use

I evaluated reservoir conditions versus habitat use for both STB and HSB by comparing temperature and DO at which tagged fish were located (via radio telemetry) with amount of corresponding lake habitat obtained (via vertical profiles collected as previously described). The Kolmogorov-Smirnov Goodness of Fit test (α=0.05) for continuous data (Zar 1999) was used to evaluate if fish habitat was distributed similar to lake habitat. For each tracking event, the distribution (temperature and DO) of habitat used by each species (HSB and STB) was tested against the distribution of temperature and DO at current reservoir conditions.

Habitat quality and HSI model development

I established habitat suitability index (HSI) curves by constructing suitability models similar to those used by Crance (1984). Crance (1984) provided guidelines for habitat suitability for inland populations of STB based on physical conditions of a body of water. These guidelines were based on mean daily water temperature at mid-afternoon (depth unspecified) and minimum DO concentration "near the surface" (specific depth unspecified). Temperature and DO were selected as the two habitat criteria, as both high temperatures and low DO are the most frequent problems to STB growth and survival (Axon and Whitehurst 1985). Although the HSI developed by Crance (1984) did not require temperature and DO use by individual fish to be factors in the model, it also did not address thermal refuge areas that STB are known to use. Therefore, I developed HSI models to be utilized with measurements taken from actual fish locations determined from biotelemetry studies.

I developed values for STB and HSB HSI models based on a compilation of data collected in biotelemetry studies of STB and HSB habitat use (Tables 4-7). I characterized habitat of temperature and dissolved oxygen by using the following categories: optimal, suboptimal, and poor. Poor habitat was determined as that avoided by fish, suboptimal was that determined by those studies where fish selected refugia for temperature or DO, when either temperature or DO suitability would have been minimized in another location. Preferred habitat was determined from studies that observed a broad range of temperature or DO conditions when the other was not limiting. For example, in a study conducted on Melton Hill Reservoir by Bettoli (2000), DO remained high (>5 mg/L) in temperatures ranging from 7-24°C, but STB selected seasonal temperatures averaging from 12.8-16.7°C. Therefore, in this study, DO availability did not constrain STB to any particular temperature and STB were free to actually select a preferred habitat (temperature).

Optimal temperature for STB is difficult to determine from many radiotelemetry studies, because most studies have been conducted in stratified reservoirs. Therefore, deeper, cooler areas of reservoirs are uninhabitable during the summer because of anoxic hypolimnions, and few studies have been able to estimate true temperature preferences. For instance, STB in Lake Whitney, TX were found to occupy water that was 26-27°C during the warmest months, but that

Table 4. References used to determine STB temperature delineations for development of a revised Habitat Suitability Index with the categories of optimal (selected for), suboptimal (selected for if only suboptimal and poor habitat was available), or poor (avoided by, or used as a last resort by fish).

Reference	Optimal (preferred)	Suboptimal (refuge)	Poor (avoided)
Bettoli (2000)	12.8-15.7°C		24°C
Bjorgo et al. (2000)		18-26°C	>27°C
Brashler et al. (1998)			29°C
Cheek et al. (1985)	18.0-20.0°C	23°C	25°C
Coutant (1985)			>25°C
Coutant (1990)	19.0-23.0°C	23-25°C	>25°C
Coutant and Benson (1990)	20-22°C		
Crance (1984)	18-24°C	24-30°C	>30°C
Erickson (1979)			26-30°C
Farquhar and Gutreuter (1989)		25-26°C	27-29°C
Hampton et al. (1988)		>25°C	
Hightower and Jackson (2000)		26°C	
Jackson and Hightower (2001)			27-28°C
Matthews et al. (1989)			>22°C
Moss (1985)		25-26°C	27°C
Poarch (1989)		20-22°C	
Schaffler and Isely (2002)	<24°C	24°C	
Schaich and Coutant (1980)	16-20°C		
Van Den Avyle and Evans (1990)	17-23°C		23-25°C
Van Horn et al. (1996)		20.0-26.1°C	
Waddle (1979)	18-22°C	22.1-26.9°C	27°C
Young and Isely (2002)	16.5-19.4°C		25.1°C
Zale et al. (1990)			27°C

Table 5. References used to determine STB DO. Delineations for development of a revised Habitat Suitability Index with the categories of optimal (selected for), suboptimal (selected for if only suboptimal and poor habitat was available), or poor (avoided by, or used as a last resort by fish).

Reference	Optimal (preferred)	Suboptimal (refuge)	Poor (avoided)
Cheek et al. (1985)		>4.0 mg/L	
Chittendon (1981)			<3.0 mg/L
Coutant (1985)	5.0 mg/L	>3.0-3.0 mg/L	<2.0 mg/L
Coutant and Benson (1990)		2.0-3.0 mg/L	
Crance (1984)	5.0 mg/L	2.5-5.0 mg/L	<2.5 mg/L
Hill et al. (1981)			<4.9 mg/L
Hightower and Jackson (2000)		>2.0 mg/L	
Jackson and Hightower (2001)		>2.0 mg/L	<2.0 mg/L
Matthews et al. (1985)			<0.5 mg/L
Schaffler and Isely (2002)			<2.5 mg/L
Xummers (1982)		>4.0 mg/L	
Van Horn et al (1996)		2.5-4.7 mg/L	
Young and Isely (2002)	5.0 mg/L	2.3-4.0 mg/L	<2.3 mg/L
Zale etl al (1990)		>2.0 mg/L	

Table 6. References used to determine HSB temperature delineations for development of a revised Habitat Suitability Index with the categories of optimal (selected for), suboptimal (selected for if only suboptimal and poor habitat was available), or poor (avoided by, or used as a last resort by fish).

Reference	Optimal (preferred)	Suboptimal (refuge)	Poor (avoided)
DeMauro (1990)	21.5-27°C	>21.5[1]°C	
Douglas and Jahn (1987)			>27°C
Muncy et al. (1990)			27-29°C
Phalen et al. (1988)	18-24°C	>24°C	27°C
Piner (1993)		32[2]°C	
Windham (1986)	18-24°C	26-28°C	28.5°C

[1]Tagged fish sought warmest available temperature when temp <21.5°C
[2]All tagged fish < 3 kg

Table 7. References used to determine HSB DO delineations for development of a revised Habitat Suitability Index with the categories of optimal (selected for), suboptimal (selected for if only suboptimal and poor habitat was available), or poor (avoided by, or used as a last resort by fish).

Reference	Optimal (preferred)	Suboptimal (refuge)	Poor (avoided)
DeMauro (1990)	>4.0 mg/L	2-4 mg/L	<2 mg/L
Douglas and Jahn (1987)	>4.0 mg/L		<2 mg/L
Muncy et al. (1990)	>4.0 mg/L		
Phalen et al. (1988)		<6 mg/L	
Piner (1993)	4-5 mg/L		
Windham (1986)		<4 mg/L	

was the coolest water available that still contained suitable (>4 mg/L) DO levels (Farquhar and Gutreuter 1989). This does not mean that STB *preferred* these temperatures, only that they were the best conditions available under the current conditions. Determination of temperature preference under laboratory conditions is difficult, however, due to the large size, pelagic nature, and potential bias of these studies. I am unaware of any such laboratory study dealing with adult (>2 years old) STB or HSB temperature preference.

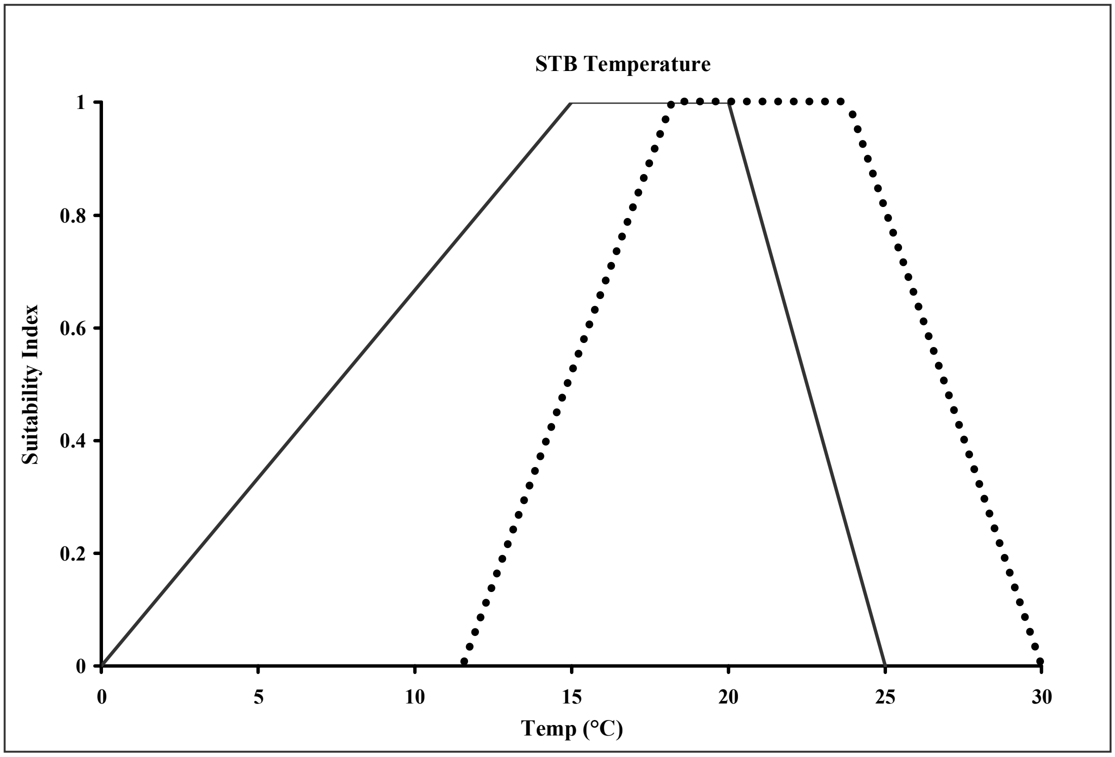
Crance (1984) first suggested the HSI model that included optimal temperatures of 18-24°C, suboptimal temperatures of 24-30°C, and poor habitat as >30°C. Although temperatures above 30°C may result in fish mortality (Crance 1984), several authors provide evidence that temperatures above 25°C are strongly avoided by adult STB (Cheek et al. 1985; Coutant 1985; Young and Isely 2002). Therefore, I used 25°C as the upper limit of my HSI curve for STB (Figure 8); temperatures above 25°C were defined as poor habitat.

Hartman and Brandt (1995) predicted adult (1.0 kg) optimal STB growth to occur at about 15.0°C. In a study conducted on the tailwaters of Norris Reservoir, TN (Melton Hill Reservoir), STB, even during the warmest summer months, had the opportunity to select temperatures from 11.0-25.0°C. Striped bass in this study selected mean temperatures during summer and fall from 15.3-16.7°C, which closely agreed with optimal habitat predicted by Hartman and Brandt (1995). Therefore, I selected 15.0°C as the low end of "optimal habitat" for the development of my HSI model. Cold water avoidance by STB is difficult to determine. During winter, STB seem to utilize warm-water discharges (Benson, 1988; Cheek et al. 1985; Poarch 1989). However, this may simply be in response to forage densities being higher in warmer water areas (Benson 1988). Therefore, I simply considered anything less than 15°C to be suboptimal.

Suboptimal, or thermal refuge areas are difficult to determine from radio-telemetry studies. For instance, Bjorgo et al. (2000), observed STB to stay in 18-26°C water to avoid warmer water temperatures (>26°C) in the Combahee River, South Carolina, but STB sought thermal refuge (22.0°C) when temperatures rose to above 23°C in Watts Bar reservoir, Tennessee (Cheek et al. 1985). Because I had established an upper boundary of >25.0°C (poor habitat) and optimal habitat as 15.0-20.0°C, I chose temperatures from >20.0°C to ≤25.0°C as suboptimal. This temperature range represents the descending slope on my HSI curve (Figure 8).

Similar to temperatures, optimal DO levels for STB are difficult to determine. I am unaware of any laboratory studies on adult STB and from telemetry studies it is difficult with which to determine actual preference. As much of the volume of cooler refuge habitat may be anoxic in summertime conditions, fish often seek a balance between temperature and dissolved oxygen (Cheek 1985). Therefore, DO used by telemetered fish may not represent true DO selection, but represents best habitat under current temperature and DO conditions. For instance, in Lake Norman, North Carolina, STB were found to tolerate water temperatures of 25.6-26.1°C in order to stay in water of >3.1 mg/L (Van Horn et al. 1996) This likely does not represent DO preference, however, as warmer (>27.0°C), well oxygenated water was available.

I used the DO criteria for my models originally proposed by Crance (1984) (Figure 8). Preferred DO levels of ≥5.0 mg/L have been supported by both Coutant (1985) and Young and Isely (2002). Although there is some variability among findings from telemetry studies, many authors have also documented avoidance by STB of DO levels of less than 2-3 mg/L (Chittendon 1971; Coutant 1985; Jackson and Hightower 2001; Schaffler and Isely 2002, Young and Isely 2002); thus, the lower limit of 2.5 mg/L set forth by Crance (1984) appears reasonable.



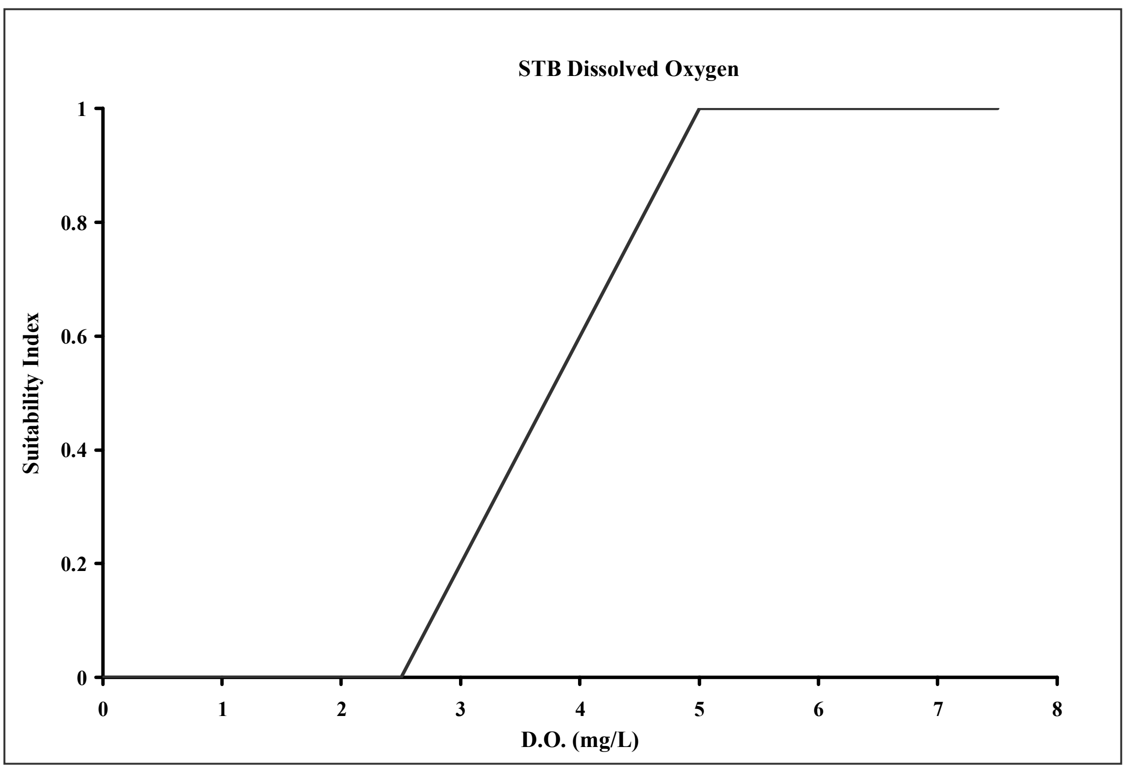


Figure 8. Adult STB habitat suitability curves. For comparative purposes, Crance's (1984) habitat suitability curve for temperature is shown as dashed line.

Therefore, the HSI model developed for STB DO habitat is optimal at ≥5.0 mg/L, suboptimal at ≥2.5 to <5.0 mg/L, and poor at <2.5 mg/L.

There is no HSI model developed for HSB. Therefore, I also developed HSB HSI models for both temperature and DO using the same methods used for STB (Figure 9). The habitat categories of optimal, suboptimal, and poor were also used for HSB.

Only one study (DeMauro 1990) documented actual avoidance of cool water (<21.5°C), so I chose this as my lower optimal HSB temperature. Upper optimal temperature has been documented as between 24°C (Windham 1986; Phalen et al. 1988) and 27°C (DeMauro 1990). However, the upper limit (27°C) is likely high, as Phalen et al. (1988) found that temperatures of >27°C were avoided by HSB. Therefore, I picked 25.5°C as my upper optimal temperature (the average between 24°C and 27°C). I modeled temperatures of >25.5°C and ≤27°C as suboptimal, and temperatures >27.0°C as poor. I considered anything less than 21.5°C to be suboptimal.

Many authors have documented DO preferences for HSB to be between 4.0 and 5.0 mg/L (Douglas and Jahn 1987; DeMauro 1990; Muncy et al., 1990; Piner 1993). Therefore, I selected optimal DO levels of ≥4.5 mg/L. Dissolved oxygen levels of <2 mg/L have also been found to be avoided by HSB (Douglas and Jahn 1987; DeMauro 1990). Therefore, I determined habitat to be poor at ≤2.0 mg/L, and DO levels of >2.0 to ≤4.5 mg/L as suboptimal.

Each fish observation was assigned an HSI score ranging from 0 to 1, according to the HSI models (Figures 8-9). Values of 0 represent poor habitat, values of 1 represent optimal habitat, and all intermediate scores were designated as sub-optimal. To evaluate time spent in each category (optimal, suboptimal, and poor), I used this HSI with all of my fish locations. Data were pooled by species and month to obtain average HSI values. To plot the change in habitat quality over the warmer months, I used my HSI models to determine by percentages the

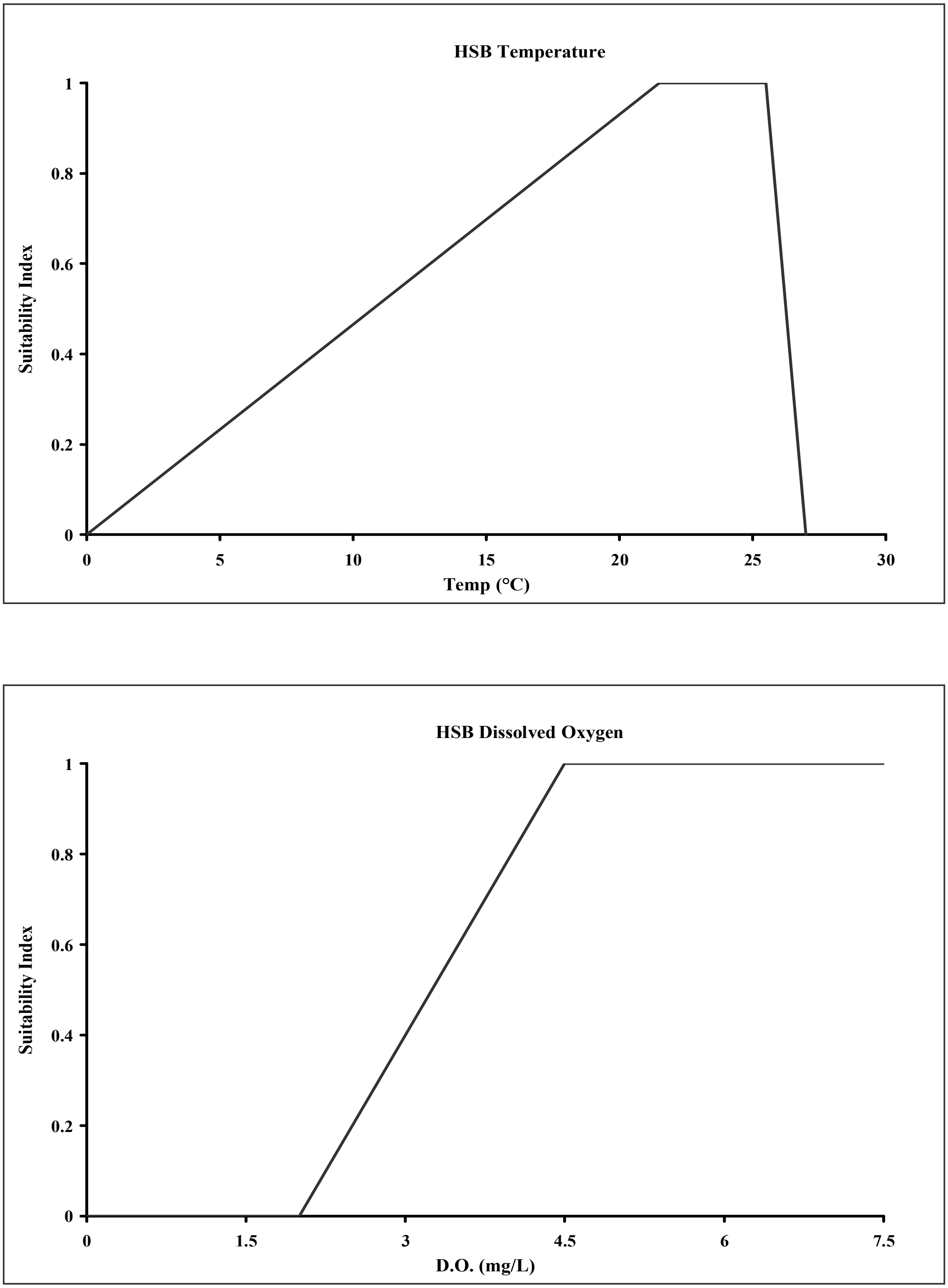


Figure 9. Adult HSB habitat suitability curves.

volume of water in each of the categories of optimal, suboptimal, and poor. The formulas used to calculate HSI scores are as follows for STB (Figure 8) and HSB (Figure 9);

Striped bass

Temperature

If temp <15°C, I considered the habitat suboptimal and used the following formula, as determined from the ascending slope of the model;

$$\mathbf{HSI_{STB\ temp}=0.0667*temp\ (°C)}$$

The formula was determined by the ascending slope of the model.

If ≤15°C≤ temp≤20°C, I considered the habitat optimal and assigned an H.S.I score of 1.0

If temp 20°C<temp≤25°C, I considered the habitat suboptimal and used the following formula, as determined from the descending slope of the model;

$$\mathbf{HSI_{STBtemp} = -0.2*temp\ (°C) + 5.0}$$

If temp > 25°C, I considered the habitat poor and assigned an HSI score of 0.0.

Dissolved Oxygen

If D.O. <2.5 mg/L, I considered the habitat poor and assigned an HSI score of 0.0.

If ≤2.5 mg/L≤ DO< 5.0, I considered the habitat suboptimal and used the following formula, as determined by the ascending slope of the model;

$$\mathbf{HSI_{STB\ DO} = 0.4*DO\ (mg/L) - 1}$$

If DO > 5.0 mg/L, I considered the habitat optimal and assigned an HSI score of 1.0.

Hybrid striped bass

Temperature

If temp <21.5°C, I considered the habitat suboptimal and used the following formula, as determined by the ascending slope of the model;

$$\mathbf{HSI_{HSBtemp}=0.0465*temp\ (°C)}$$

If 21.5°C≤ temp ≤25.5°C, I considered the habitat optimal and assigned an H.S.I score of 1.0

If temp 25.5°C< temp ≤27°C, I considered the habitat suboptimal and used the following formula, as determined by the descending slope of the model;

$$\mathbf{HSI_{HSBtemp}=-0.667*temp\ (°C) + 18.0}$$

If temp > 27°C, I considered the habitat poor and assigned an HSI score of 0.0.

Dissolved Oxygen

If DO <2.0 mg/L, I considered the habitat poor and assigned an HSI score of 0.0.

If ≤2.0 mg/L≤ DO< 4.5, I considered the habitat suboptimal and used the following formula, as determined by the ascending slope of the model;

$$\mathbf{HSI_{HSB\ DO}=0.4*DO\ (mg/L) - 0.8}$$

If DO > 4.5 mg/L, I considered the habitat optimal and assigned an HSI score of 1.0.

Dam operation effect on reservoir habitat

I used Onset® StowAway XTI temperature loggers (accurate from –4 to +37°C) to estimate temperature impacts from dam generation cycles on summertime lake habitat. From August 5-August 12, 2002, five loggers were suspended from the bouyline, located about 0.4 km in front of Claytor dam. They were attached to a rope at depths of 15-19 m, exactly 1-m apart.

Two diving weights were attached to the bottom logger to keep the rope vertical. During the course of this data collection, the turbines of Claytor dam were operated under auto-cycle conditions, generating for 21 minutes from the top of each hour, followed by 39 minutes of inactivity (Theresa P. Rogers, American Electric Power, personal communication). Loggers recorded temperature every 5-min. ANOVA was used (α=0.05) to determine if dam operation had an impact on reservoir temperature distribution.

Tailrace occupation and emigration

Attempts were made to both locate any fish that may have migrated through Claytor dam and to tag fish with internal anchor tags by electrofishing in the tailrace area of the New River below Claytor Lake. The entire tailrace area, from the base of the dam to the first set of riffles downstream (about 2 km), and from the mouth of the Little River to the Little River dam (about 1 km) was electrofished on six occasions, from April-June 2001. However, only on one occasion (5/9/01) were fish (one STB; 92.7 cm TL and eight HSB; 45.1-61.6 cm TL) captured for internal anchor tagging.

In the spring of 2002, I again attempted to capture fish from the tailrace area for tagging and possibly identify any fish that were tagged in the reservoir and had emigrated through Claytor dam. Again, few fish were collected and I only internal anchor tagged twelve HSB (32.4-58.1 cm TL) and two STB (57.8-63.2 cm TL). Of these fish, both STB and 8 of the HSB were implanted with internal implant radio tags, similar to the ones used in the reservoir. The tailrace was subsequently tracked once a month from May-December, 2002 to determine if these fish remained in the tailrace, and for how long.

Exploitation

I tagged both STB (n=82, 21-94 cm TL) and HSB (n=390, 25-79 cm TL) from Claytor Lake (Figure 10) with internal anchor tags, using the tagging methods described above. Fish were collected via electrofishing, gillnets, and angling. Internal anchor tags were used because of their superior retention, as compared to other tags (Bonner 1965; Henderson-Arzapalo et al. 1995). I estimated rates of fishing mortality for each species from tag returns over the course of this study. Rewards ranging from $5 to $50 were offered, and signs were posted at local tackle shops, at Claytor Lake State Park, and at boat launch areas (Figure 11).

To estimate non-reporting rate, I used window tags (n=100) (Zale and Bain 1994), printed with similar information as reported on signs and reward tags (Figure 12). Each yellow 3 in. x 5 in index card was assigned a random number and were distributed at Claytor Lake boat ramps (State Park, Dublin ramp, DeHaven Park, Allisonia, and Lighthouse bridge). On dates that I visited boat ramps, all vehicles with empty boat trailers were given a window tag, placed under the driver side windshield wiper. The correction factor derived from window tag returns was applied to actual reported tags to correct for non-reporting rates from fishermen who caught but did not report tagged fish.

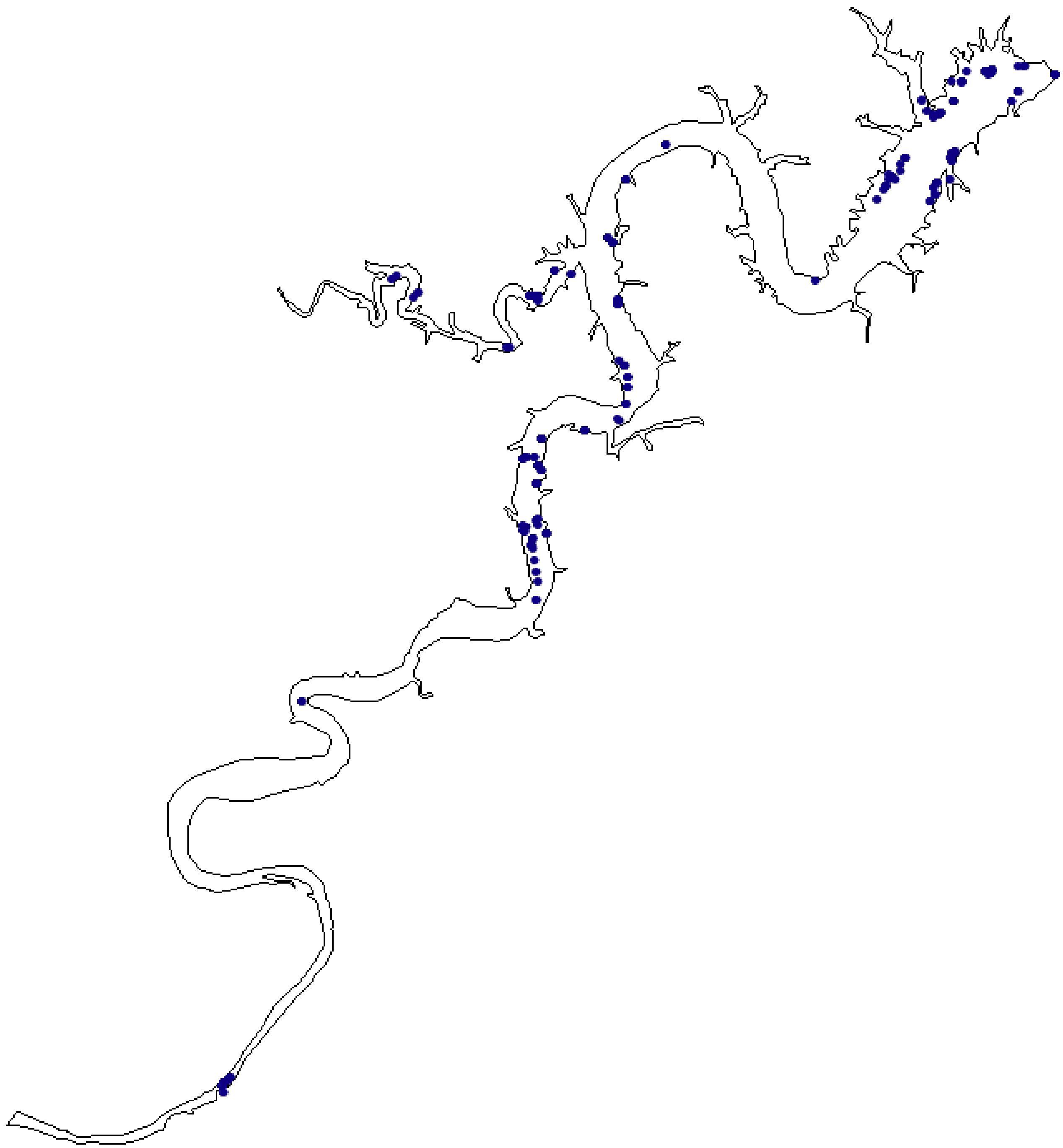


Figure 10. Capture/release sites for STB and HSB tagged with internal anchor tags, 2001 and 2002. Each site may represent multiple captures.

$ $ $ REWARD $ $ $

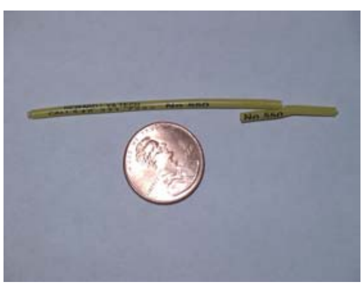
STRIPED BASS and **HYBRID STRIPED BASS** have been tagged in Claytor Lake and the Claytor Lake tailwater area! Rewards of $5 to $50 are being offered to anglers who catch these fish and report the tags to VIRGINIA TECH or VIRGINIA DEPARTMENT OF GAME AND INLAND FISHERIES biologists. Information necessary to receive rewards include:

TAG NUMBER
LENGTH OF FISH
WHERE FISH WAS CAUGHT (APPROXIMATE)
IF FISH WAS RELEASED OR HARVESTED

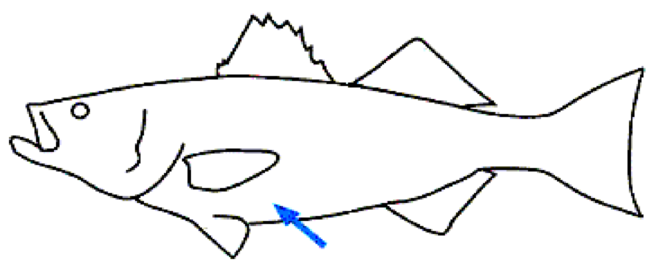
If a tagged fish is encountered, call **(540) 231-7292** with the required information, or write to:

John Kilpatrick
Department of Fisheries and Wildlife Sciences
100 Cheatham Hall
Virginia Tech
Blacksburg, VA 24061

Tag Size



Tag Location



***Fish do not have to be harvested to receive reward. If fish is to be released, simply report tag #.**

Figure 11. Reward notification sign posted at Claytor Lake boat launch areas, nearby tackle shops, and Claytor Lake State Park.

Attention Anglers

Reward !!!

Return this card or call Virginia Tech to receive a reward ranging from $5 to $50. This is part of the striped bass / hybrid striped tagging project VA Tech and VDGIF is conducting on Claytor Lake. For reward, call **540-231-7292** with information on back of card, or simply return card to Department of Fisheries and Wildlife Sciences

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Name__________________
Address______________________
City________State__Zip___
Phone______

Did you already know about this tagging project?_____

Have you ever caught a tagged striped bass or hybrid striped bass?_____________
If yes, did you return the tag?__________

Thank you for your assistance!

Figure 12. Window tags (front and back) used to estimate non-reporting rates.

RESULTS

Movement

During this study, STB in Claytor Lake exhibited both a spring and fall up-lake migration, but inhabited the lower end of the reservoir during the warmer months (Appendix 1). During spring of 2001, STB occupied primarily the lower end of the reservoir, but were found as far as 11 km from the dam (Figure 13). Fish occupation of the upper end of the reservoir was likely not detected, as sampling began in May of 2001 and I likely missed the spring spawning migration. By late spring, all STB were found below Clapboard Hollow in the lower half of the reservoir, where they remained throughout the summer months (Figure 14). In the fall of 2001, STB began to migrate up lake (Figure 15). However, by late fall 2001, STB were mostly in the lower half of the reservoir, although some fish were found in Peak Creek (Figure 16). Tagged STB were found only in the lower half of the reservoir during early winter (Figure 17), but were at an apparent staging location in February (Figure 18). In late winter and early spring, STB began to migrate up lake and into Peak Creek (Figure 19). By mid-spring 2002, fish had returned again to the lower end of the reservoir (Figure 20). All tagged STB were located in the lower half of Claytor Lake during the summer of 2002 (Figure 21). In fall 2002, fish again dispersed throughout the reservoir, including Peak Creek (Figure 22). Striped bass remained dispersed until the conclusion of this study in December 2002. Striped bass were often found in close proximity to the shoreline (Figure 20), and were often found in close association with underwater islands or extended flats near shore.

Hybrid striped bass in Claytor Lake had seasonal movement patterns similar to those of STB, exhibiting an upstream springtime migration, but remaining in the lower half of the reservoir throughout much of the year. In spring of 2001,. tagged HSB were found in

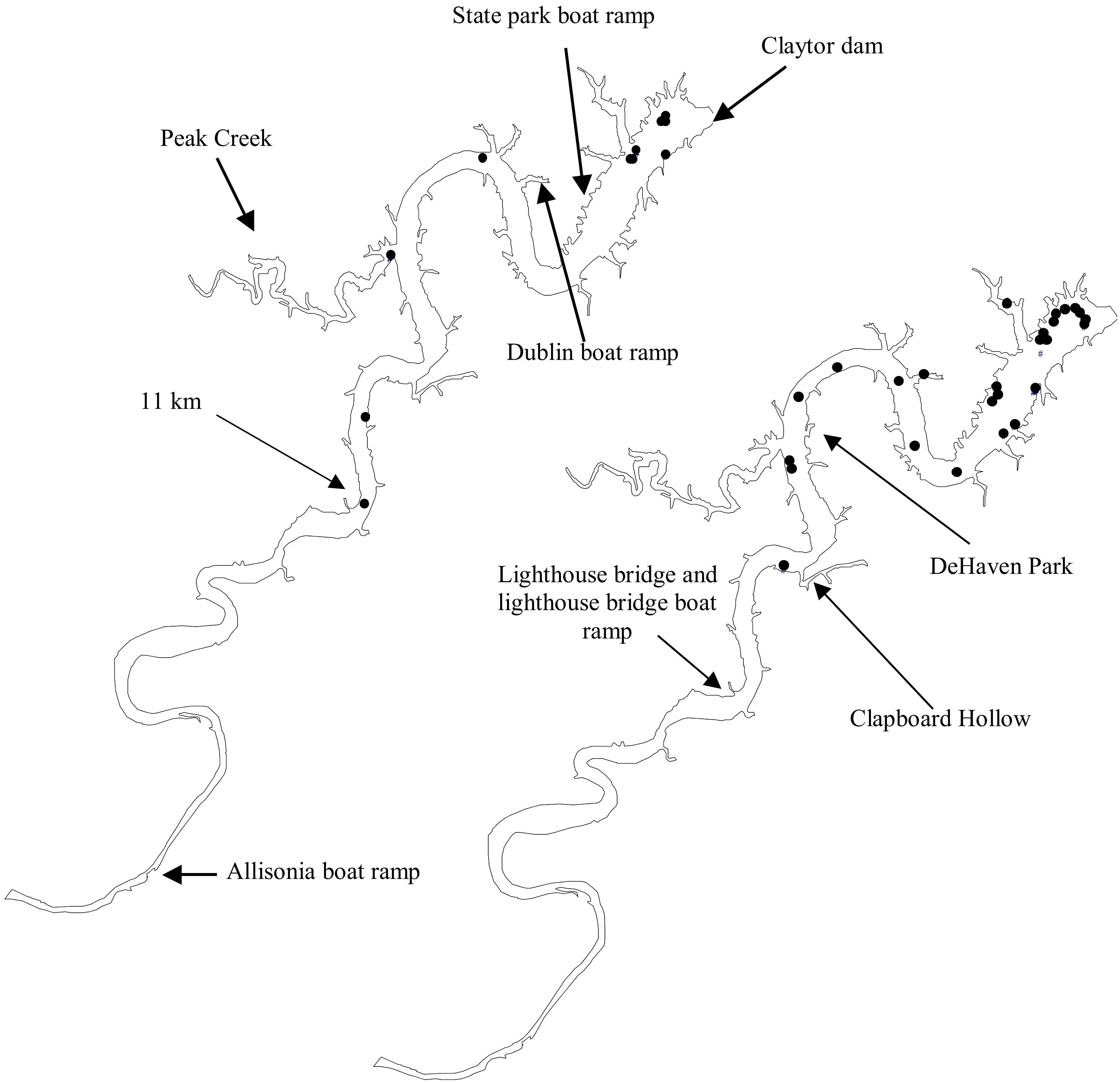


Figure 13. Striped bass (left) and hybrid striped bass (right) locations May 2001.

Figure 14. Striped bass (left) and hybrid striped bass (right) locations August 2001.

Figure 15. Striped bass (left) and hybrid striped bass (right) locations September (STB) and August (HSB) 2001.

Figure 16. Striped bass (left) and hybrid striped bass (right) locations November 2001.

Figure 17. Striped bass (left) and hybrid striped bass (right) locations January 2002.

Figure 18. Striped bass (left) and hybrid striped bass (right) locations March 2002.

Figure 19. Striped bass (left) and hybrid striped bass (right) locations May 2002

Figure 20. Striped bass (left) and hybrid striped bass (right) locations June 2002

Figure 21. Striped bass (left) and hybrid striped bass (right) locations August 2002

Figure 22. Striped bass (left) and hybrid striped bass (right) locations October 2002.

the lower end of the reservoir (Figure 13). Tagged HSB remained in the lower end of the reservoir throughout the summer months (Figure 14). In the fall of 2001, HSB demonstrated an upstream movement (Figure 15). Hybrid striped bass remained dispersed throughout the lower end of the reservoir throughout the winter (Figure 17), but were moved to about the middle of the reservoir in late February, in an apparent pre-spawn staging pattern. In late winter/early Spring, HSB were found in the upper end of Claytor Lake and two fish were found in Peak Creek (Figure 18). By mid-spring 2002, most HSB were in the lower 1/3 of the reservoir, although a few fish remained in the upper 1/3 of Claytor Lake and in Peak Creek (Figure 19).   By late spring, all fish were found in the lower 1/3 of the reservoir, and many HSB were found within 1.6 km of the dam (Figure 20). Fish remained in the lower reservoir through late summer, although they were no longer were located in close proximity to the dam (Figure 21). Tagged HSB were found throughout most of the lower 12 km of Claytor and in Peak Creek in October 2002 (Figure 22). Hybrid striped bass remained dispersed until the conclusion of this study in December, 2002. Similar to STB, HSB were often found in close association with underwater islands or extended flats near shore (Figure 13).

The movement patterns and seasonal locations of both STB and HSB were similar. Although I was unable to document exactly when spawning took place for either STB or HSB, the timing at which they migrated upstream in the spring of 2002 was approximately the same (during March, 2002, when surface water temperatures were about 9-10°C). I did not detect any fish that migrated out of the reservoir and into the upper New River, although I searched the New River in April of 2002 from the upper end of Claytor Lake (Allisonia) to Buck Dam, a distance of about 37 km. This stretch was searched by driving along the New River Trail with the antenna pointed at the nearby river

Without considering the depth component, the horizontal locations of each species closely approximate one another (Appendix 1). During the warmest months of July and August of 2001, few fish were found above Peak Creek, and only on two occasions were fish found above Clapboard Hollow. However, during August of 2002, most HSB and even STB were found above Peak Creek, with one STB being found actually in Peak Creek. During summer stratification in 2001 and 2002, both STB and HSB utilized the area of the lake close to the dam during May-July. However, during August-September of 2001, fish were above about 3 km from Claytor dam. During August of 2002, both HSB and STB were mostly located about 6 km above.

Biological centers of activity and utilization distributions

There was little evidence to suggest defined BCA for either STB or HSB in Claytor Lake (Appendix 2). Seasonal pooled STB utilization areass (95% kernel estimated areas) did not statistically differ between seasons (n=59; df=6; F=2.00; P=0.083). Hybrid striped bass also did not differ seasonally between their pooled utilization distribution areas (n=94; df=6; F=1.98; P=0.078). The kernel-estimated BCA was less for both STB and HSB when only using data from only one season of observations (Figures 23-24). Although utilization distribution sizes did not differ between seasons for STB or HSB, actual locations of fish did vary, with fish being found in lower stretches of the reservoir during summer and upper sections in the fall and spring.

When seasonal utilization distribution comparisons between species were made, STB utilized larger areas than HSB only in the summer of 2001 (Table 8). While there was no statistical difference (n=59, df=23, F=1.41, P=0.18) in utilization distribution total area (m^2) used by individual STB, actual fish locations within the reservoir did vary somewhat among

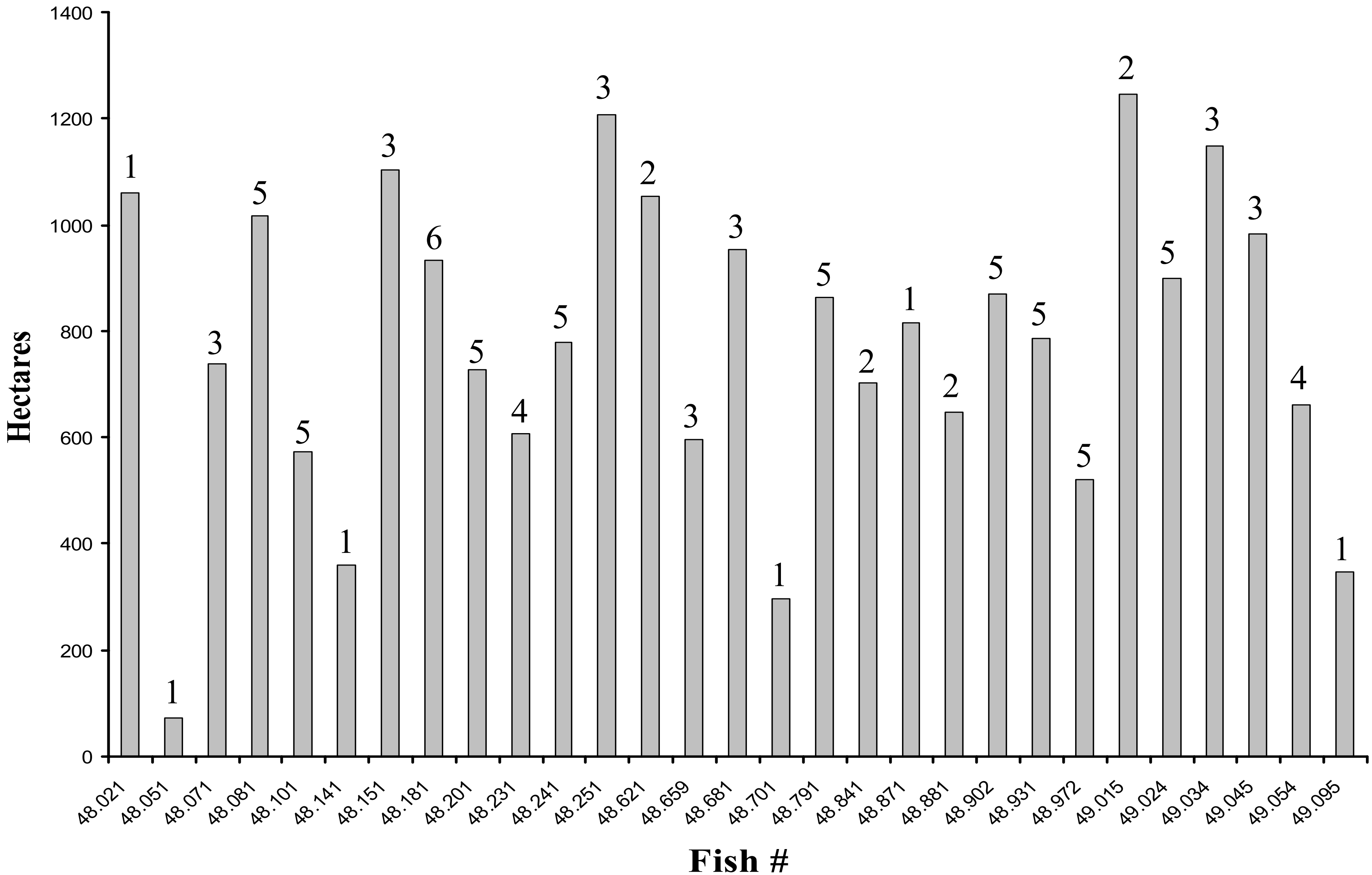


Figure 23. Individual HSB utilization distribution areas. Number of seasons each fish was observed is listed above bars.

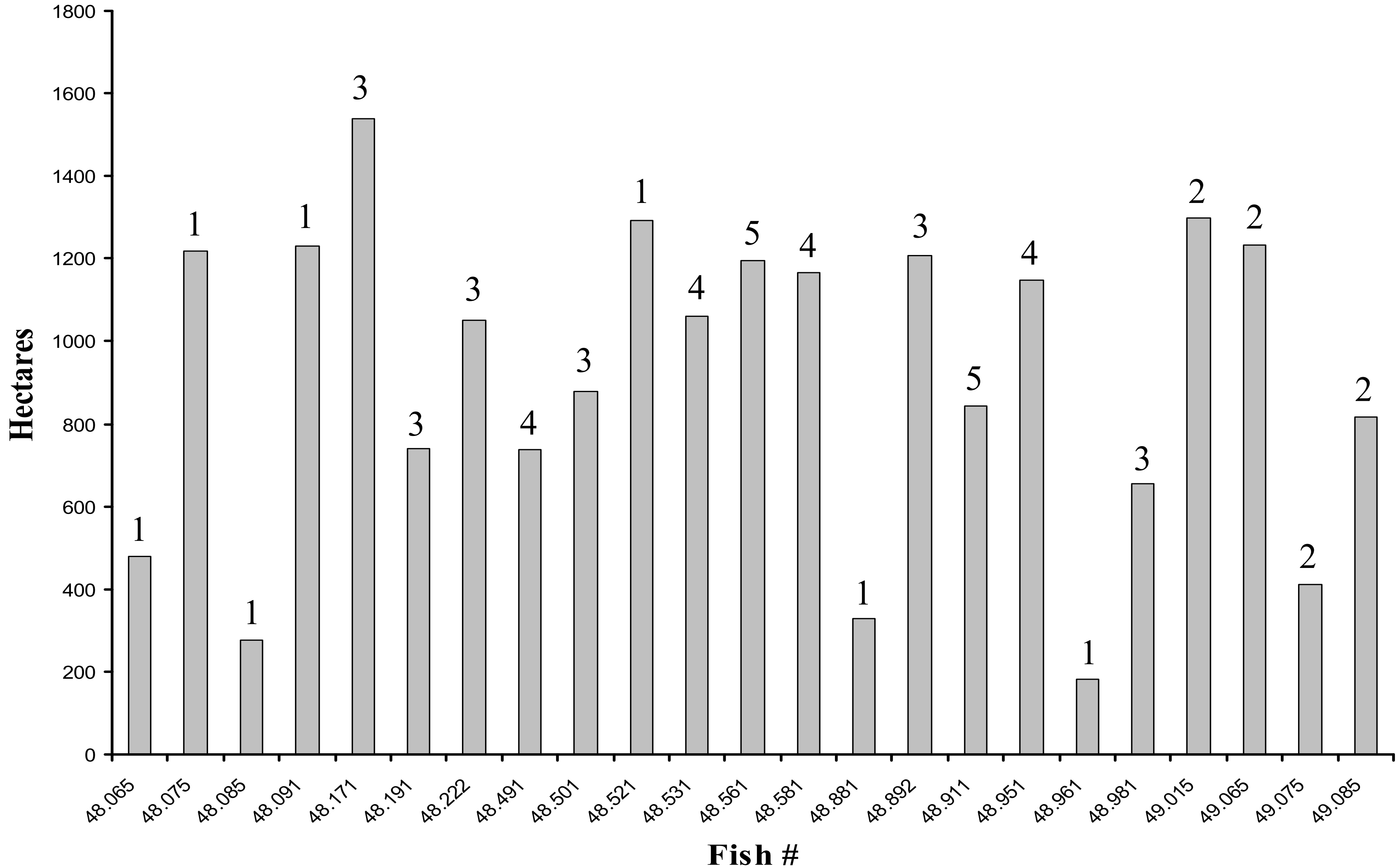


Figure 24. Individual STB utilzation distribution areas. Number of seasons each fish was observed is listed above bars.

individuals, suggesting that individual fish do occupy at least general areas of Claytor Lake differently (Figure 25). Similarly, HSB differed in their locations among individual fish (Figure 26), suggesting some independence in movement and habitat use between different fish of the same species. However, HSB also did not differ in utilization distribution areas (ha) of individuals (df=28, F=1.07, P=0.40) or STB (df=23, F=1.41, P=0.18). Hybrid striped bass exhibited a larger difference from largest (1245 ha) to smallest (72 ha), whereas STB had a smaller difference between largest (1234 ha) and smallest (482 ha) utilization distributions. It is also apparent that different individuals utilize different areas of the reservoir, but may simply travel through some sections to move from one area to another (e.g., the separation between 95% use areas; Figures 25-26).

Striped bass minimum movement, defined as shortest straight line swimming distance between successive dates for each fish , differed among seasons (n=304; df=6; F=5.00; P<0.01). The largest mean STB minimum daily distance moved was in the Spring of 2001 (756.5 m/day), while the least distance moved was in the Summer of 2002 (256.5 m/day) (Table 8). Hybrid striped bass minimum movement did not statiscally differ between seasons (n=487; df=6; F=2.00; P=0.06). The largest mean minimum daily distance moved for HSB was in the summer of 2001 (484.9 m/day) while the smallest difference moved was fall of 2002 (256.5 m/day) (Table 8).

Diel movement

I had difficulty trying to track multiple fish in one 24-hour period; many fish disappeared for periods of time, it took more than one hour to find every fish, and, as fish traveled sometimes in opposite directions, it proved unreasonable to try to find more than one fish per hour.

Therefore, my data includes STB (n=3) and HSB (n=2) that I reliably located every hour for a period of 24 hours. This included the time period from June-October 2002.

In general, fish traveled in a circular pattern over diel periods; they exhibited either an upstream or downstream movement during evening, stayed in one general area overnight, and moved to a new area during morning, generally traveling back the direction they started from the day before (Figures 27-31). This was important to note, as even daily radio-tracking would have seriously underestimated the minimum hourly movement made by both STB and HSB if fish were found close to the same location each day, but had traveled to a new location and returned again in between tracking events.

Hourly movement rates averaged 237-276 m/h for STB and from 313-425 m/h for HSB (Table 9). There was no difference in hourly movement rates between STB and HSB (df=1, n=120, F=0.64, P=0.43). There was also not a difference in movement rates between daytime (0800-2000) and nighttime (2000-0800) for either STB (n=72, F=2.15, P=0.15) or HSB (n=48, F=5.14, P=0.28). Crepuscular movement rates were higher than other time periods for HSB (467 m/h (SE=119 m/h) crepuscular, 216 (48) m/h during day/night) (F=5.14, P=0.03) but were similar for STB (501 (172) m/h crepuscular, 296 (48) m/h during day/night) (F=2.15, P=0.15).

Habitat use

The patterns of summer stratification differed between 2001 and 2002 in Claytor Lake and STB and HSB seemed to respond. Stratification during August of 2001 provided coolwater refuge areas (<25°C) with DO levels of >5.0 mg/L, whereas stratification during August of 2002 left water that was <25°C devoid of DO and thus uninhabitable (Figure 32). My radio-telemetry equipment was unable to consistently locate fish that were deeper than about 17 m. Therefore, fish that inhabited the coolwater refuges available in 2001 were not successfully located for up to

Table 8. Comparisons of minimum daily movement and home ranges by seasons for STB and HSB in Claytor Lake, Virginia

	Minimum daily distance (m/d)						Utilization distribution (ha)						
	STB			HSB			STB			HSB			
	N[1]	Mean	SE[2]	Mean	SE	P-value[3]	Mean	N[5]	SE	Mean	N	SE	P-value[4]
Spring 01	90	756.5	134.7	384.4	58.2	**<0.01**	865.1	6	151.2	505.7	8	98.6	0.06
Summer 01	86	1506.1	104.7	484.9	55.8	0.68	1191.8	4	170.7	702.8	8	132.2	**0.04**
Fall 01	98	181.1	44.9	256.5	35.6	0.74	988.2	7	116.5	828.2	14	93.5	0.32
Winter 02	98	496.5	102.0	340.2	57.1	0.07	1305.5	9	65.7	968.8	14	137.4	0.08
Spring 02	180	325.6	37.8	406.5	47.8	0.25	763.0	14	108.8	756.5	22	80.7	0.96
Summer 02	128	246.7	33.6	287.8	27.8	0.52	1076.0	9	143.5	806.0	18	97.4	0.13
Fall 02	115	365.0	61.4	274.3	55.7	0.91	836.6	10	205.4	1039.1	10	77.9	0.38

Table 9. Average hourly movement rates for STB and HSB

Species (Fish Number)	Mean hourly movement (m/h)	Standard error	Minimum/Maximum hourly movement
HSB (48.021)	261	63	0-1093
HSB (48.071)	276	71	0-1377
STB (48.171)	237	37	27-756
STB (48.561)	313	74	28-1681
STB (48.881)	425	119	17-1865

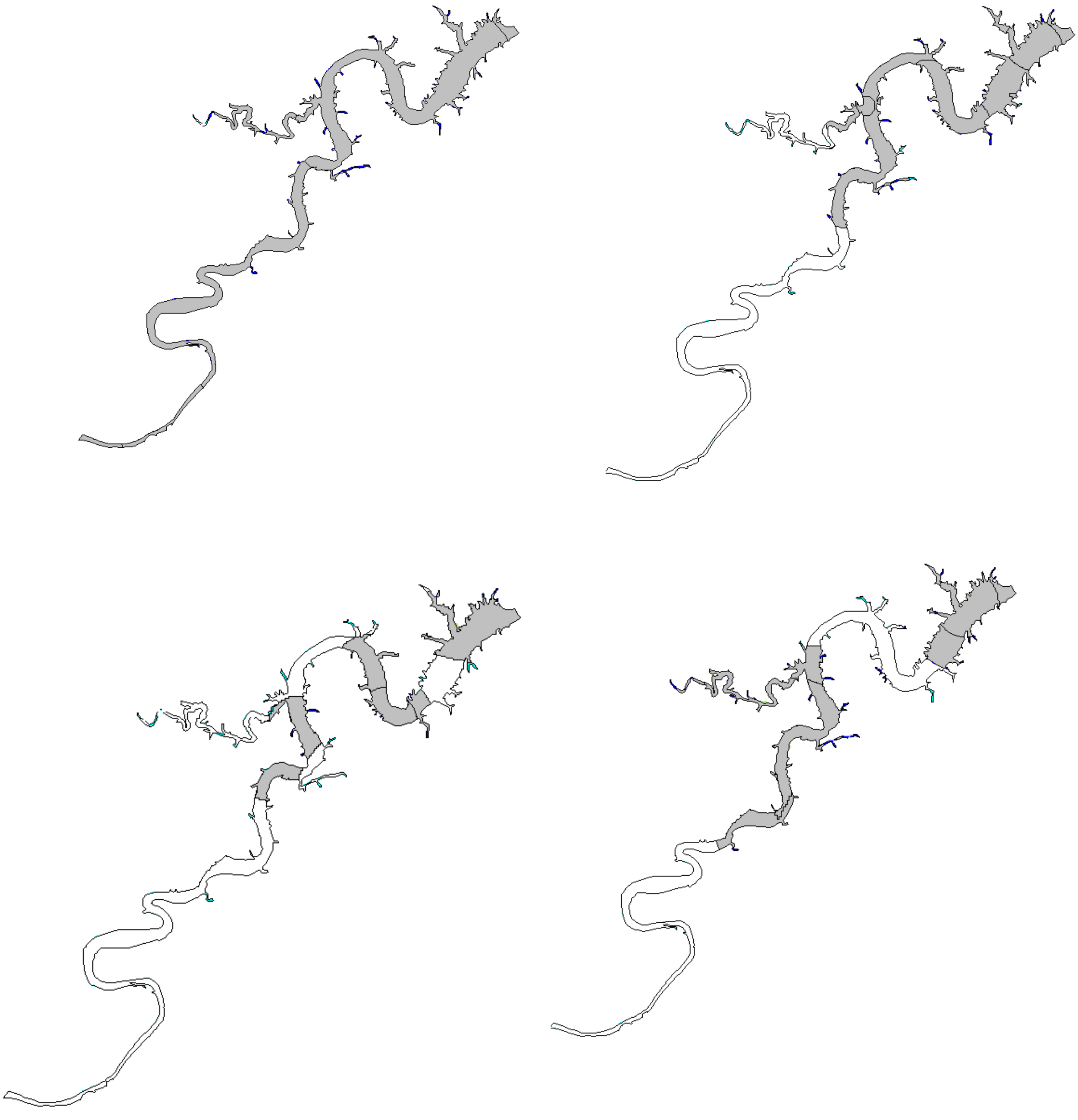


Figure 25. Utilization distribution areas for STB tracked during Spring-Fall, 2002. Fish number and number of times located during this time period clockwise from upper left include fish numbers 48.171 (n=15), 48.191 (n=14), 48.501 (n=16), and 48.881 (n=12). Shaded areas represent 95% kernel estimated confidence bounds.

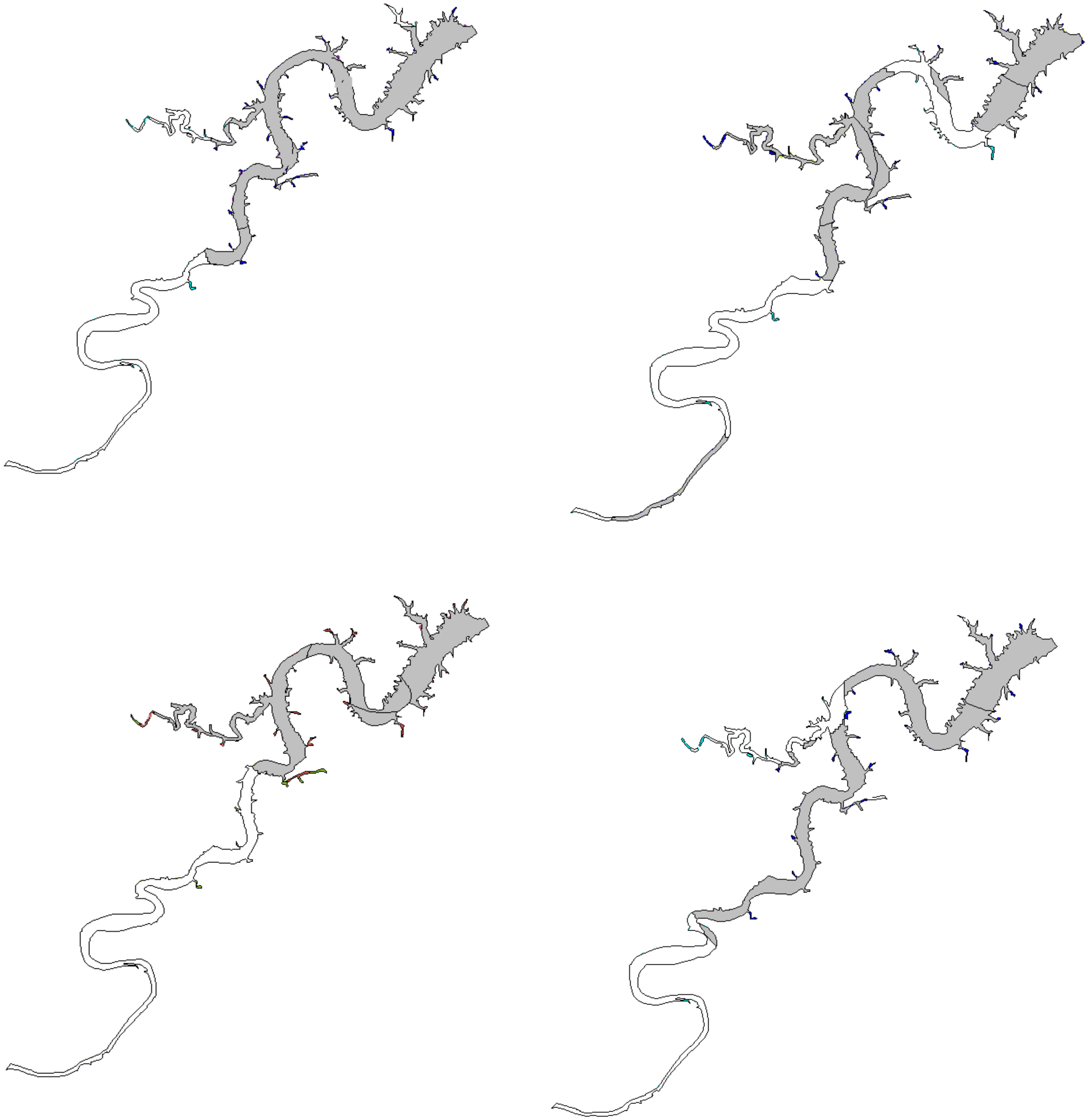


Figure 26. Utilizaztion distribution areas for HSB tracked during Spring-Fall, 2002. Fish number and number of times located during this time period clockwise from upper left include fish numbers 48.151 (n=16), 48.251 (n=13), 48.681 (n=12), and 49.045 (n=16). Shaded areas represent 95% kernel estimated confidence bounds.

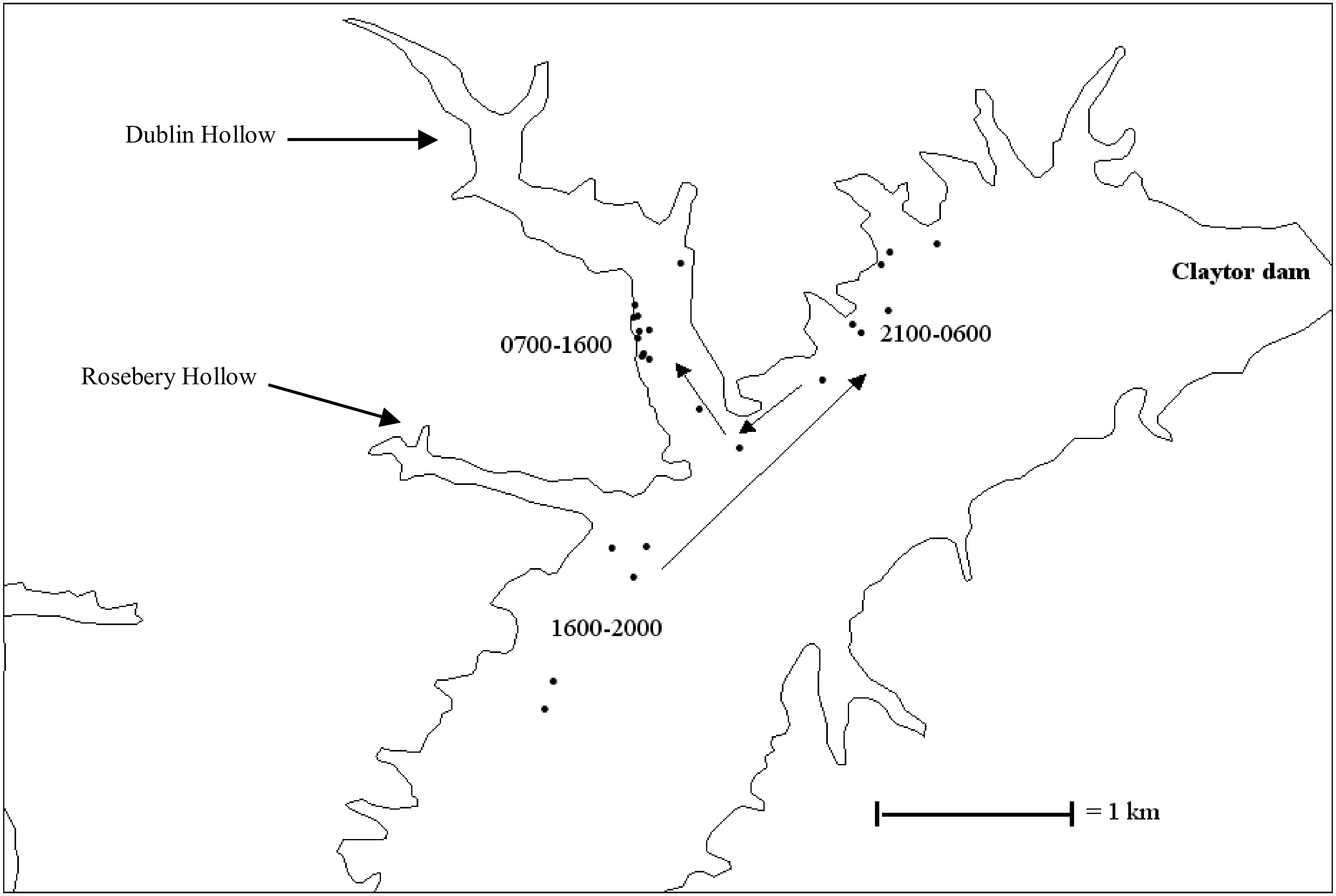


Figure 27. Diel movement from HSB #48.021. Fish was tracked hourly from 1600 on 6/17/02 to 1600 on 6/18/02.

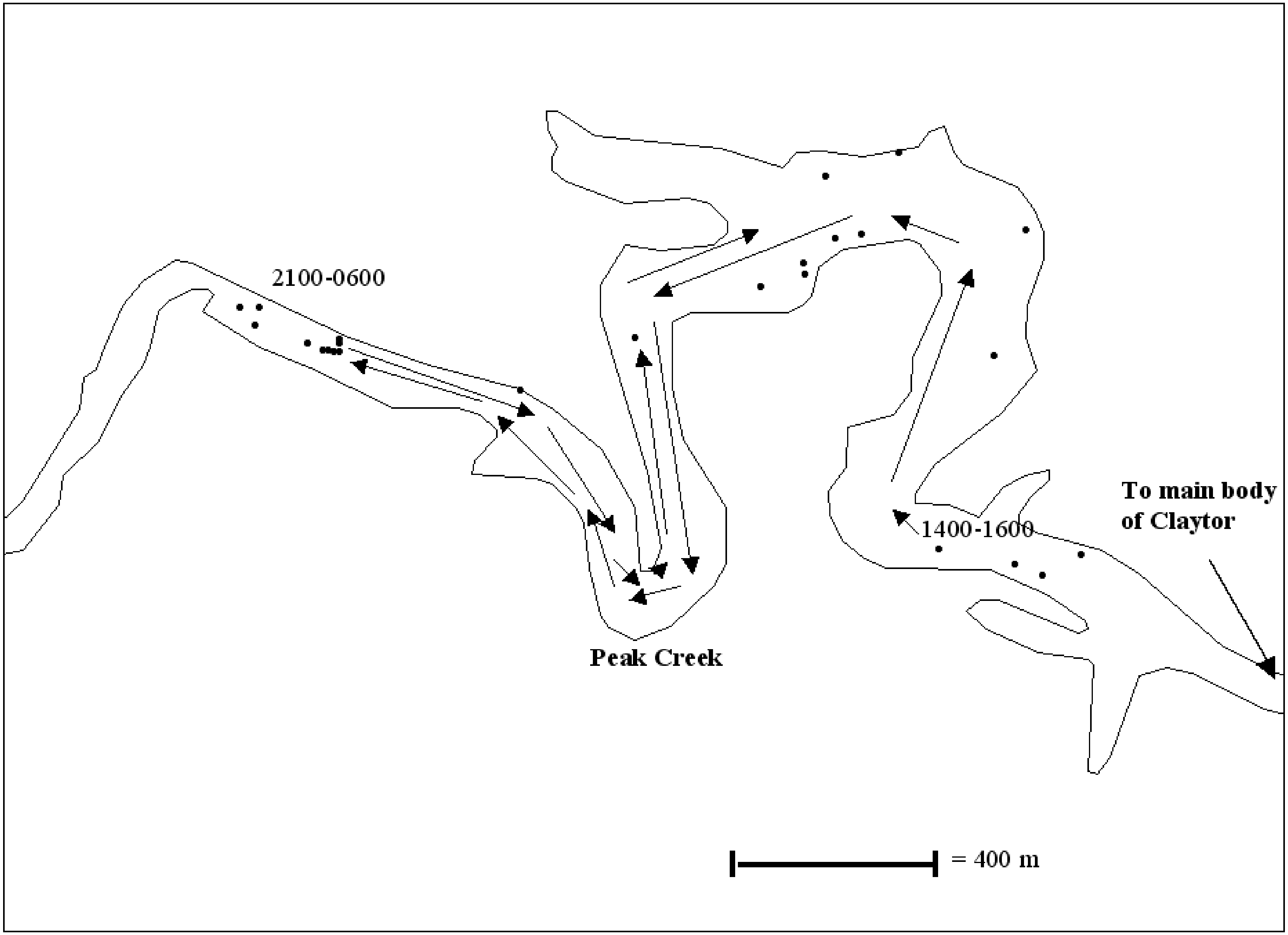


Figure 28. Diel movement from HSB #48.071. Fish was tracked hourly from 1400 on 10/14/02 to 1400 on 10/15/02.

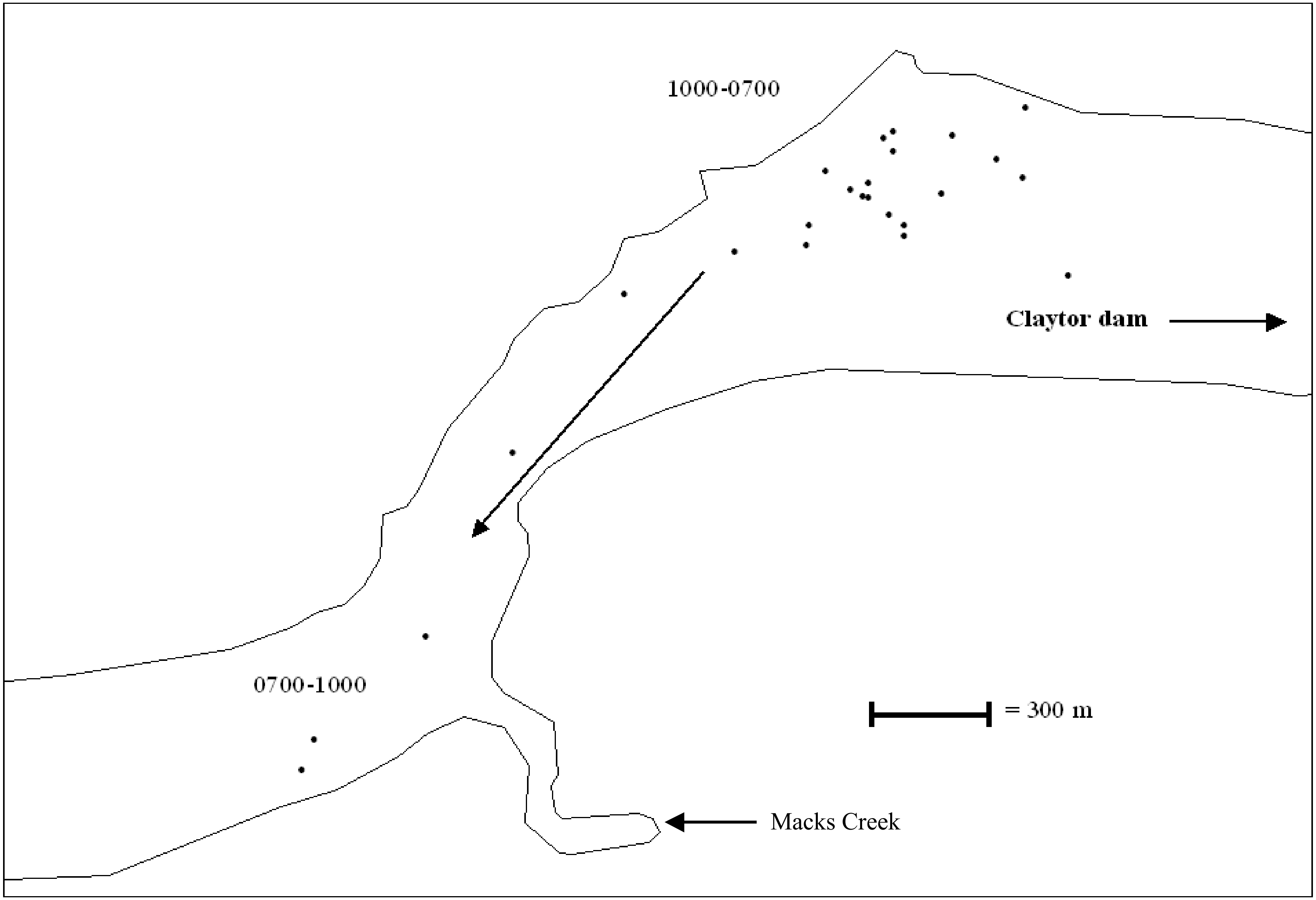


Figure 29. Diel movement from STB #48.171. Fish was tracked hourly from 1000 on 9/16/02 to 1000 on 9/17/02.

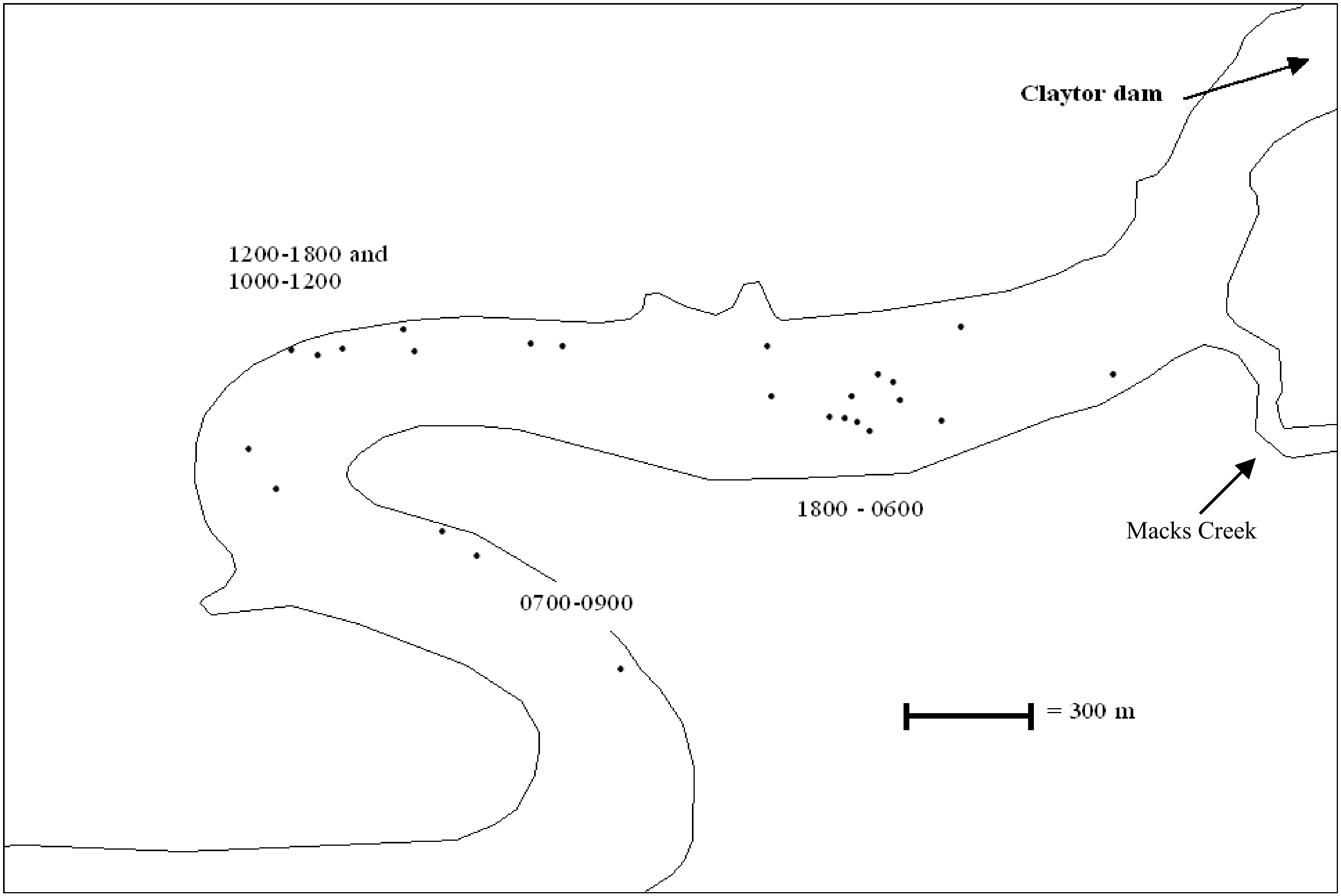


Figure 30. Diel movement from STB #48.561. Fish was tracked hourly from 1200 on 10/28/02 to 1200 on 10/29/02.

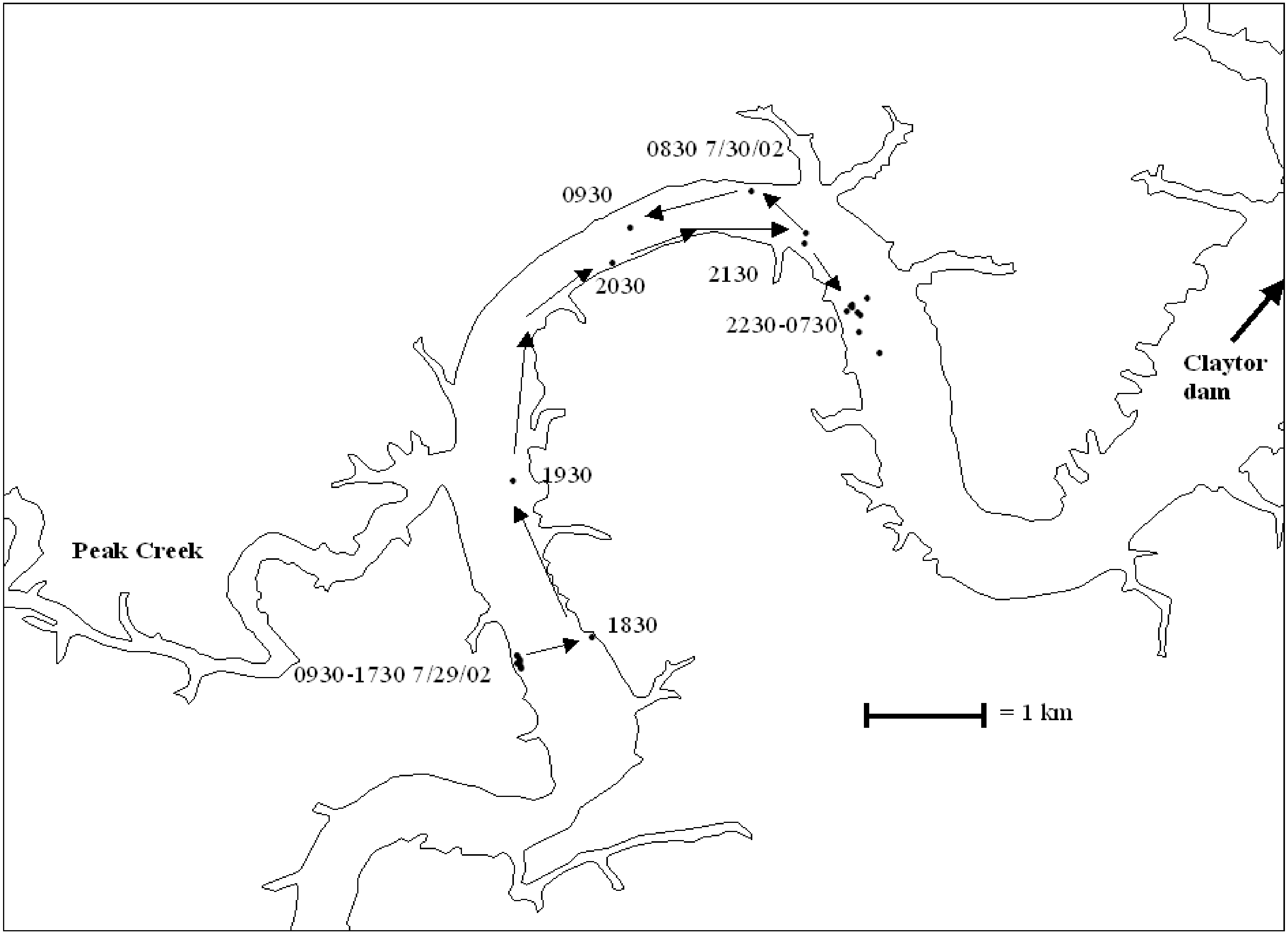


Figure 31. Diel movement from STB #48.881. Fish was tracked hourly from 0930 on 7/29/02 to 0930 on 730/02.

3 months. During this time period, STB became increasingly difficult to find, but readings from the boat-mounted sonar and reports from fishermen supported the idea that STB were located near the bottom of the metalimnetic DO maximum (Figure 32) during summer stratification in 2001 (Figure 4). During this time, HSB occupied shallower and warmer water and seemed to be vertically separated from STB. In 2002, however, because of the DO deficiency and subsequent loss of useable habitat (DO > 2.0 mg/L), both STB and HSB were located in shallower but warmer water during summer stratification.

As determined from locations of radio-tagged fish, depth (n=305; df=6; F=22.35; P<0.01), water temperature (n=309; df=6; F=125.73; P<0.01), and DO (n=309; df=6; F=55.11; P<0.01) use differed for STB among seasons. Habitat use for STB was quite variable (Table 10); temperatures occupied ranged from 3.7-27.0 °C, DO from 0.8-11.7mg/L, and depths from 0.5-26.0 m. In the summer of 2001, STB utilized cooler (mean 22.5°C) and deeper (mean 12.0 m) water than in 2002, where they were found in warmer (mean 24.9°C) and shallower (mean 7.7 m) water. Dissolved oxygen at which STB were located was similar between the two summers (mean 5.0 mg/L in 2001 vs. 4.7 mg/L in 2002). Across both years of data collection, STB were found in statistically similar temperatures only during the fall of 2001 and 2002, but all other seasons differed. Of note was that mean depths used by STB in 2002 were less than 7.7 m for all seasons, but mean STB depths used in 2001 were greater than 9.5 m for all seasons.

Depth (n=469; df=6; F=45.74; P<0.01), water temperature (n=469; df=6; F=264.1; P<0.01), and DO (n=469; df=6; F=80.43; P<0.01) use differed for radio-tagged HSB among seasons (Table 11). Temperatures occupied by HSB ranged from 3.4-27.4 °C, DO ranged from 0.2-12.0 mg/L, and depths ranged from 0.5-28.8 m. Similar to STB, tagged HSB were found in cooler (mean 23.8°C) and deeper (mean 11.3m) water in 2001 than in 2002, where they were

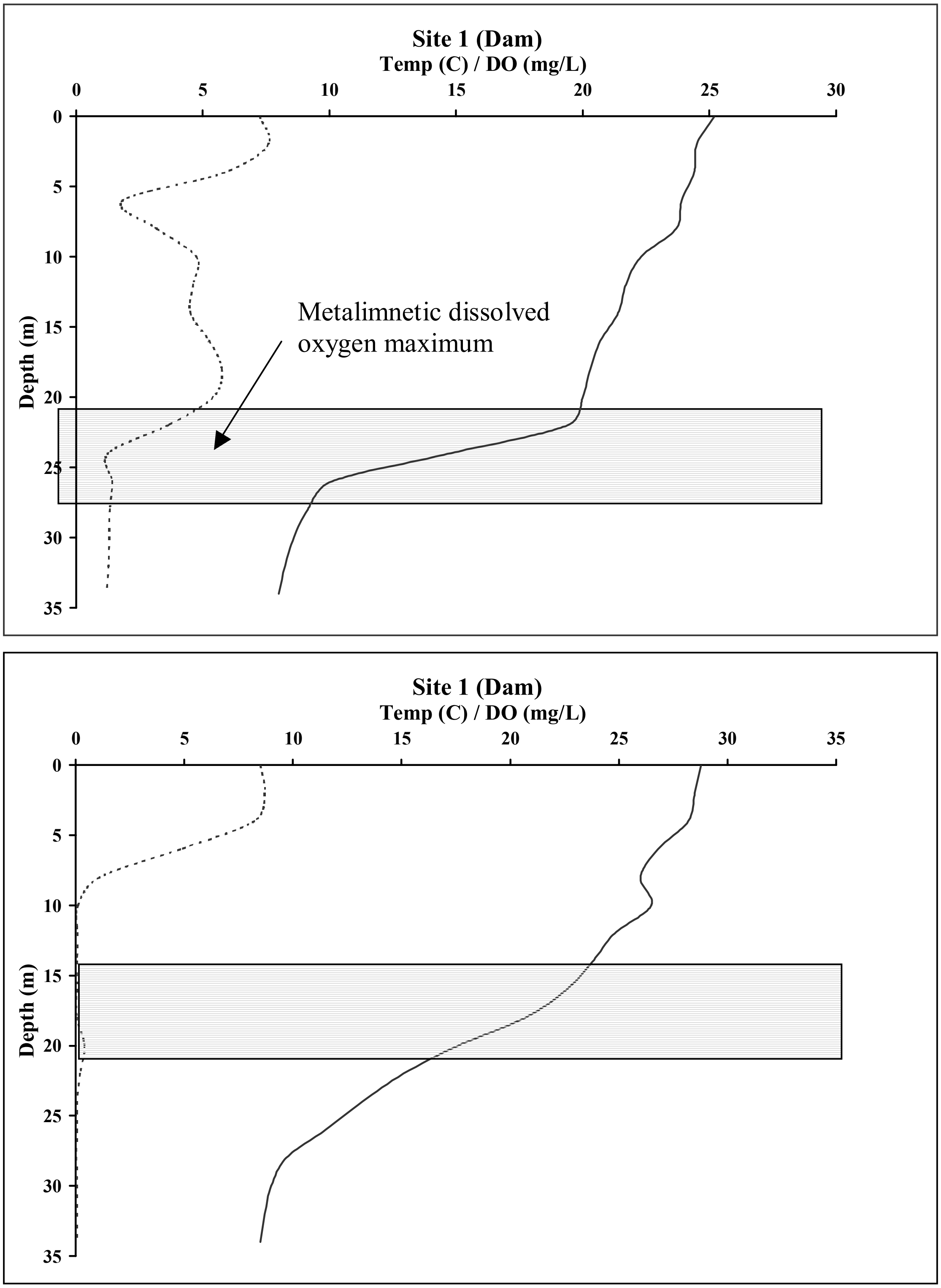


Figure 32. Vertical profile for both temperature and DO during August 2001(top) and August 2002 (bottom). Shaded box represents potential coolwater refuge that was inhabitable in 2001 but was devoid of DO and represents unusable habitat in 2002.

Table 10. Striped bass seasonal habitat comparisons of mean water temperature, dissolved oxygen, and depth.

Season	Water Temperature (°C)				Dissolved Oxygen (mg/L)				Depth (m)			
	N[1]	Mean[2]	SE[3]	Distribution[4]	N	Mean	SE	Distribution	N	Mean	SE	Distribution
Spring 01	18	19.8[a]	0.5	13.9-24.4	18	6.4[a]	0.4	2.9-9.6	18	9.5[a]	1.0	4.3-22.6
Summer 01	24	22.5[b]	0.4	17.7-24.8	24	5.0[b]	0.4	1.7-8.4	24	12.0[b]	0.8	6.0-20.5
Fall 01	40	13.3[c]	0.5	9.2-19.9	40	7.9[c]	0.3	4.7-11.7	37	13.9[b]	1.3	0.5-26.0
Winter 02	45	7.9[d]	0.3	4.2-11.2	45	9.8[d]	0.1	8.5-11.3	45	6.5[c]	0.6	1.0-20.0
Spring 02	79	17.8[e]	0.3	11.2-21.4	79	7.6[c]	0.2	3.7-11.0	78	5.6[c]	0.3	1.0-11.9
Summer 02	43	24.9[f]	0.4	17.9-27.0	43	4.7[b]	0.2	0.8-7.3	43	7.7[ac]	0.3	1.0-17.4
Fall 02	61	12.4[c]	0.8	3.7-22.1	61	8.0[c]	0.2	5.8-10.0	60	6.8[c]	0.4	1.0-17.0

[1]Number of individual samples per season
[2]Means followed by the same letter are not significantly different
[3]Standard Error
[4]Minimum and maximum

Table 11. Hybrid striped bass seasonal habitat comparisons of mean water temperature, dissolved oxygen, and depth.

Season	Water Temperature (°C)				Dissolved Oxygen (mg/L)				Depth (m)			
	N[1]	Mean[2]	SE[3]	Distribution[4]	N	Mean	SE	Distribution	N	Mean	SE	Distribution
Spring 01	32	22.5[a]	0.3	18.3-25.2	32	8.0[a]	0.4	3.4-12.0	32	5.9[a]	0.3	3.2-12.9
Summer 01	64	23.8[b]	0.2	18.2-27.4	64	4.0[b]	0.3	0.2-10.5	64	11.3[b]	0.4	4.3-19.0
Fall 01	61	14.1[c]	0.5	9.6-25.4	68	7.6[a]	0.2	3.8-10.8	61	13.3[c]	0.8	1.0-26.9
Winter 02	54	7.4[d]	0.3	3.4-10.3	55	9.8[c]	0.1	8.5-11.5	54	9.0[d]	0.8	1.5-28.8
Spring 02	111	19.9[e]	0.3	10.0-26.9	111	7.7[a]	0.1	3.5-11.0	111	4.6[a]	0.2	0.5-15.0
Summer 02	84	25.5[f]	0.1	21.0-27.1	85	5.8[d]	0.2	0.8-9.1	84	6.0[a]	0.2	2.0-10.0
Fall 02	54	13.8[c]	0.8	3.8-21.9	55	7.5[a]	0.2	5.7-9.9	54	8.9[d]	0.6	0.5-22.0

[1]Number of individual samples per season
[2]Means followed by the same letter are not significantly different
[3]Standard Error
[4]Minimum and maximum

found in warmer (mean 25.5°C) and shallower (mean 6.0 m) water during summer stratification. Dissolved oxygen, however differed between the summer of 2001 (mean 4.0 mg/L) and 2002 (mean 5.8 mg/L).

Hybrid striped bass were found in warmer water temperatures than STB during spring (22.5 vs. 19.8°C) and summer (23.8 vs. 22.5°C) of 2001 and spring of 2002 (19.9 vs. 17.8°C) (Table 12). Striped bass were found in deeper water during spring of 2001 (9.5 vs. 5.9 m) and summer of 2002 (7.7 vs. 6.0 m), but HSB were deeper than STB during winter (9.0 vs. 6.5 m) and fall (8.9 vs. 6.8 m) of 2002. Because of the inability to detect fish that were below about 17 m and my belief that STB were located at depths below 18 m during the summer of 2001, the mean depth for STB may have been statistically different than from HSB during the summer of 2001. Striped bass were found in water with higher DO than HSB during summer of 2001 (5.0 vs. 4.0 mg/L) and fall of 2002 (8.0 vs. 7.5 mg/L), but HSB occupied water with higher DO levels in the spring of 2001(8.0 vs. 6.4 mg/L) and the summer of 2002 (5.8 vs. 4.7 mg/L).

Available habitat

Spatial and temporal variability

There was little or no difference in temperature or dissolved oxygen at specific depths when comparing profile locations at transects perpendicular to the river channel (Figure 6) at either the site directly in front of Claytor dam or 2 miles above the dam (Table 13). However, at mile 4, vertical profiles taken at successive lateral positions were different in both temperature and DO at several depths. Although statistically significant differences did occur across transects, primarily at mile 4, the largest difference found between mean temperatures at a given depth was only 1.7°C, and only 6 of 72 readings differed by more than 0.5°C. At mile 4,

Table 12. Seasonal temperature, DO, and depth use comparisons between STB and HSB in Claytor Lake during 2001 and 2002.

Significant differences are highlighted in bold.

	Depth (m)					Water Temperature (°C)					Dissolved Oxygen (mg/L)				
Season	N[1]	F[2]	P[3]	HSB[4]	STB[5]	N	F	P	HSB	STB	N	F	P	HSB	STB
Spring 01	50	17.13	**<0.01**	5.9	9.5	50	24.25	**<0.01**	22.5	19.8	50	5.43	**0.02**	8.0	6.4
Summer 01	87	0.78	0.38	11.3	12.0	87	11.57	**<0.01**	23.8	22.5	87	5.21	**0.04**	4.0	5.0
Fall 01	97	0.18	0.67	13.3	13.9	107	1.31	0.25	14.1	13.3	107	0.80	0.37	7.6	7.9
Winter 02	98	5.68	**0.02**	9.0	6.5	99	1.18	0.28	7.4	7.9	99	0.05	0.83	9.8	9.8
Spring 02	188	5.89	**0.02**	4.6	5.6	189	20.12	**<0.01**	19.9	17.8	189	0.41	0.52	7.7	7.6
Summer 02	126	16.98	**<0.01**	6.0	7.7	127	3.6	0.06	258.5	24.9	127	12.48	**<0.01**	5.8	4.7
Fall 02	113	7.46	**<0.01**	8.9	6.8	115	1.76	0.19	13.8	12.4	115	4.59	**0.03**	7.5	8.0

[1]Sample size
[2]ANOVA F-Statistic
[3]ANOVA P-Value
[4]Seasonal mean value for hybrid striped bass
[5]Seasonal mean value for striped bass

Table 13. Results from MANOVA, testing if temperature and DO readings taken at specific depths differ from other transverse locations (see Figure 6). Pillai's trace statistics (P-value) are listed along with maximum differences between mean temperatures and DO readings from each location. Significant differences are highlighted in bold.

	Dam		Mile 2		Mile 4	
Depth	P-value	Differences (temp,DO)	P-value	Differences (temp,DO)	P-value	Differences (temp,DO)
4	0.40	0.10°C, 0.43 mg/L	**0.04**	0.20°C, 0.93 mg/L	**<0.01**	0.17°C, 0.60 mg/L
5	0.40	0.07°C, 0.20 mg/L	0.14	0.03°C, 0.77 mg/L	**0.01**	0.13°C, 0.23 mg/L
6	0.36	0.07°C, 0.00 mg/L	0.34	0.03°C, 0.33 mg/L	**<0.01**[4]	0.07°C, 0.33 mg/L
7	0.08	0.07°C, 0.17 mg/L	**0.04**[1]	0.10°C, 0.27 mg/L	0.30	0.07°C, 1.47 mg/L
8	0.34	0.03°C, 0.27 mg/L	0.17	0.13°C, 0.53 mg/L	**<0.01**[3]	0.10°C, 3.27 mg/L
9	0.12	0.07°C, 1.70 mg/L	0.11	0.14°C, 1.07 mg/L	0.06	0.07°C, 1.20 mg/L
10	0.34	0.33°C, 0.93 mg/L	0.48	0.23°C, 0.27 mg/L	0.034	0.27°C, 0.13 mg/L
11	0.64	0.17°C, 0.20 mg/L	0.37	0.20°C, 0.10 mg/L	0.09	0.07°C, 0.30 mg/L
12	0.67	0.13°C, 0.07 mg/L	0.38	0.23°C, 0.07 mg/L	**<0.01**	0.13°C, 0.23 mg/L
13	0.53	0.27°C, 0.03 mg/L	0.52	0.40°C, 0.07 mg/L	**<0.01**[5]	0.27°C, 0.00 mg/L
14	0.80	0.23°C, 0.03 mg/L	0.10	0.43°C, 0.03 mg/L	0.89	0.07°C, 0.00 mg/L
15	0.15	0.27°C, 0.07 mg/L	0.33[2]	0.33°C, 0.00 mg/L	0.19	0.40°C, 0.00 mg/L
16	0.64	0.13°C, 0.20 mg/L	0.22	0.37°C, 0.27 mg/L	0.64	0.23°C, 0.23 mg/L
17	0.16	0.23°C, 0.30 mg/L	0.67	0.33°C, 0.27 mg/L	0.06	0.17°C, 0.04 mg/L
18	0.14	0.27°C, 0.27 mg/L	0.37	0.17°C, 0.20 mg/L	0.11	0.10°C, 0.13 mg/L
19	0.13	0.30°C, 0.23 mg/L	0.06	0.27°C, 0.07 mg/L	0.19	0.07°C, 0.30 mg/L
20	0.70	0.20°C, 0.10 mg/L	0.24	0.20°C, 0.17 mg/L	0.10	0.07°C, 0.20 mg/L
21	0.75	0.33°C, 0.13 mg/L	0.16	0.57°C, 0.27 mg/L	**0.03**	0.43°C, 0.30 mg/L
22	0.69	0.67°C, 0.03 mg/L	**0.05**	0.70°C, 0.40 mg/L		
23	0.65	1.00°C, 0.13 mg/L	0.11	1.07°C, 0.33 mg/L		
24	0.47	0.40°C, 0.23 mg/L	0.19	0.73°C, 0.30 mg/L		
25	0.23	0.37°C, 0.43 mg/L	0.17	0.47°C, 0.13 mg/L		
26	0.15	0.43°C, 0.20 mg/L				

[1] There was little variability in temperature. However there was an increasing trend in temperature from west to east at this depth.

[2] ANOVA p-value for temp only. All DO values were 0.0, so MANOVA using DO is meaningless (mean squares were 0, so any number divided by 0 is meaningless).

[3] Significance questionable because of no variance in temperature for positions 1, 2, and 3

[4] Significance questionable because of no variance in temperature for positions 2 and 3.

[5] ANOVA p-value for temp only. All DO values were 0.0.

differences between DO readings were slightly higher (maximum difference of 3.27 mg/L), but only 9 of 72 compared mean DO levels across transects differed by more than 0.5 mg/L.

Overall, data support the general conclusion that at one location in the reservoir (in river miles from the dam), lateral position has little effect upon the temperature/dissolved oxygen profile. The preponderance of significantly different MANOVA values for the vertical profiles taken at the 4-mile mark suggest that more research may be needed to evaluate position effect throughout the reservoir. More research is also needed to determine lateral variability in temperature and DO during different seasons, temperatures, flow rates, and times of day. There was a significant temporal difference ($P<0.05$) between the three sampled time periods (0900-1000 , 1300-1400, and 1700-1800) at almost all depths when comparing vertical profiles of temperature and DO taken in Claytor Lake 3.2 km above the dam (Table 14). Therefore, caution must be used when taking a vertical profile and assuming steady-state throughout a day.

When comparing mean profile values for each depth, the largest difference in temperature was only 1.28°C, and out of 16 depths, differences greater than 0.5°C were found only at 5 depth strata. In general, temperatures rose throughout the day, even at water depths of 24 m. Maximum differences in mean DO readings for the three time periods were even less, with none of them being larger than 0.5 mg/L. There was no specific trend throughout the day for DO habitat except for water 2 m and less, where DO levels rose each time period, likely due to oxygen inputs from photosynthesis and wave action. More research is needed to estimate bounds of temperature and dissolved oxygen fluctuation by season, flow, temperature, and time periods. These data support that Claytor Lake is a dynamic system and not in steady state, even over the time frame of one day.

Table 14. Results from MANOVA, testing if temperature and DO readings taken at specific depths differ by time periods in Claytor Lake. The three time periods of 9-10 AM, 1-2 PM, and 5-6 PM were tested by comparing the means of 5 replicate vertical profiles taken within each period. Pillai's trace statistics (P-value) are listed along with maximum differences between mean temperatures and DO readings and temperature and DO means taken within each time period. Significant differences are highlighted in bold.

	Mean temperature (°C)				Mean dissolved oxygen (mg/L)				
Depth	9-10 AM	1-2 PM	5-6 PM	Max. temp difference	9-10 AM	1-2 PM	5-6 PM	Max DO difference	P-value
0	26.58	27.24	27.54	0.96	7.79	7.94	8.23	0.44	**<0.01**
2	26.5	26.74	27.44	0.94	7.90	8.16	8.39	0.48	**<0.01**
4	26.46	26.46	26.58	0.12	7.86	7.53	7.49	0.37	0.20
6	25.70	25.60	25.62	0.10	3.26	2.77	2.90	0.48	0.22
8	25.22	25.30	25.58	0.16	0.98	1.22	1.43	0.45	**<0.01**
10	24.94	24.98	25.10	0.16	0.53	0.49	0.67	0.18	**<0.01**
12	24.14	24.44	24.56	0.42	0.11	0.07	0.07	0.04	**<0.01**
14	23.18	23.44	23.62	0.44	0.02	0.05	0.04	0.03	**<0.01**
16	21.30	21.48	22.00	0.70	0.10	0.05	0.05	0.06	**<0.01**
18	18.46	18.86	18.98	0.52	0.87	0.64	0.54	0.33	**<0.01**
20	17.06	17.22	17.02	0.20	0.95	0.98	0.97	0.03	0.09
22	14.66	14.82	14.98	0.32	0.21	0.42	0.41	0.21	**<0.01**
24	11.18	11.80	12.46	1.28	0.10	0.10	0.07	0.03	**<0.01**
26	9.86	10.20	10.12	0.34	0.08	0.07	0.06	0.02	**<0.01**
28	9.22	9.32	9.26	0.10	0.08	0.07	0.05	0.03	**<0.01**
30	8.96	8.98	9.00	0.04	0.08	0.06	0.05	0.03	**0.02**

I calculated lake volumes within each cell (Figure 7) by each 2-m stratum (Table 15). My total calculated lake volume at full pond was 2.75 x 10^8 m^3. About 73% of Claytor's water volume is in the lower 9.7 km (6 miles), and 60% in the lower 6.4 km (4 miles) (Table 16). In addition, most (54%) of Claytor's volume at normal pool is 11 m or less, while only 20% is deeper than 19 m. Although fish were often found in Peak Creek, this tributary arm represents only about 4% of the volume of Claytor Lake.

Mean monthly temperature and dissolved oxygen calculations were made by weighting each depth stratum by volume (Table 17). Overall water temperature were highest during August of both years, but was higher in 2002 (mean 23.1°C) than in 2001 (mean 22.1°C). Overall mean DO remained above 5.0 mg/L except in July of 2001 (3.8 mg/) and July (3.6 mg/L), August (2.7 mg/L), and September (3.6 mg/L) of 2002. January of 2002 had the lowest water temperature mean (4.8°C) and the highest DO (11.4 mg/L).

Habitat availability vs. habitat use

Temperature and DO data distributions determined from telemetered fish locations differed, as tested by Kolmogorov-Smirnov goodness of fit tests, from vertical profile distributions of temperature and DO in Claytor Lake throughout much of this study (Table 18). This suggests non-random use of habitat for both STB and HSB throughout most of the year in Claytor Lake (Appendix 3). During colder water periods, fish tended to occupy the warmest water possible. For instance, on February 19, 2002, only about 10% of Claytor Lake was at or above 6°C, but over 70% of HSB and 55% of STB were found in water >6°C (Figure 33). Both STB and HSB avoided water temperature greater than about 26°C as long as DO levels remained above 2 mg/L (Figure 34). However, when DO levels dropped to below 2 mg/L, both STB and HSB were forced into water temperatures in excess of 26°C (Figure 35).

Table 15. Lake volumes (x 10^5 m^3) for each depth and cell in Claytor Lake.

	Cell Number													
Depth (m)	1	2	3	4	5	6	7	8	9	10	11	12	13	14
0-1	35.3	22.1	15.9	16.5	16.3	15.7	8.9	12.0	7.3	6.1	2.8	5.6	3.8	1.8
1-3	68.1	43.4	31.1	32.3	31.1	30.3	15.3	22.0	13.1	8.4	2.8	10.8	7.1	2.9
3-5	63.4	41.9	29.7	31.0	28.0	28.2	10.3	18.3	7.9	2.3		9.7	5.9	1.6
5-7	59.3	40.4	28.4	29.8	25.4	26.0	6.0	14.1	2.1			8.8	4.6	0.5
7-9	55.6	38.9	27.2	28.8	23.8	23.6	3.5	5.9				7.9	3.3	
9-11	52.0	37.3	26.0	27.9	22.8	21.0	1.3					7.1	2.1	
11-13	48.7	35.8	24.9	27.0	21.5	18.1						6.3	1.2	
13-15	46.3	34.4	23.8	26.2	19.8	14.2						5.6	0.4	
15-17	44.2	33.0	22.7	25.4	17.9	6.0						4.8		
17-19	42.0	31.5	21.4	24.5	15.8							4.1		
19-21	39.8	30.0	19.8	21.9	10.4							3.2		
21-23	37.6	28.5	18.1	18.0	3.1							2.2		
23-25	34.8	26.3	16.4	15.2								0.9		
25-27	31.3	23.0	14.4	12.6										
27-29	27.2	19.0	12.4	5.4										
29-31	22.3	15.1	5.7											
31-33	15.9	6.6												
33-35	6.2													

Table 16. Lake volume percentages for water in each cell and at each depth in Claytor Lake. Total percentages are listed at bottom of table.

	Cell Number													
Depth (m)	1	2	3	4	5	6	7	8	9	10	11	12	13	14
0-1	1.3	0.8	0.6	0.6	0.6	0.6	0.3	0.5	0.3	0.2	0.1	0.2	0.1	0.1
1-3	2.6	1.7	1.2	1.2	1.2	1.2	0.6	0.8	0.5	0.3	0.1	0.4	0.3	0.1
3-5	2.4	1.6	1.1	1.2	1.1	1.1	0.4	0.7	0.3	0.1		0.4	0.2	<0.1
5-7	2.3	1.5	1.1	1.1	1.0	1.0	0.2	0.5	0.1			0.3	0.2	
7-9	2.1	1.5	1.0	1.1	0.9	0.9	0.1	0.2				0.3	0.1	
9-11	2.0	1.4	1.0	1.1	0.9	0.8	0.1					0.3	0.1	
11-13	1.9	1.4	1.0	1.0	0.8	0.7						0.2		
13-15	1.8	1.3	0.9	1.0	0.8	0.5						0.2		
15-17	1.7	1.3	0.9	1.0	0.7	0.2						0.2		
17-19	1.6	1.2	0.8	0.9	0.6							0.2		
19-21	1.5	1.1	0.8	0.8	0.4							0.1		
21-23	1.4	1.1	0.7	0.7	0.1							0.1		
23-25	1.3	1.0	0.6	0.6								<0.1		
25-27	1.2	0.9	0.5	0.5										
27-29	1.0	0.7	0.5	0.2										
29-31	0.8	0.6	0.2											
31-33	0.6	0.3												
33-35	0.2													
Total	27.9	19.4	12.9	13.1	9.0	7.0	1.7	2.8	1.2	0.6	0.2	2.9	1.0	0.2

Table 17. Seasonal available habitat comparisons of mean water temperature, dissolved oxygen, and depth in Claytor Lake, Virginia. Means, both weighted and unweighted, by lake volumes are listed.

Season	N[1]	Water temperature (°C)			Dissolved oxygen (mg/L)		
		Mean[2]	SE[3]	Distribution[4]	Mean	SE	Distribution
July 01	120	21.6[a]	0.5	8.0-27.9	3.8[a]	0.3	0.2-9.2
August 01	240	22.1[bc]	0.2	8.0-28.0	5.9[bc]	0.2	0.2-14.2
September 01	240	22.1[b]	0.2	8.5-25.9	4.9[d]	0.2	<0.1-8.7
October 01	240	18.6[d]	0.2	8.7-21.2	5.6[b]	0.2	<0.1-10.6
November 01	262	13.2[e]	0.2	6.7-16.1	7.5[e]	0.2	0.2-12.9
December 01	262	11.1[f]	0.1	7.6-12.7	7.8[e]	0.1	0.1-10.9
January 02	131	4.8[g]	0.3	3.4-5.9	11.4[f]	<0.1	10.6-12.3
February 02	131	5.2[g]	0.5	4.5-7.3	11.2[f]	<0.1	10.4-12.6
March 02	163	8.5[h]	0.1	5.4-10.6	9.5[g]	<0.1	8.9-10.7
April 02	131	11.1[f]	0.4	6.8-16.4	9.5[g]	0.1	7.6-11.0
May 02	393	16.2[g]	0.2	7.5-24.2	6.9[h]	0.1	0.2-10.7
June 02	262	19.9[h]	0.4	8.1-29.1	5.2[d]	0.2	<0.1-11.3
July 02	262	21.8[ab]	0.4	8.2-29.5	3.6[a]	0.2	<0.1-9.8
August 02	262	23.1[c]	0.4	8.5-29.3	2.7[i]	0.2	<0.1-9.7
September 02	262	21.8[ab]	0.3	8.7-25.4	3.6[a]	0.2	0.1-8.3
October 02	262	18.6[d]	0.2	8.7-22.0	5.0[c]	0.2	0.1-10.0
November 02	262	11.7[f]	0.2	6.1-13.9	7.5[e]	0.1	0.2-11.0
December 02	224	5.5[g]	0.1	1.8-7.5	9.5[g]	0.1	1.8-11.9

[1]Number of readings per month (at 2-m depth intervals)
[2]Means followed by the same letter are not significantly different
[3]Standard Error
[4]Minimum and maximum

Table 18. Kolmogorov-Smirnov test result P-values. Significant differences (in bold) indicate that temperature and DO data distributions of fish locations, as determined by radio-telemetry data, differed from temperature and DO distributions in Claytor Lake, as determined by vertical profiles.

	HSB		STB[1]	
Date	Temp	DO	Temp	DO
July 17, 2001	0.17	0.10	0.67	0.73
August 2, 2001	**0.03**	0.65	0.24	0.29
August 28, 2001	0.09	0.10	0.80	0.83
September 5, 2001	**0.03**	**<0.01**	0.06	0.02
September 18, 2001	0.08	**<0.01**	0.06	0.18
October 1, 2001	**<0.01**	0.50	**<0.01**	**0.03**
October 14, 2001	0.05	0.11	**0.02**	**<0.01**
November 3, 2001	0.12	0.90	0.87	0.47
November 24, 2001	**<0.01**	0.51	**0.02**	0.23
December 7, 2001	0.22	0.44	0.55	0.92
December 19, 2001	0.45	**<0.01**	0.82	**<0.01**
January 24, 2002	0.22	**<0.01**	0.11	**<0.01**
February 19, 2002	**<0.01**	**<0.01**	**<0.01**	**<0.01**
March 15, 2002	**<0.01**	0.16	**<0.01**	0.22
March 21, 2002	**<0.01**	**<0.01**	**<0.01**	**<0.01**
April 11, 2002	**0.04**	0.07	**<0.01**	0.72
May 4, 2002	**<0.01**	**<0.01**	**<0.01**	**<0.01**
May 15, 2002	**<0.01**	**0.03**	**<0.01**	**<0.01**
May 28, 2002	**<0.01**	**<0.01**	**<0.01**	**<0.01**
June 11, 2002	**<0.01**	**<0.01**	**0.02**	**<0.01**
June 25, 2002	**<0.01**	**<0.01**	**0.03**	**<0.01**
July 2, 2002	**<0.01**	**<0.01**	0.70	0.29
July 23, 2002	**<0.01**	**<0.01**	**0.03**	0.15
August 5, 2002	**<0.01**	**<0.01**	**<0.01**	**<0.01**
August 26, 2002	**<0.01**	**<0.01**	**<0.01**	**0.04**
September 9, 2002	**<0.01**	**<0.01**	**<0.01**	**0.03**
September 23, 2002	**<0.01**	0.03	**<0.01**	**0.04**
October 9, 2002	0.08	**<0.01**	0.49	**<0.01**
October 23, 2002	0.06	0.21	0.42	0.74
November 6, 2002	**<0.01**	**0.02**	0.37	0.78
November 19, 2002	**<0.01**	**0.02**	0.61	0.11
December 5, 2002	**<0.01**	**<0.01**	**<0.01**	**0.03**
December 19, 2002	0.18	0.15	0.11	0.19

[1] Small sample size in Spring and Summer of 2001 reduced power to detect statistical differences.

February 19, 2002

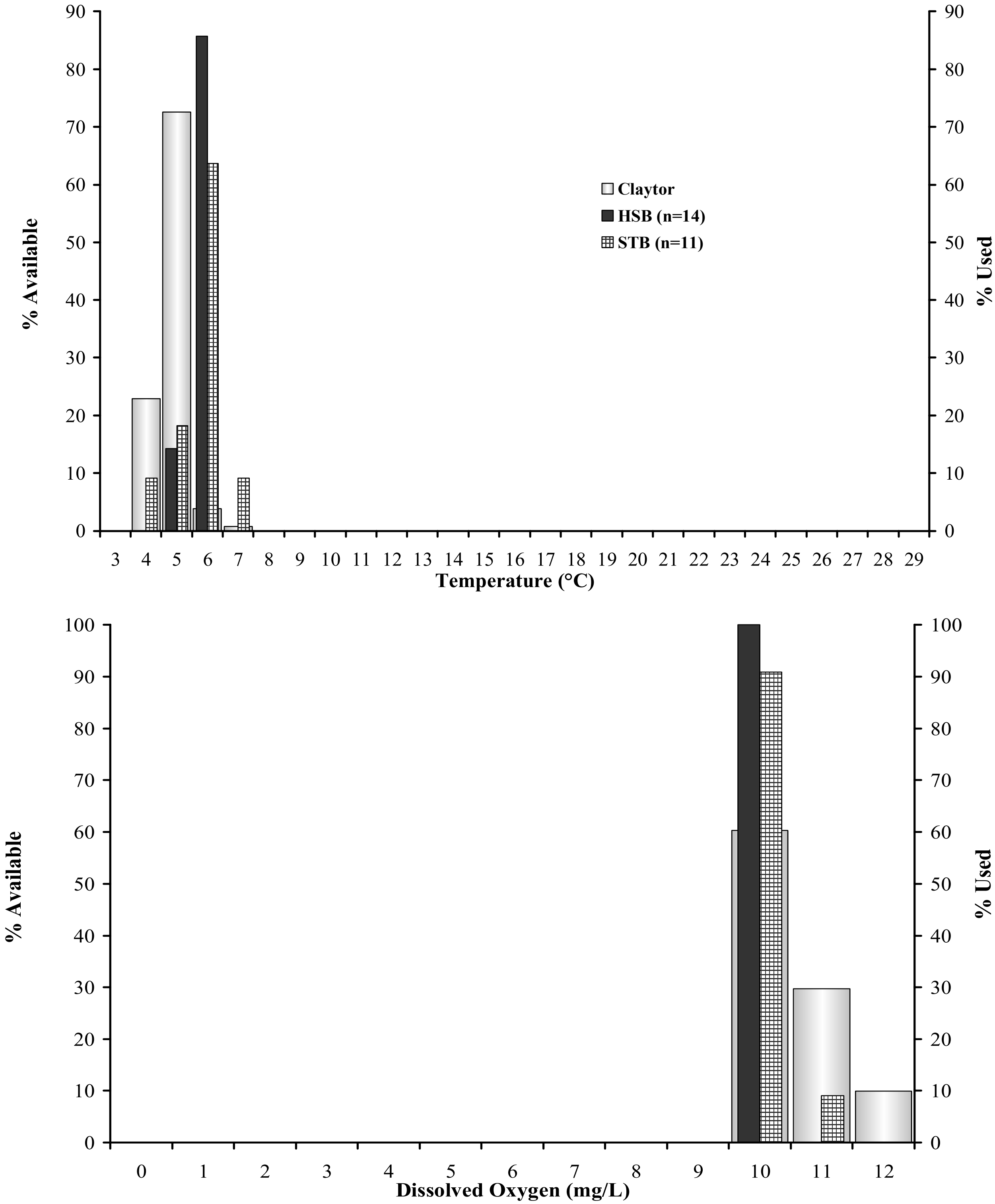


Figure 33. Comparison of percentage of available habitat (gray bars) and habitat used by telemetered STB (hatched bars) and HSB (black bars) during January 2002.

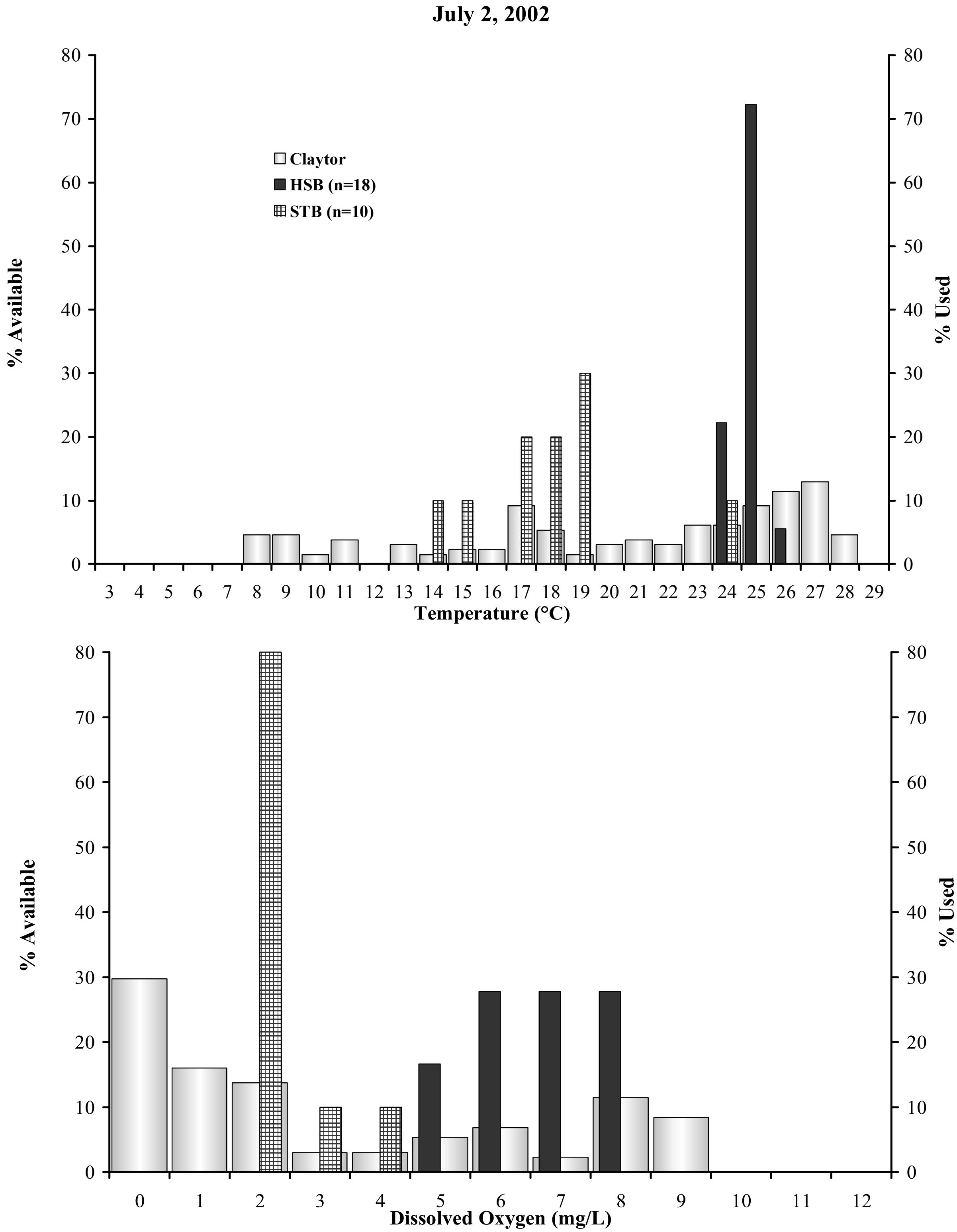
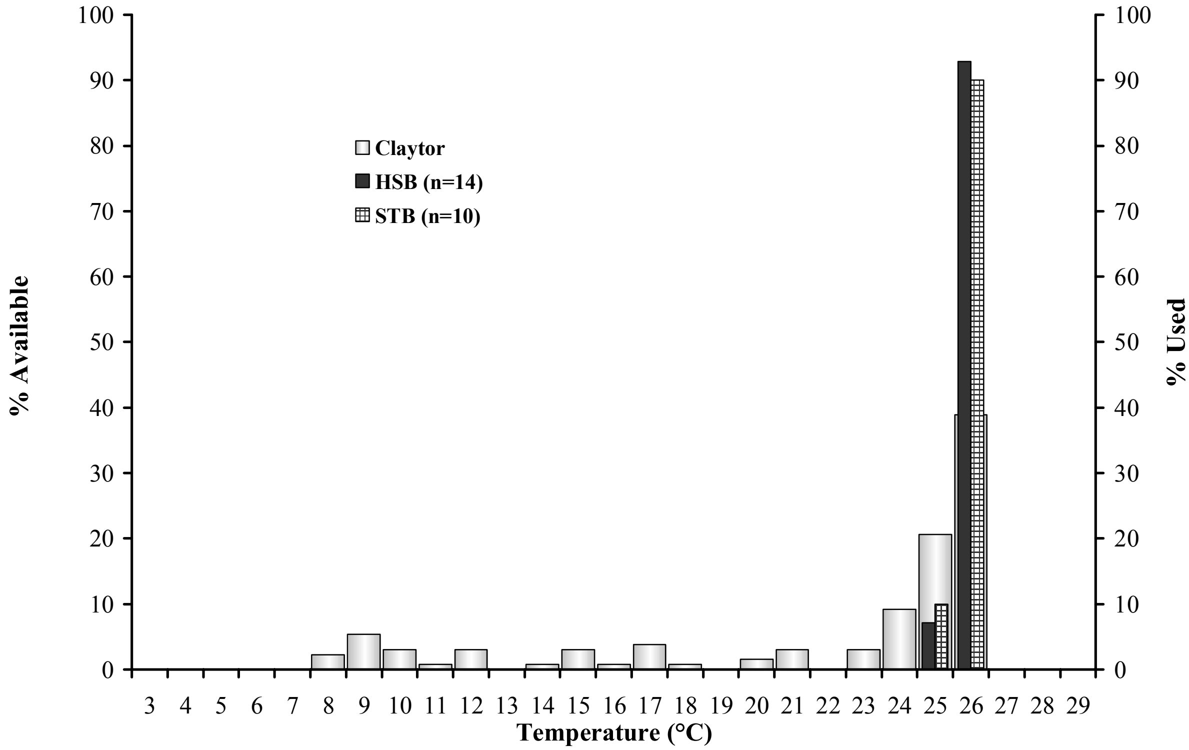


Figure 34. Percentage of available habitat, based on temperature and DO profiles taken from Claytor Lake, compared to habitat use, as measured from telemetered STB and HSB, July 2, 2002.

August 26, 2002



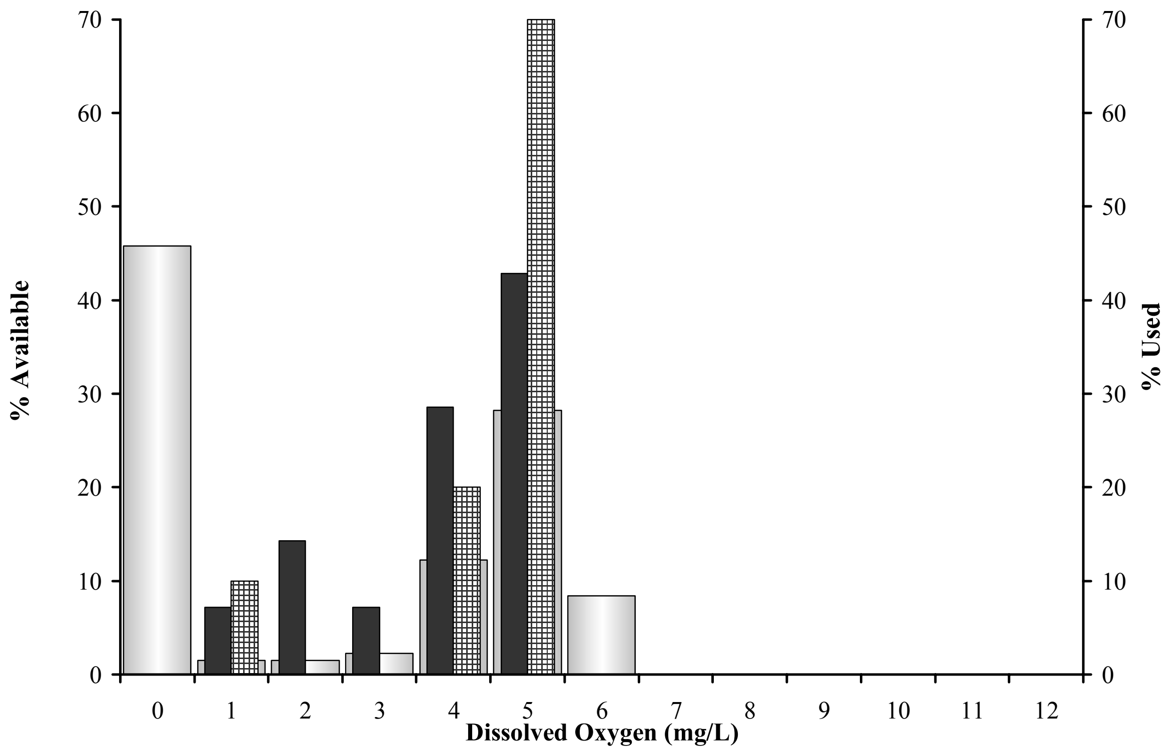


Figure 35. Percentage of available habitat, based on temperature and DO profiles taken from Claytor Lake, compared to habitat use, as measured from telemetered STB and HSB, August 26, 2002.

Striped bass and hybrid striped bass demonstrated a tendency to separate in their habitat usage during early summer stratification of 2002. Although they were located in similar horizontal positions in the reservoir (Figure 36), HSB and STB showed little temperature or DO habitat overlap in early June (Figure 37). Because STB were found in water with less than optimal DO levels (3.0-4.0 mg/L), but cooler water (18-20°C) than HSB (23-26°C) that weremostly in water with optimal DO levels (>5.0 mg/L), it can be inferred that STB, in early June, sacrificed DO in order to inhabit preferred temperature.

Differences in habitat use versus temperature and DO distribution in the reservoir were not significant for STB during the summer of 2001; However, sample sizes were small ($n < 8$) and temperature and DO differences likely existed. For example, on August 28, 2001, only one STB was located, but larger sample size may have resulted in statistical differences being found (Figure 38). A notable problem with radio-tracking fish was that the telemetry equipment was poor at detecting signals from fish deeper than about 17 m. During the summer of 2002, I was able to detect radio signals from tagged HSB, but had poor success finding STB. However, sonar readings (Figure 4) confirmed reports from anglers that STB were located at depths of about 20 m. On August 28, 2001, I was only able to detect one STB in water at about 23.0°C, 3.6 mg/L, and 12.9 m depth. It is likely that other radio-tagged STB were with schooling STB at depths of about 20m. Schooling STB at this time were located about 6.4 km (4 miles) above the dam, and the 20-m strata of water represented habitat of about 20°C and 5 mg/L. At this time, HSB were found in shallower water (<15 m) in water temperatures of >21°C and DO levels of 3-5 mg/L. Therefore, although STB and HSB were in similar horizontal locations (Figure 39), vertical separation of the two existed during August 2001 (Figure 40).

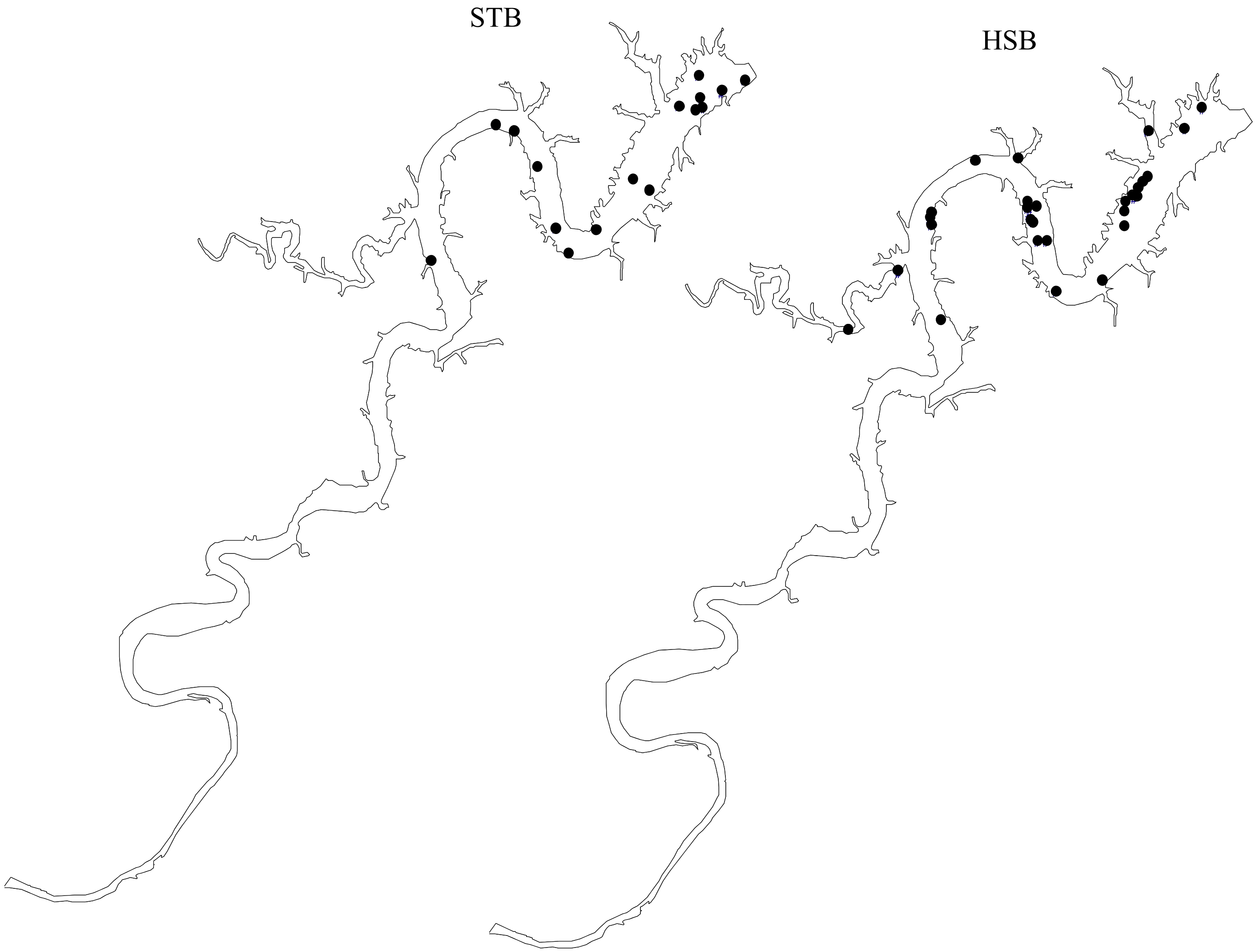


Figure 36. Striped bass (left) and HSB (right) horizontal locations of telemetered fish, June 2002.

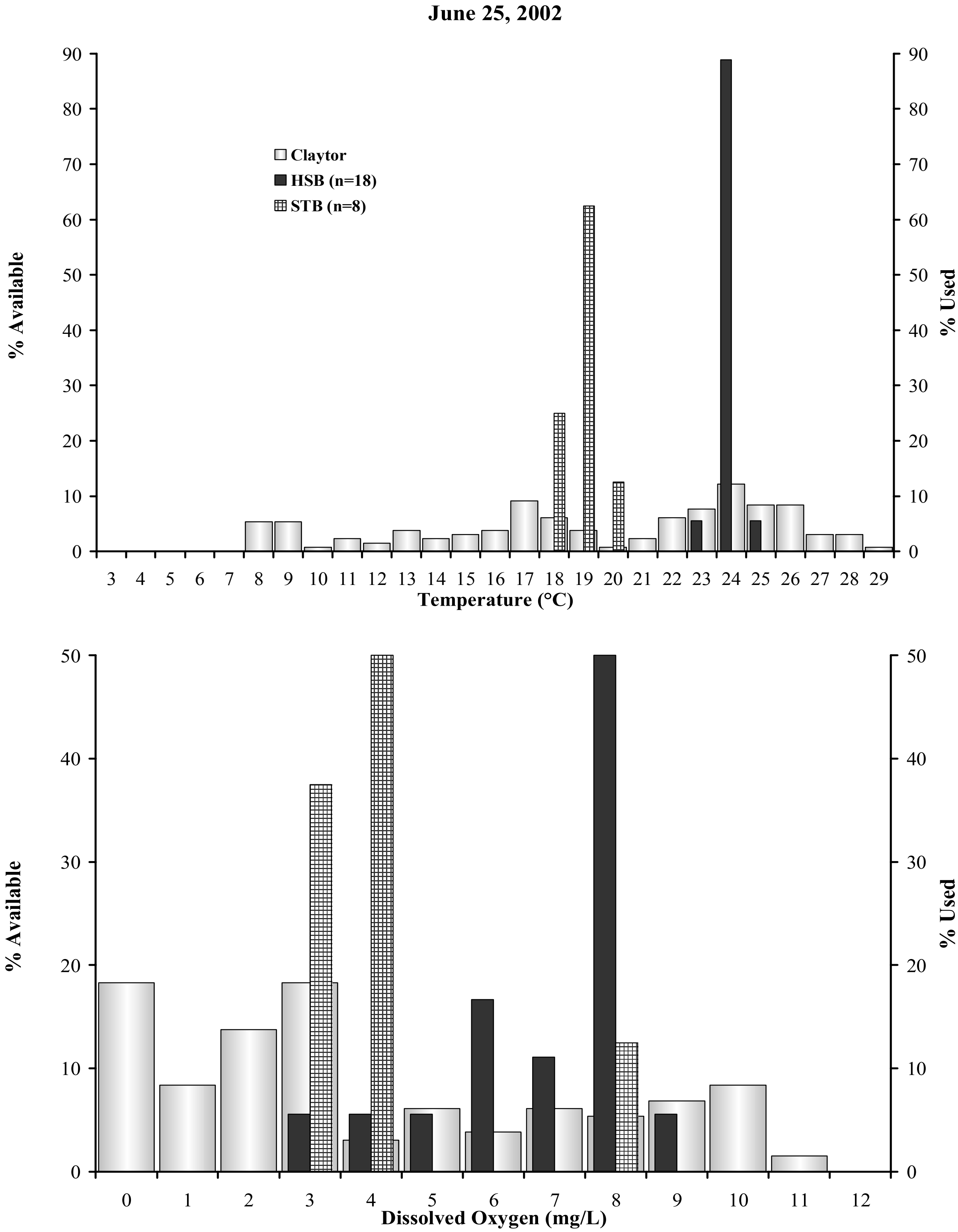


Figure 37. Percentage of available habitat, based on temperature and DO profiles taken from Claytor Lake, compared to habitat use, as measured from telemetered STB and HSB, June 25, 2002.

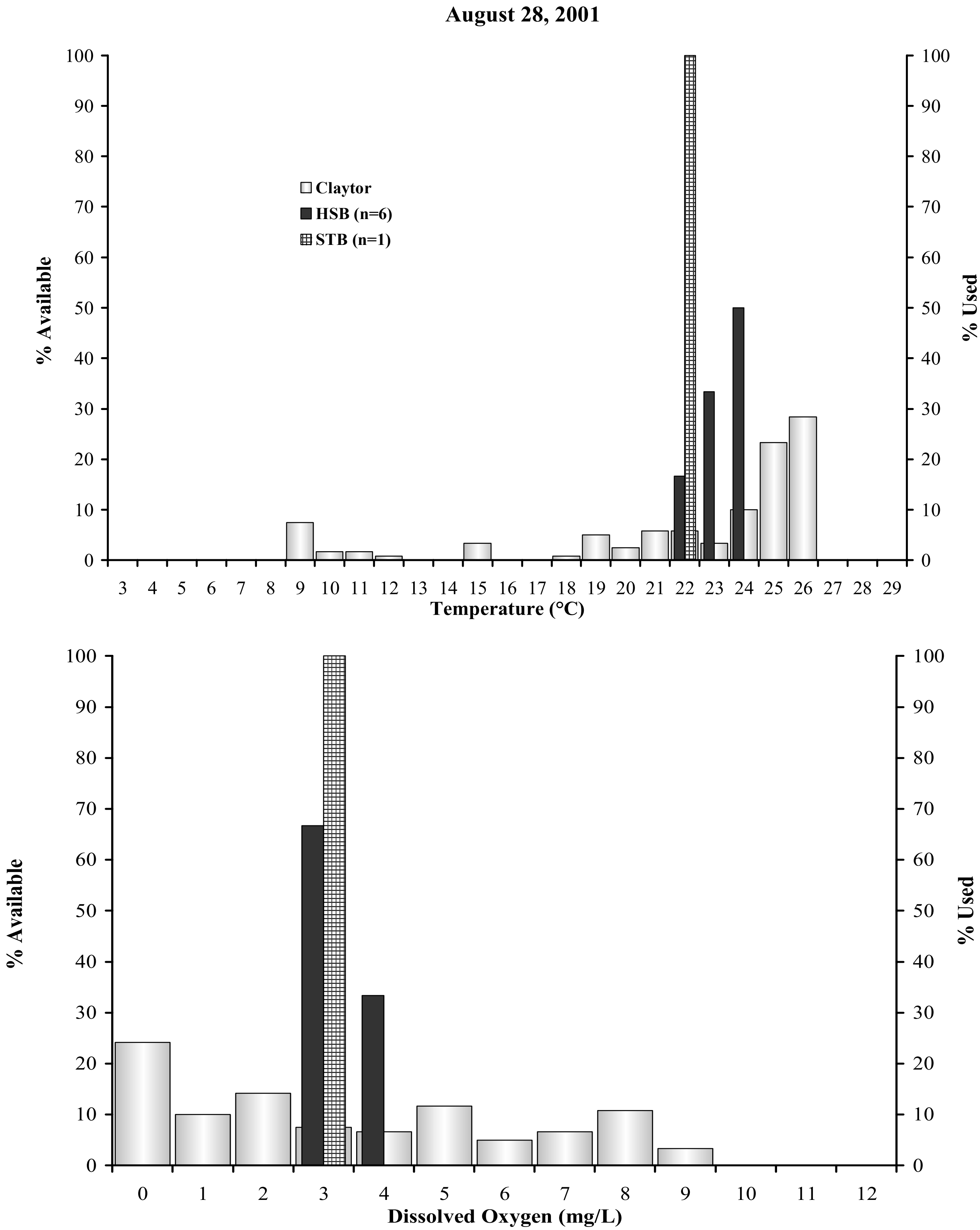


Figure 38. Percentage of available habitat, based on temperature and DO profiles taken from Claytor Lake, compared to habitat use, as measured from telemetered STB and HSB, August 28, 2001.

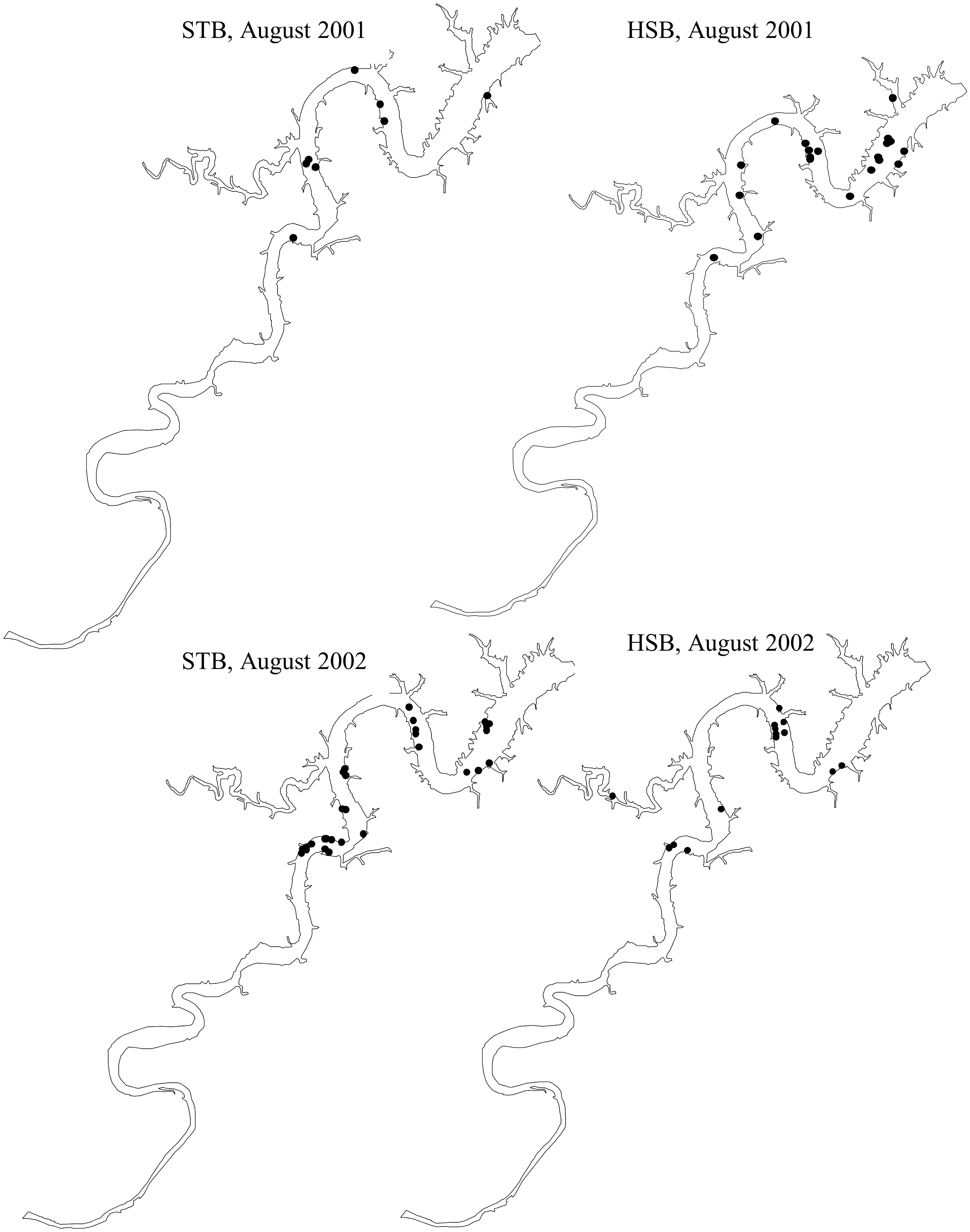


Figure 39. Horizontal locations of telemetered STB (top left) and HSB (top right) in August 2001, and STB (bottom left) and HSB (bottom right) in August 2002.

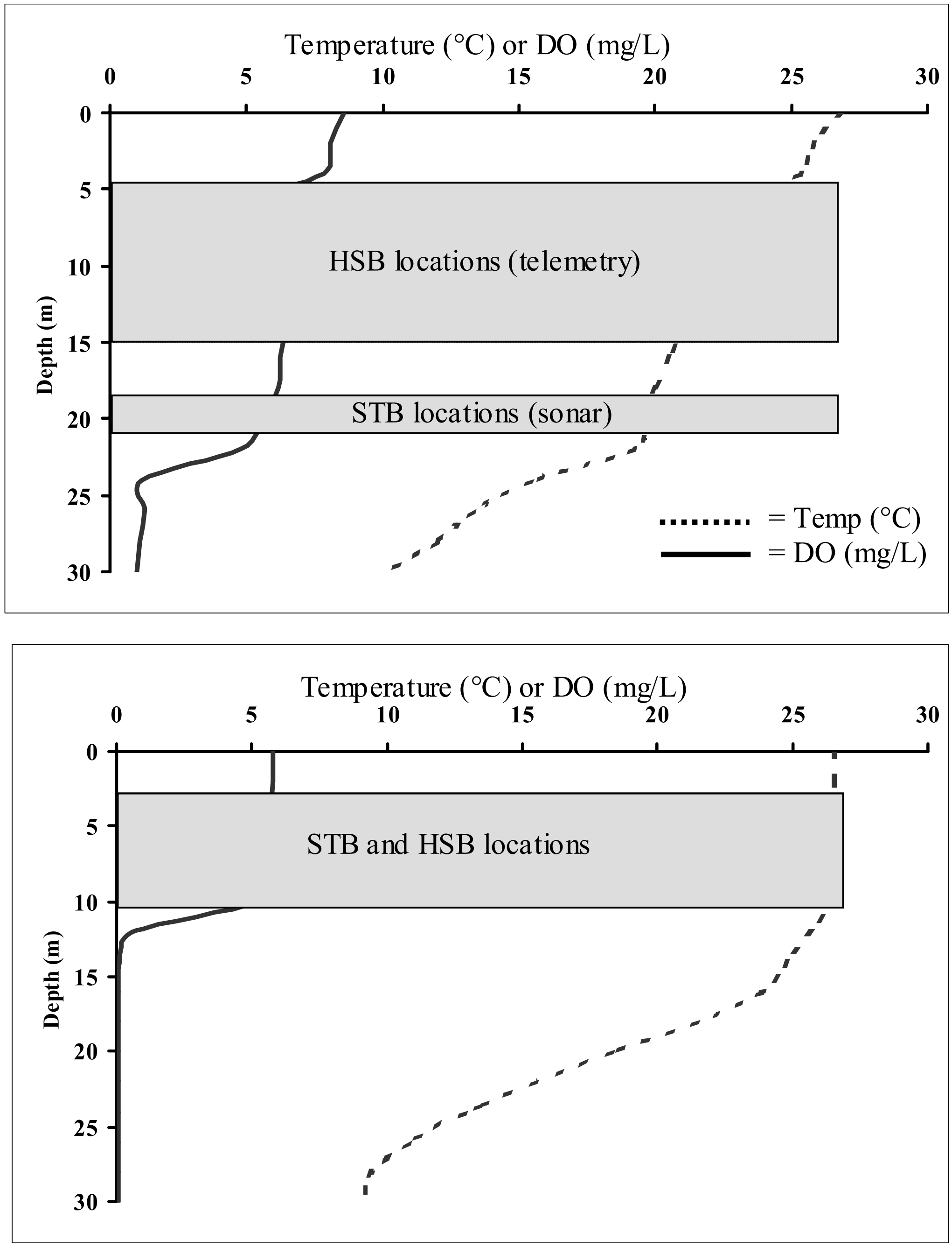


Figure 40. Claytor Lake vertical profiles, August 2001 (top) and August 2002 (bottom), demonstrating STB and HSB locations, as determined by radio-telemetry data. During August of 2001, STB were too deep to be consistently located with telemetry equipment, but were confirmed by boat-mounted sonar to be at depths of about 20-m. In 2001, thermal refuge existed for STB, and they were vertically separated from HSB. However, in 2002, no oxygenated thermal refuge existed and both STB and HSB were in water <10 m.

When summer habitat availability in 2001 is compared to that in 2002 (Figure 40), it is evident that summertime refuge (water <25°C, DO <5 mg/L) was not available to STB in 2002. Similar to 2001, STB and HSB were in similar horizontal locations (Figure 39), but were also at the same depths in Claytor Lake. Therefore, more potential for direct competition existed in 2002, not only for food, but also for spatial habitat.

Throughout most of the fall, winter, and early spring periods sampled, STB and HSB were in similar habitats, usually at depths <2.0 m apart and temperatures <1.5°C apart (Table 12). The only time at which larger differences occurred was during late spring of both years (e.g., Figures 39, 42). During the period of June through July of 2002, STB were in cooler water (15-20°C) than HSB (20-25°C). However, STB sacrificed optimal DO (≥5.0 mg/L) during this time and were found in DO levels of about 2.5 mg/L (several fish below even 1.0 mg/L) in order to be in optimal water temperature habitat. HSB were able to inhabit water in both optimal temperature (21.5-25.5°C and DO ≥4.5 mg/L). In addition, STB in the summer of 2001 were likely also in largely different (>2.0 m depth and >2.0°C) habitats, although I was unable to detect STB believed to be deeper than our telemetry equipment could monitor. Therefore, when refugia habitat (preferred temperature, suboptimal to optimal DO) existed for both STB (15-20°C and DO >2.5 mg/L) and HSB (21.5-25.5°C and DO > 2.0 mg/L), they vertically separated and occupied two "stories" of Claytor Lake.

Habitat quality

There were large differences in the amount of Claytor Lake volume that could potentially be used as moronid habitat between summers of 2001 and 2002. For instance, anoxic water (<1.0 mg/L) during late August of 2001 represented only about 25% of Claytor Lake, whereas more than 45% of Claytor Lake contained less than 1.0 mg/L in August of 2002. Oxygenated

(>2.0 mg/L) thermal refuge for STB (<22.0°C) and HSB (<25°C) was available to fish during much of the summer of 2001. However, in September 2001, water cooler than 23°C became anoxic, oxygenated thermal refuge for both STB and HSB disappeared, and moronids were found in warmer water (STB >24°C, HSB > 25°C). During early September of 2002, both STB and HSB were found in water temperatures 24-25°C and 3-7 mg/L DO. By October, the reservoir had cooled, no water was warmer than 23°C, and fish were no longer found at DO levels of <4.0 mg/L. Vertical temperature and DO profiles taken from Claytor throughout this study are presented in Appendix 4.

Summertime conditions in 2001 were in contrast to those in 2002. Habitat quality, as determined by the amount of refuge habitat, was diminished in 2002 because of a largely anoxic metalimnion and hypolimnion. As a result, the only thermal habitat that was available from late July to early September was >24.0°C, well outside optimal conditions for STB and at the upper edge of optimal habitat for HSB. [As determined by the revised HSI models, optimal habitat was 15-20°C and >5.0 mg/L for STB and 21.5-25.5°C and >4.5 mg/L for HSB].

Habitat suitability index temperature scores (0.0 to 1.0), as calculated from the revised HSI model, reveal lower monthly mean values for STB than HSB from July-September of 2001 (Figure 41). Temperature HSI scores were also lower for STB than for HSB during stratification in 2002, but were worse than 2001; STB average HSI scores were almost zero throughout the entire month of August, whereas HSB HSI scores remained at about 0.40. Suitability of DO habitat, as calculated from the revised HSI model, remained high (>0.8) through most of both years for both STB and HSB (Figure 42). However, DO habitat was degraded in September of 2001 (0.30 for STB and 0.55 for HSB). Dissolved oxygen habitat was also degraded in August of 2002, although only for STB (0.40).

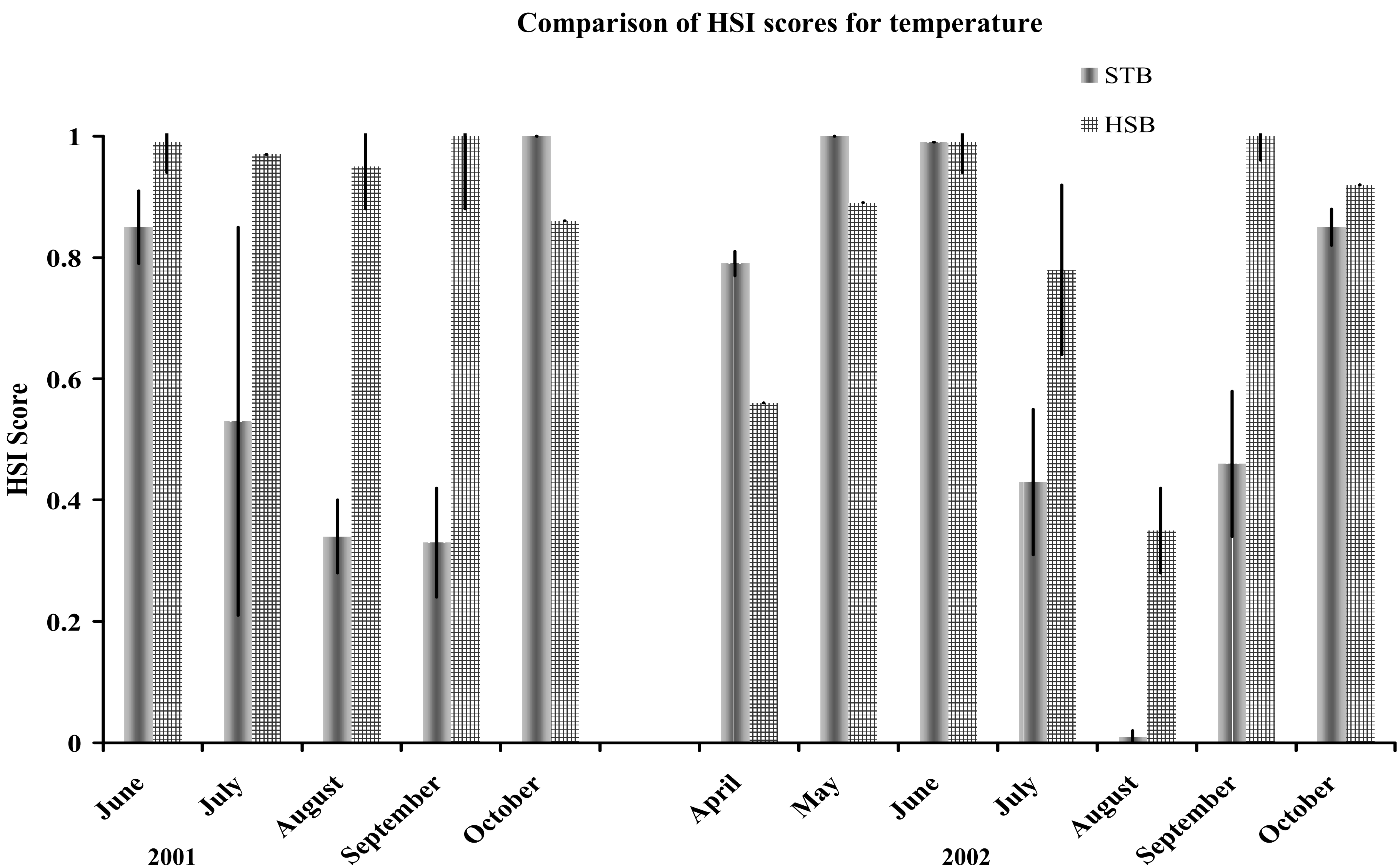


Figure 41. Comparison of temperature habitat suitability index scores (with standard error bars) from telemetered STB and HSB during summer stratification in Claytor Lake.

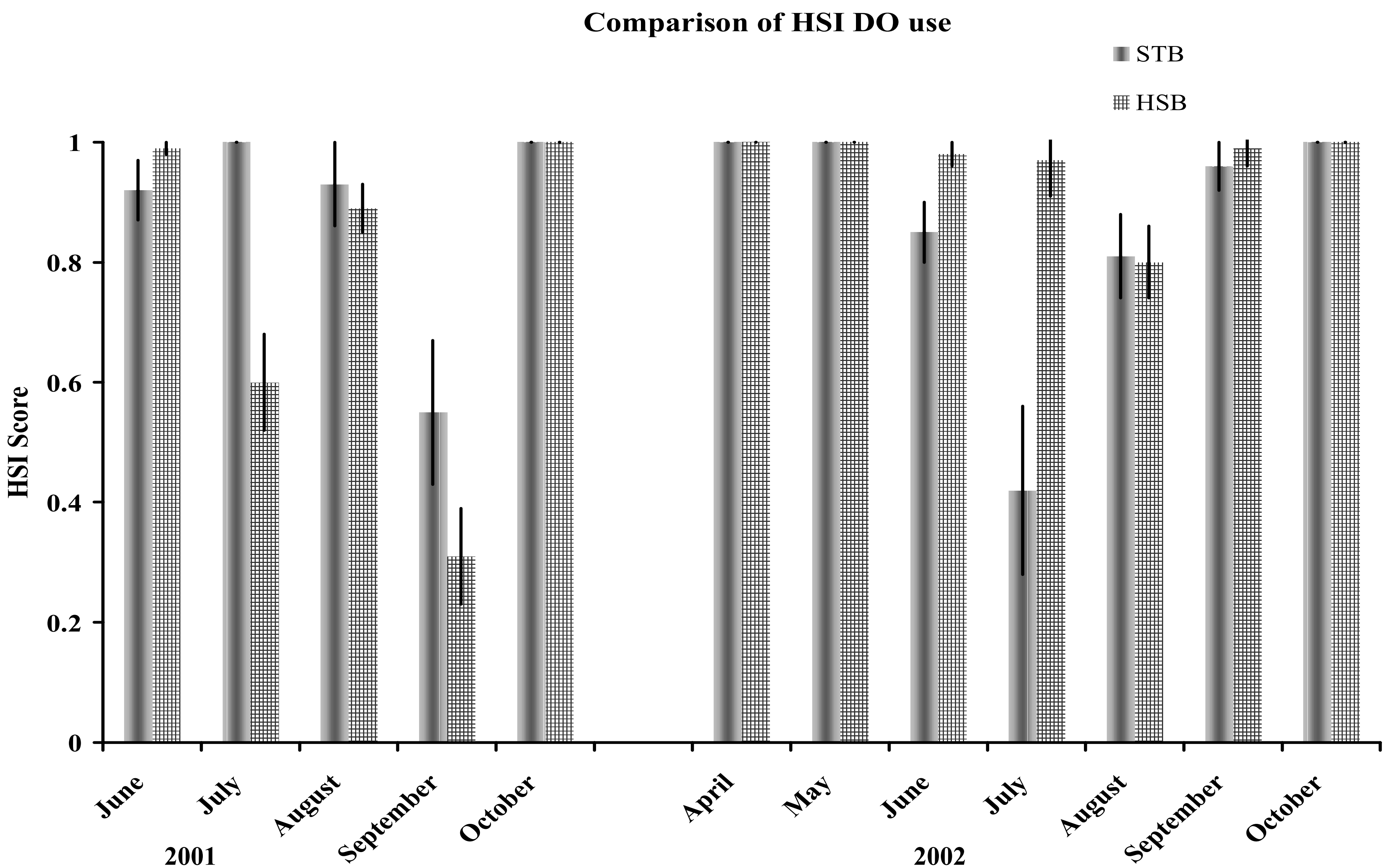


Figure 42. Comparison of DO habitat suitability index scores (with standard error bars) from telemetered STB and HSB during summer stratification in Claytor Lake, 2001 and 2002.

When only the minimum HSI scores (either temperature or D.O.) were considered, which is reasonable because this represented the most stressful conditions, it was clear that STB occupied disproportionally marginal habitats to those used by HSB (Figure 43). For instance, HSB were assigned HSI scores lower than 0.6 only during September of 2001 (DO HSI score 0.31) and August of 2002 (Temperature HSI score 0.35), but STB were assigned HSI scores lower than 0.6 in July (Temperature HSI score 0.53), August (Temperature HSI score 0.34), and September (Temperature HSI score 0.35) of 2001, and July (DO HSI score 0.42), August (Temperature HSI score 0.01), and September (Temperature HSI score 0.46) of 2002. Therefore, habitat became degraded for both STB and HSB during summer stratification in 2001 and 2002, but likely was more stressful to STB than HSB during this study.

When either temperature or D.O. became suboptimal, moronids often showed a tendency to select one habitat element over the other. By comparing minimum HSI scores within species for temperature and DO, STB were found to occupy water with higher DO scores than temperature: therefore they selected DO over temperature during summer stratification (Figure 44). Hybrid striped bass exhibited two different patterns for habitat selection (Figure 45). In 2001, HSB selected temperature over DO, but selected DO over temperature in 2002.
Based on the habitats occupied by telemetered fish during the 17 months of this study under different combinations of temperature and DO, several habitat generalizations can be made. In order to inhabit temperatures <20°C, STB tolerated DO levels of 2-3 mg/L. However, to avoid DO levels of <2.0 mg/L, STB tolerated water temperatures in excess of 25°C. Hybrid striped bass tolerated water temperatures in excess of 26°C to avoid DO levels of <2.0 mg/L. They would, however, tolerate DO levels of 2-3 mg/L to inhabit water temperatures <26°C.

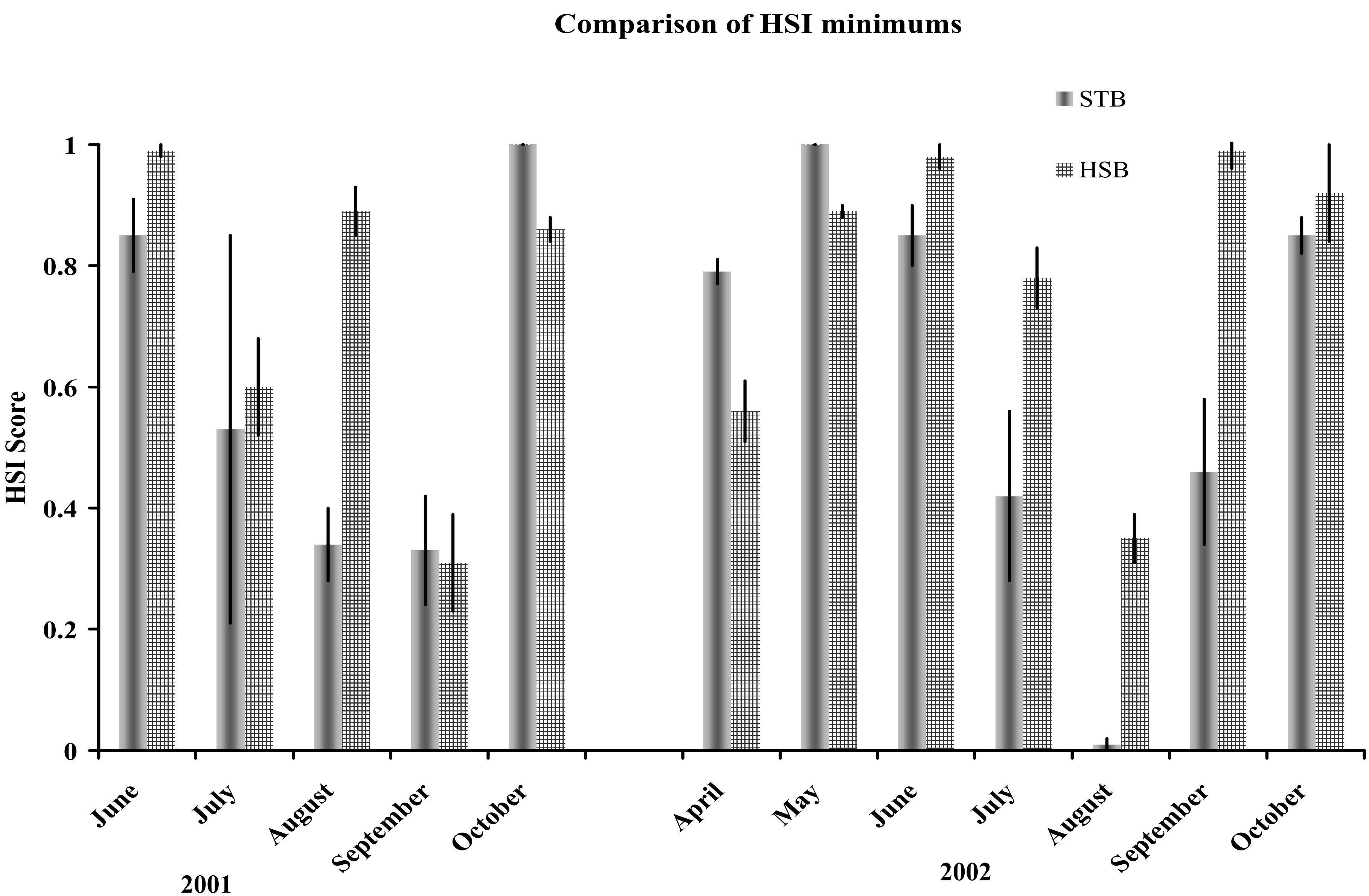


Figure 43. Comparison of minimum temperature or DO habitat suitability index scores (with standard error bars) from telemetered STB and HSB during summer stratification in Claytor Lake.

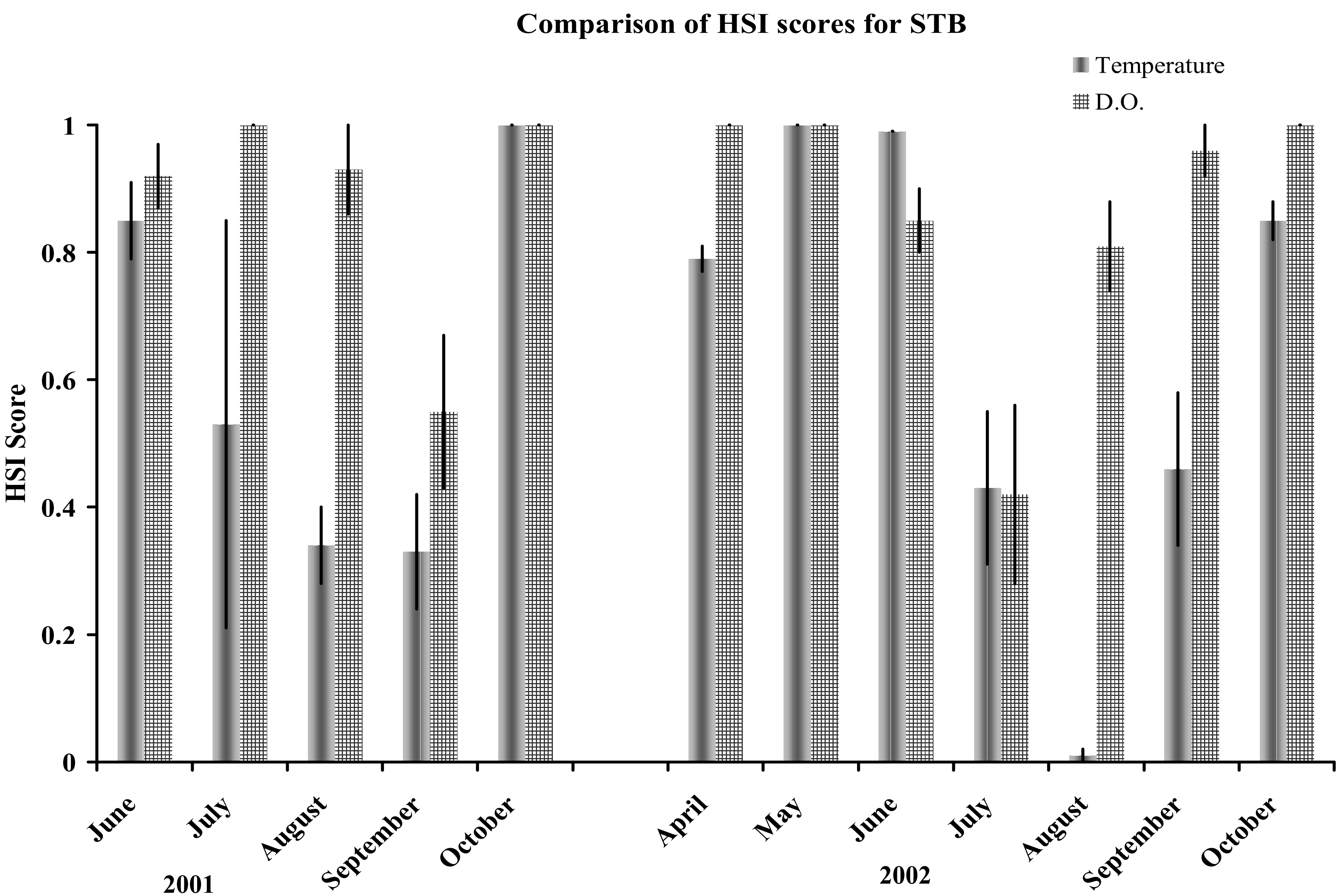


Figure 44. Comparison of temperature and DO habitat suitability index scores from telemetered STB during summer stratification in Claytor Lake.

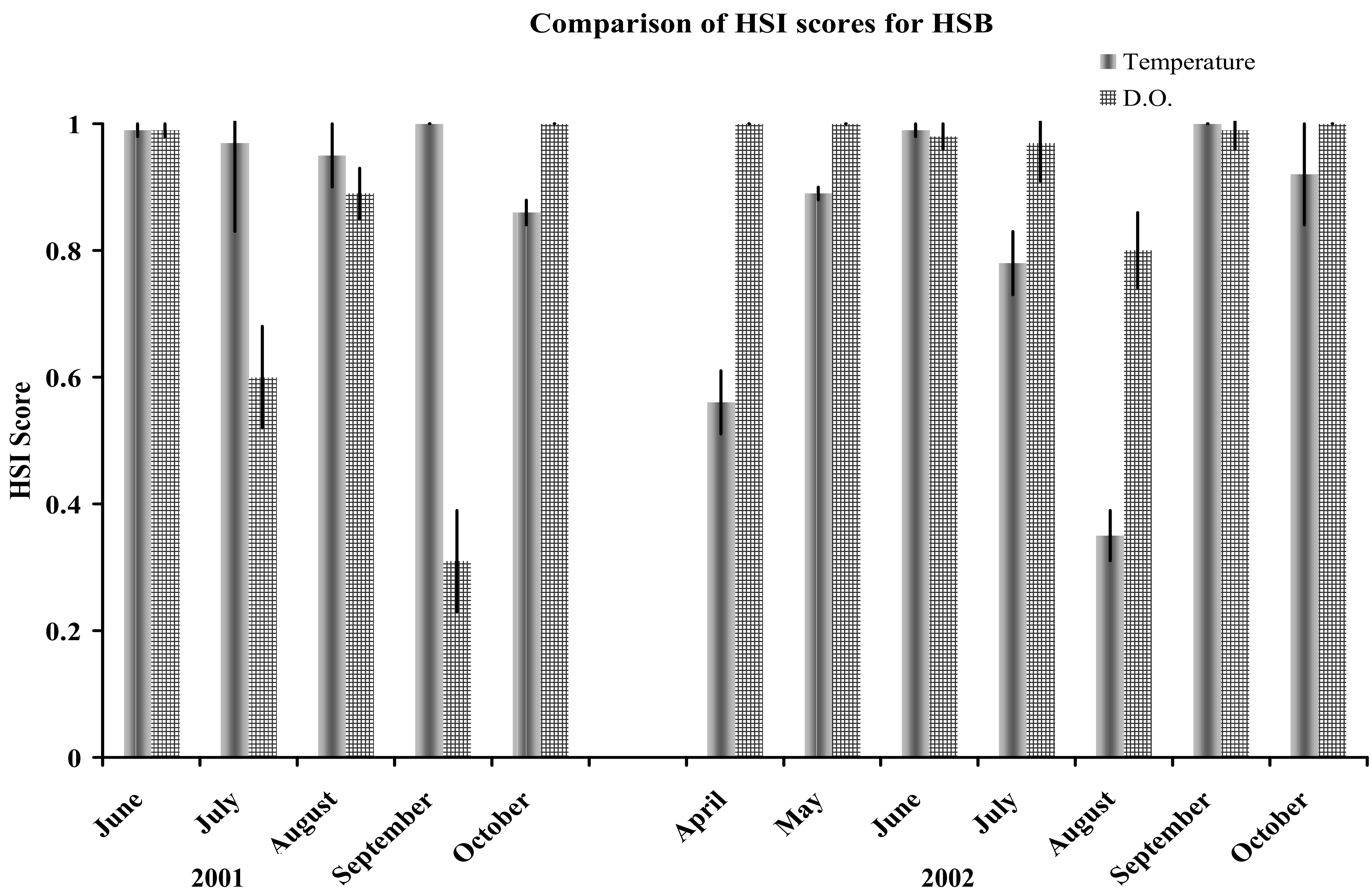


Figure 45. Comparison of temperature and DO habitat suitability index scores from telemetered STB during summer stratification in Claytor Lake.

When considering volume of water in the established habitat suitability categories of optimal, suboptimal, and poor, STB had little optimal habitat available during the summer of 2001 (Figure 46). Optimal habitat entirely disappeared from late August to early September, but refuge areas still existed (suboptimal). Even suboptimal habitat, however, comprised less than 20% of Claytor's volume in late August and poor habitat occupied most of the reservoir. In the summer of 2002, STB habitat declined even further during the warmest months (Figure 47), and from late July until late August, more than 99% of the reservoir was of poor quality.

Hybrid striped bass also experienced reduced volume of optimal habitat in the summer of 2001, although nowhere near as extreme as that for STB (Figure 40). The large percentage of suboptimal habitat in October represents cool water, below the HSB summer optimal but not usually associated with poor condition or mortality. When comparing 2001 data between STB (Figure 46) and HSB (Figure 48), it is apparent that a fairly large (>20%) volume of refuge or optimal habitat existed for both STB and HSB. Even HSB habitat, however, was severely degraded in the summer of 2002 (Figure 49). In early August, no optimal HSB habitat was available and less than 10% of Claytor's volume was HSB suboptimal refuge area.

Dam operation effect on reservoir habitat

There was a significant difference in temperatures taken 0.4 km in front of the dam between times when the generators were operating and when they were not for the depths of 16 m ($n=2081$, $F=22.88$, $P<0.01$, 17 m ($n=2081$, $F=31.70$, $P<0.01$), 18 m ($n=2081$, $F=7.80$, $P<0.01$), and 19 m ($n=2081$, $F=4.94$, $P=0.03$). No significant difference was found for the 15 m depth ($n=2081$, $F=0.11$, $P=0.73$), likely because this depth was located near the thermocline and water temperature was unstable in this stratum. For depths of 16-19 m, all mean temperatures were

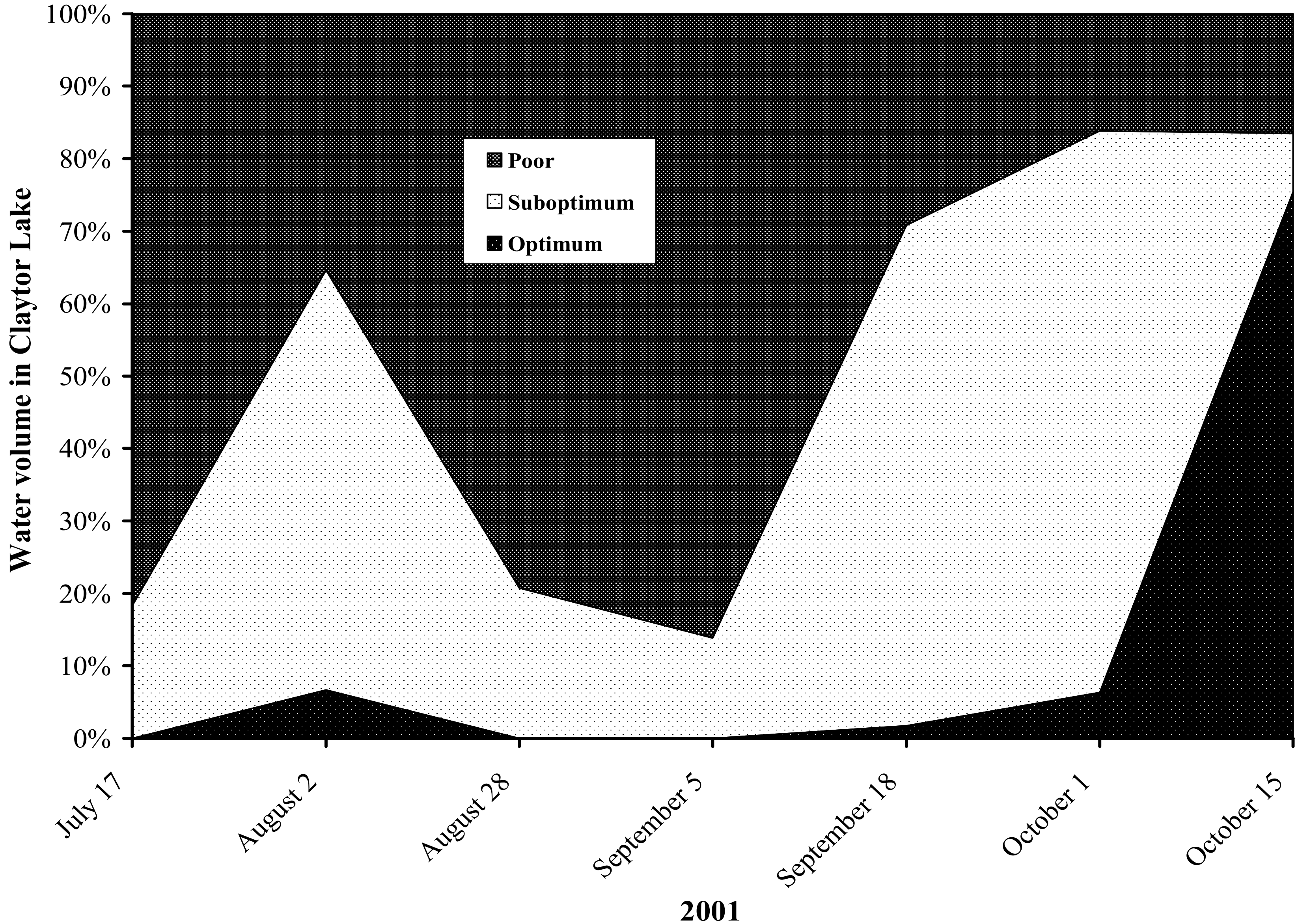


Figure 46. Available habitat for STB in Claytor Lake, Virginia during summer stratification in 2001.

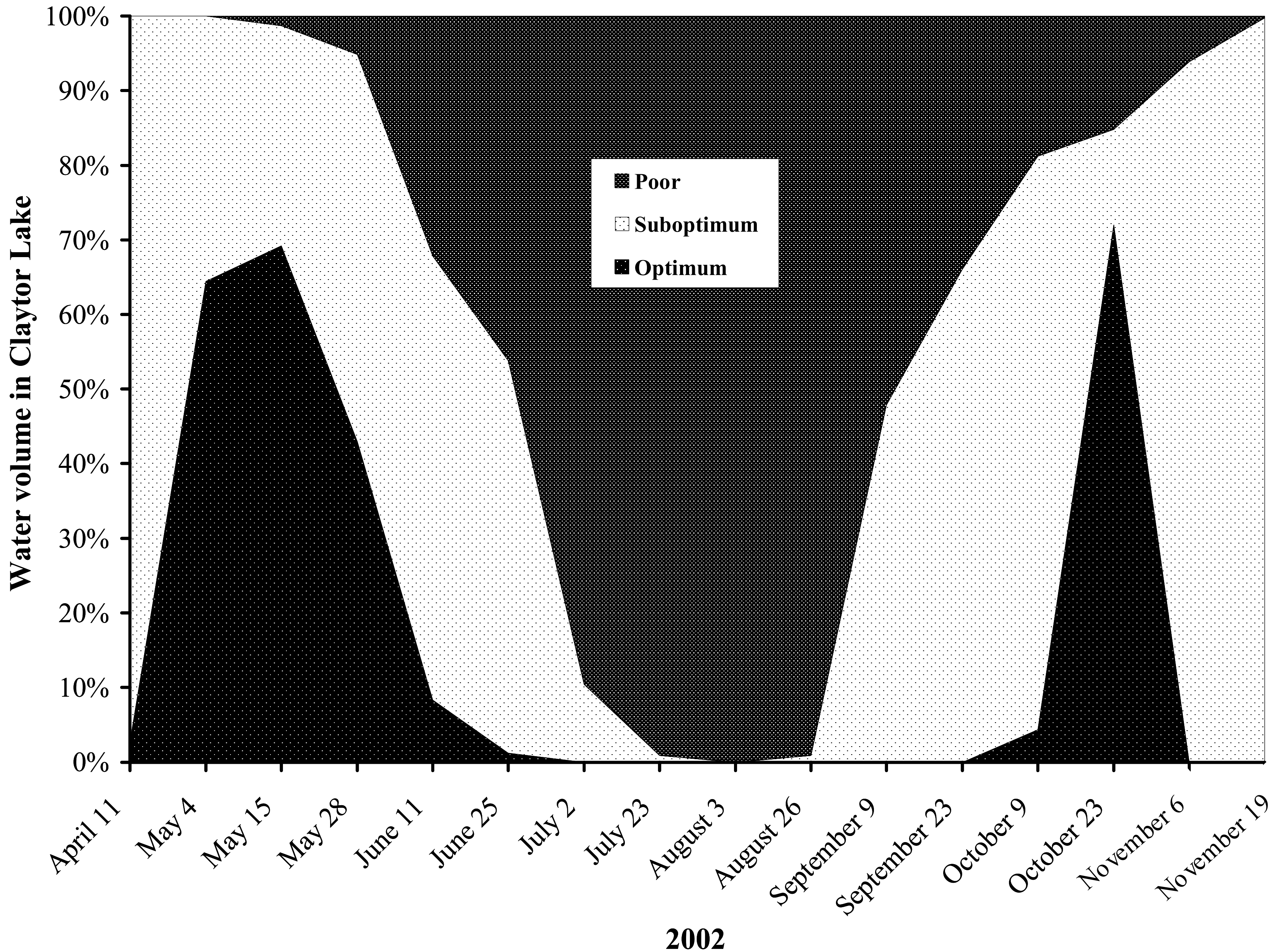


Figure 47. Available habitat for STB in Claytor Lake, Virginia during summer stratification in 2002.

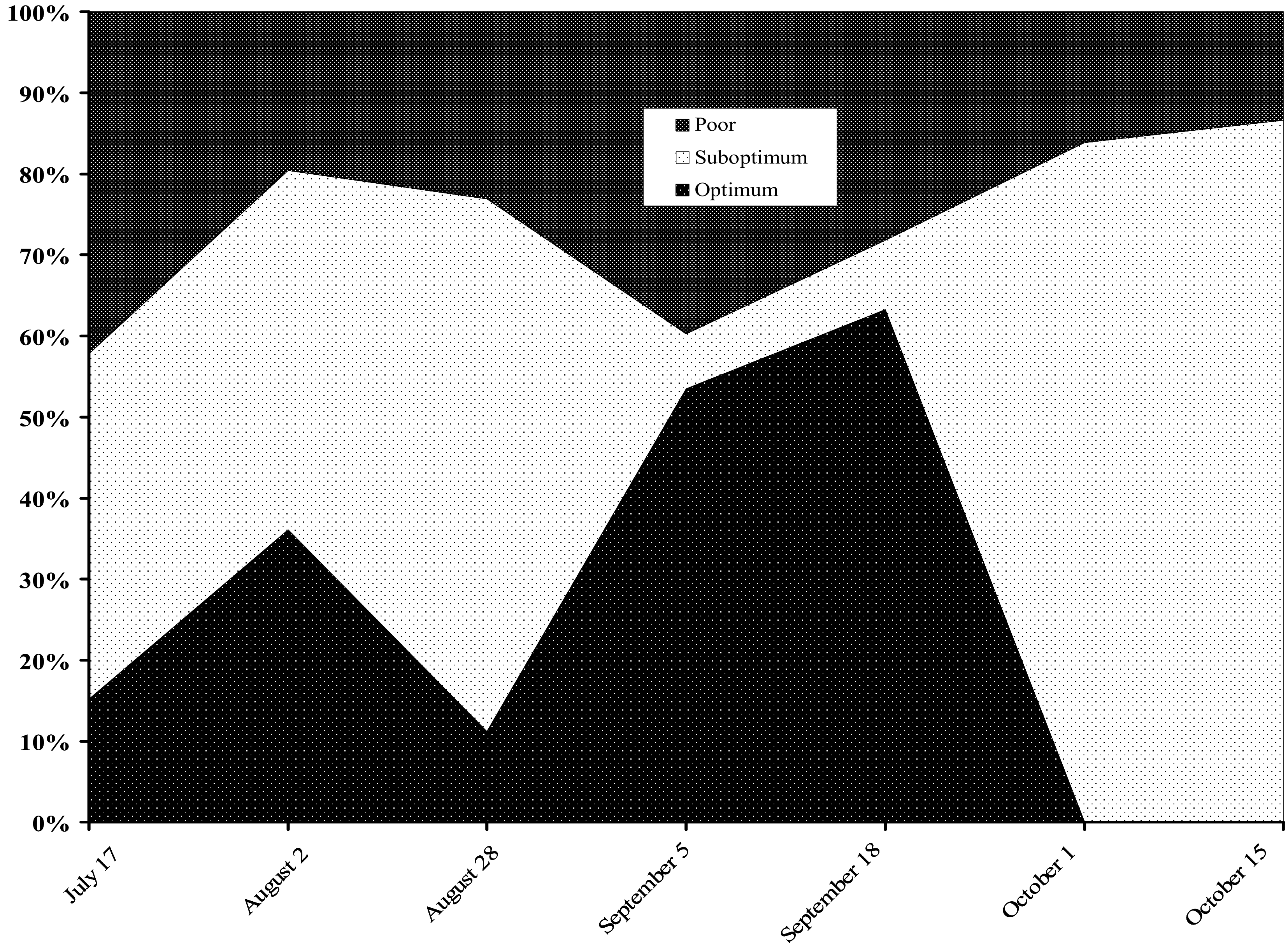


Figure 48. Available habitat for HSB in Claytor Lake, Virginia during summer stratification in 2001.

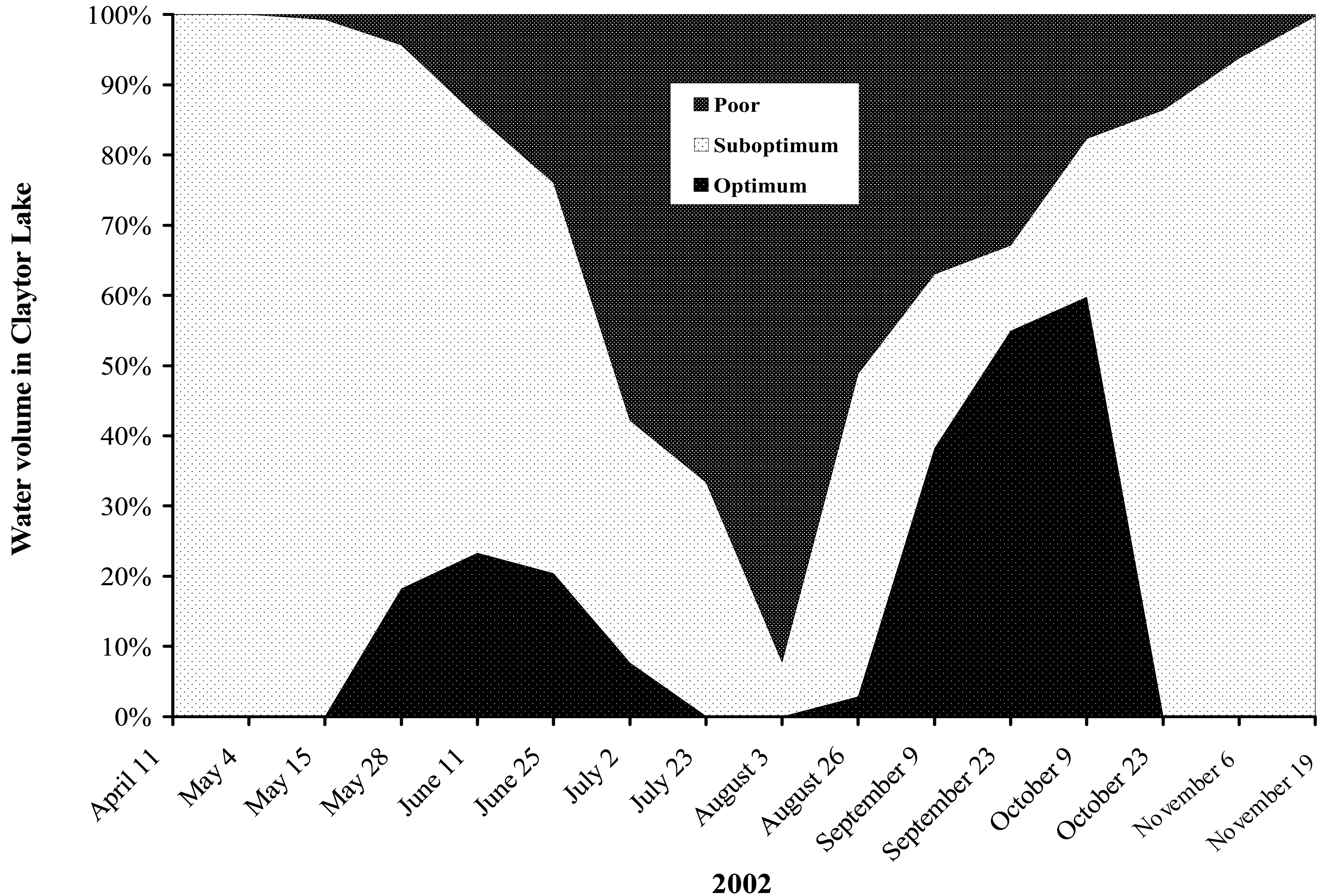


Figure 49. Available habitat for HSB in Claytor Lake, Virginia during summer stratification in 2002.

lower following generation than during generation, although the differences were only 0.18, 0.12, 0.05, and 0.06°C. The decreases in temperature occurred immediately after the opening of the generators (Figure 50), and then slowly increased when the generators ceased releasing water. Graphs from each day temperature data were taken (0.4 km above Claytor dam) are represented in Appendix 5.

Exploitation

Eight STB were reported caught during this study by 7 different anglers. In addition, 40 HSB were reported caught by 26 different anglers. Of these, 6 total STB (3 in 2001, 3 in 2002) and 32 total HSB (5 in 2001, 27 in 2002) were reported as harvested. Fourteen of the fish that were caught were also radio-tagged (6 STB, 8 HSB), including one that was tagged in and eventually harvested from the tailrace. Three STB and 10 HSB were reported as caught in 2001, whereas 5 STB and 30 HSB were reported as caught in 2002. A total of $735.00 in reward money was offered for STB ($155.00) and HSB ($580.00).

To take into consideration fish mortality from handling, I applied the following estimate of STB mortality captured on natural baits, as determined by Wilde et al. 2000:

$$\text{Fish mortality} = e^{-4.59 + 0.17*temp} / (1 + e^{-4.59 + 0.17*temp})$$

I used the mean Claytor Lake temperature (°C) for each month for which fish were collected for tagging. Using this formula, the percentage of fish that were lost during handling and tagging ranged from 2% (February 2002) to 23% (June 2002).

To estimate the average number of fish per year available to anglers, I also accounted for natural mortality. Using the instantaneous natural mortality rate (M=0.14) estimated by Hightower et al. (2001) for STB on Lake Gaston, Virginia, I estimated annual STB natural

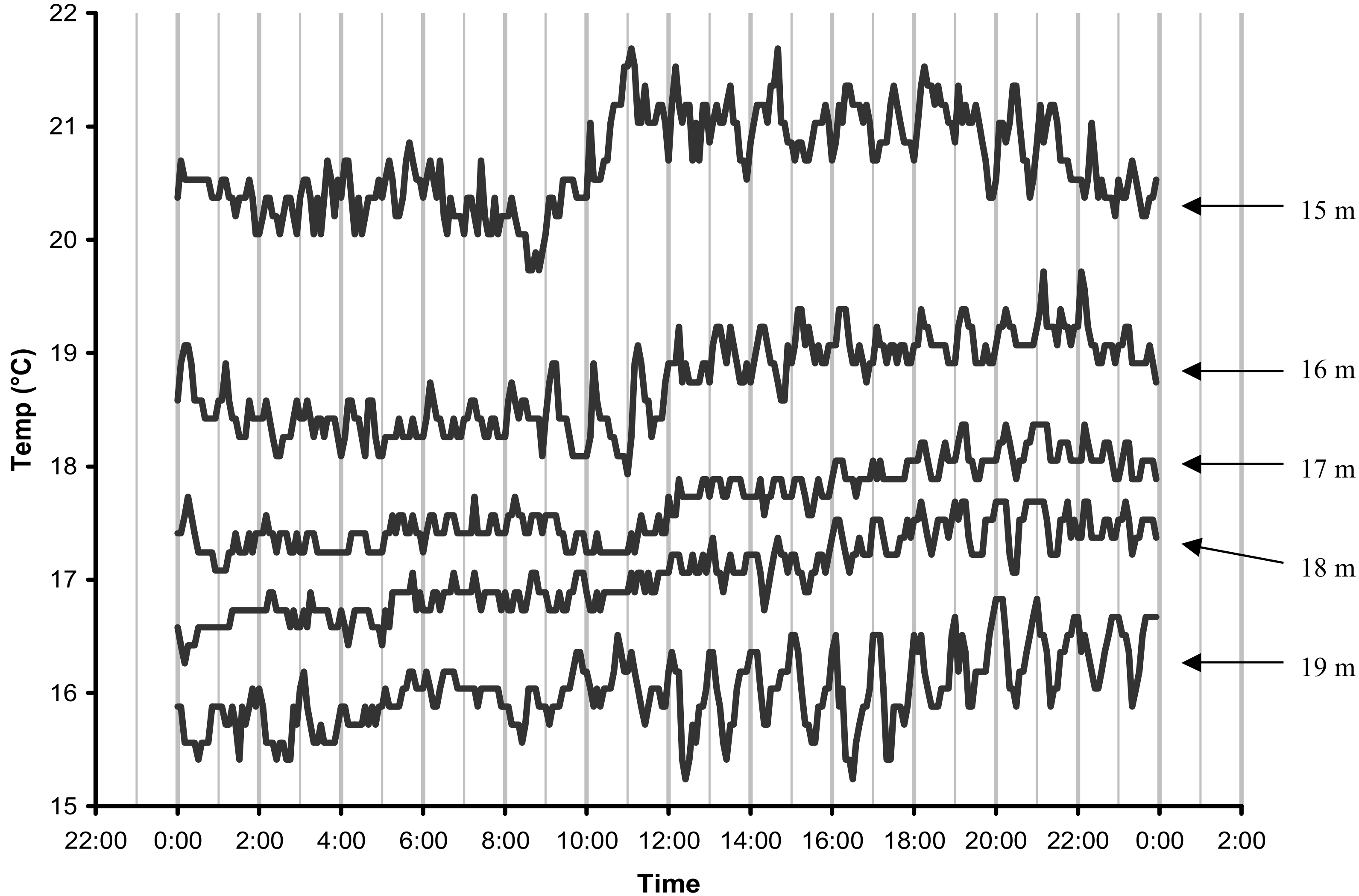


Figure 50. Temperature profiles from Claytor Lake, 8-9-02 from 15-19 m depth. Beginning at the top of each hour, each generation cycle was 21 minutes of water release followed by 39 minutes of inactivity. Vertical bars represent start times for power generation

mortality to be 13.1%. Because the natural mortality rates for HSB were unknown, I also utilized the M estimate for STB in the HSB harvest calculations. To estimate the average number of tagged fish available to anglers throughout each year, I averaged the number of fish left after handling mortality with the number of fish left at the end of each year left after the annual natural mortality rate of 13.1%. Fish left over from 2001 (minus fish that died from handling, were harvested, and died from natural mortality) were added to those tagged for 2002. Internal tag loss is negligible (Dunning et al. 1987), so 100% retention was assumed. Based on these estimates, an average of 103 tagged HSB and 14 tagged STB were available to anglers in 2001, whereas 300 tagged HSB and 60 tagged STB were available to anglers in 2002 (Table 19).

The non-reporting rate estimated from window tags was 90% (only 10 of 100 cards were returned). This rate was unreasonably low; after a 90% correction factor was included in exploitation estimation, harvest rates were above 100%, which was impossible. Reporting estimates have been generated for other systems and species (e.g., reporting rate of 20.8% for red drum *Scianops ocellatus* in South Carolina and Georgia, Denson et al. (2002); 33% for smallmouth bass in Oklahoma, Zale and Bain (1994)). However, the only known estimate either in Virginia or for STB was a study conducted on STB in Smith Mountain Lake (SML) in 2002 (D.Wilson, VDGIF, unpublished data). Therefore, I applied the non-reporting rate from SML (49.3%) to our data. Although 3in x 5in cards were used in the SML study, the cards were personally handed out to anglers instead of anonymously left on windows. Therefore, return rates from the Smith Mountain Lake study were higher and likely more accurately reflected the return rate from tagged fish.

Table 19. Exploitation data for STB and HSB on Claytor Lake, 2001 and 2002.

	Hybrid striped bass				Striped bass			
	Gross[1]	Adjusted[2]	Avg. available[3]	Exploitation (%)[4]([5])	Gross	Adjusted	Avg. available	Exploitation
2001	127	111	103	9.8 (4.8)	18	16	14	41.5 (20.5)
2002	258	234	300	18.3 (8.9)	65	57	60	4.7 (10.1)
Average[6]				**14.0**				**25.8**

[1] Number of fish caught and tagged with internal anchor tags
[2] Number of fish remaining after tagging mortality
[3] Average number of fish available to anglers in Claytor Lake, after accounting for an instantaneous natural mortality (M) of 0.14
[4] Yearly harvest percentage, after correcting for 49.3% reporting rate
[5] Uncorrected harvest percentage, not accounting for tag non-reporting rate
[6] Estimated average yearly harvest from Claytor Lake

Estimated annual harvest rates for HSB in Claytor Lake was 9.8% in 2001 and 18.3% in 2002, whereas annual harvest rates for STB were 41.5% in 2001 and 4.7% in 2002. The estimated average annual harvest from Claytor Lake was 14.0% for HSB and 25.8% for STB.

Emigration

None of the fish that were tagged in the reservoir were taken by anglers fishing the tailrace. However, on one occasion I did discover a HSB that had migrated out of the reservoir through the dam. This fish was tagged on 2/11/2002 and was recaptured via boat electrofishing on 4/19/2002. This fish (552 mm TL) appeared to be in good health and was re-released. One HSB (546 mm TL) that was tagged in the tailrace was caught by a fisherman in approximately the same location as the original capture (less than 50-m below Claytor dam). It was tagged on 5/10/02 and was recaptured on 6/27/02.

Of the 10 fish that were tagged in the tailrace, only three remained by December, 2002. Curiously, of the two STB (578-632 mm TL) that were tagged, both remained, whereas only one (530 mm TL) of the original 7 HSB tagged in the tailrace remained. On most occasions, the radio-tracked fish were located close (<50 m) to Claytor dam, and most fish were found directly in the water release chutes, both while releasing water and when generators were idle. During August, five of the nine fish (one HSB had been harvested) remained in Claytor's tailrace, despite poor water quality. Measurements taken directly below the dam on August 27, 2002 revealed a temperature of 23.3°C, but DO levels of only 1.9 mg/L. Nearby Little River offered well oxygenated water (7.5 mg/L), but tagged fish were presumably avoiding the warmer water temperature there (24.4°C). Although the whereabouts of the fish that were no longer found are unknown, this suggests that at least some portion of the fish in Claytor's tailrace represent resident populations of STB and HSB.

DISCUSSION

Habitat quality

Throughout most of the year, Claytor Lake offers adequate refuge habitat for survival and growth of adult STB (<25°C, >2.5 mg/L). However, even sub-optimal STB habitat disappeared during the summer of 2002 during most of July and the entire month of August. Summer refuge habitat (<27.5°C, >2.0 mg/L) was available for HSB during both summers of this study. Summertime habitat loss was represented by increased water temperatures and decreased DO levels.

Both STB and HSB tended to occupy water with the best available conditions, in terms of either temperature or DO. In 2001, both STB and HSB were trapped in a classic temperature/DO squeeze, similar to that documented by Coutant (1985). The development of an anoxic stratum of water at the bottom of the metalimnion discouraged STB and HSB movement out of the aerated portion of the hypolimnion, but HSB occupied shallower, warmer water than STB within the oxygenated hypoliminion. In 2002, however, the entire portion of the reservoir below the metalimnion was anoxic, and both STB and HSB were forced to occupy the shallower, but warmer (>25°C) upper metalimnion and lower epiliminion.

During both summertime periods, radio-tagged fish were only found in the lower 1/3 of the reservoir (lower 11 km). The lower portion of the reservoir represented greater depth and volume with lower productivity; therefore it contained a larger amount of habitat for both STB and HSB throughout the warmest months.

Dam operation may also influence the amount of summertime habitat available to STB. The penstock openings for water discharge through the Claytor's generators are from 6.4-20.4 m in depth. Although the depths of water susceptible to discharge were beneath the STB and HSB habitat in 2002 , it drew upon summer fish habitat during the warmest months in 2001. The location of the water draw from Claytor contributes to direct loss of habitat and possibly results in loss of adult fish through the dam. In August 2002, I determined Claytor's discharge into the New River to be about 23.3°C. This temperature corresponded to Claytor Lake water temperatures that were at a depth of about 17 m, although this represents an average temperature drawn from 6-20 m. However, the temperature that corresponded to the mean depth of 17 m suggests that the dam draw may be concentrated at a depth at which summertime refuge habitat often exists in Claytor Lake. This may have direct implications for potential hydropeaking operations on Claytor Lake. If large amounts of water are released in short periods of time, fish may be more susceptible to emigration. Also, it is apparent from the temperatures recorded near the dam (Figure 50), that declines in temperature during water release were followed by temperature recovery, a cycle that repeated every hour. This suggests that habitat is not completely lost, but is rather gradually replaced every hour. If hydropeaking occurs at Claytor Dam, the habitat loss present during generation would still likely be replaced, but both the habitat loss and recovery would be more severe. Fish are likely able to tolerate small-scale changes in habitat (cycling every hour), but may not be able to withstand larger habitat losses (cycled every 24 hours). If habitat rapidly shrinks during peaking operations, adult moronids may simply follow this habitat out of the reservoir and through the turbines.

This loss of habitat was supported by both radio-telemetry data (Appendix 3) and vertical profile data (Appendix 4). Although there was a general decline in deeper, cooler STB and HSB habitat farther from the dam, during August of 2001 and 2002, the reverse trend existed in the lower 3.2 km of Claytor Lake. During August of both years, water containing DO levels of >2.0 mg/L extended about 2 m deeper (23.5 m in 2001, 9 m in 2002) 3.2 km from the dam than directly in front of the dam (22.5 in 2001, 7 m in 2002). Water temperature at this depth during 2001 was also about 0.1-0.2°C cooler at the 3.2 km site than directly in front of the dam. Therefore, fish did experience the classic summer squeeze in Claytor Lake, but, similar to other studies (Combs and Peltz 1982; Hampton et al. 1988; Farquhar and Gutreuter 1989; Schaffler et al. 2002; Young and Isely 2002) were not located within very close proximity to the dam during the warmest months, presumably due to habitat loss via dam operations.

Although the decline of habitat during summertime conditions was expected, the difference in habitat between 2001 and 2002 warrants further discussion. The flow regime in Claytor differed dramatically between the two years (Figure 51). Springtime flows in 2002 were slightly higher than in 2001. However, two of these days experienced water flow averaging about 20,000 cfs, and a large amount of organic matter was deposited into Claytor (G. J. Devlin, Virginia Department of Environmental Quality, personal communication). As these organics gradually settled into the deeper layers of Claytor Lake, the lake began to warm up and stratify. By May 2002, the reservoir had fully stratified, but flows remained low. The organics remaining in the hypolimnion coupled with the low degree of mixing from incoming water currents rendered the deeper portions of Claytor anoxic in 2002, and led to almost a complete loss of STB habitat (<25°C and >2.5 mg/L) during the warmest months of 2002 (late July-August). Flows were also below average in the spring of 2001, but flows during the warmer periods of May-August of 2001 remained approximately average. Therefore, in 2001, water turnover rate was fairly high in the metalimnion and hypolimnion, not as many organics were introduced in the spring, and STB habitat persisted throughout the year.

The loss of habitat in 2002 left concern for fish mortality. Although I did not see a definitive pattern in radio-tagged fish mortality, I did notice an increase in fish mortality (dead fish floating) both in the summer of 2001 and 2002. Striped bass mortality from loss of habitat has been documented on many other reservoirs. Most documented mortality occurring in southeastern reservoirs occurs in the warmer months (Matthews 1985). Larger STB may have less temperature tolerance (Coutant 1985), and are likely more susceptible to summer mortality. This was consistent with reports from Matthews (1985), that most summer mortality was concentrated on fish > 5kg in Lake Texoma. I noticed dead fish every time I radio-tracked on Claytor during the summer of 2002, but only observed sporadic mortality during 2001. The fish mortalities that I inspected, whether from natural or hooking mortality, were concentrated on larger (>5 kg) STB especially in 2002. Few HSB mortalities were noted during this study, even during times of apparent high concurrent STB mortality. This would be consistent with the higher temperature tolerance of HSB, subjecting them to a less physiological stress during the summer of 2001 and 2002. My study did not likely identify patterns of natural mortality partly because most of my tagged fish were < 5.0 kg.

Because both STB and HSB were in warmer water in 2002 than in 2001, I did, however, suspect that they might be in poorer condition in 2002. Relative weight (Wr) is an easily determined measure of fish body condition, and criteria were developed by Brown and Murphy (1991). We obtained relative weight (Wr) data for STB and HSB from the VDGIF fall gillnet sampling on Claytor Lake for both 2001 and 2002. Although Bonds (2000) identified faster growth rates and larger Wr values for STB from Claytor Lake following an illegal introduction of gizzard shad into Claytor in the early 1990s it was unknown how a year in which habitat was of poor quality, such as in 2002, might influence fish growth and condition. While Wr values were high (94 for STB, 100 for HSB) in fall 2001, they both dramatically decreased in fall 2002 (84 for STB and 86 for HSB) (Figure 52). Because the gillnet samples did not sample fish larger

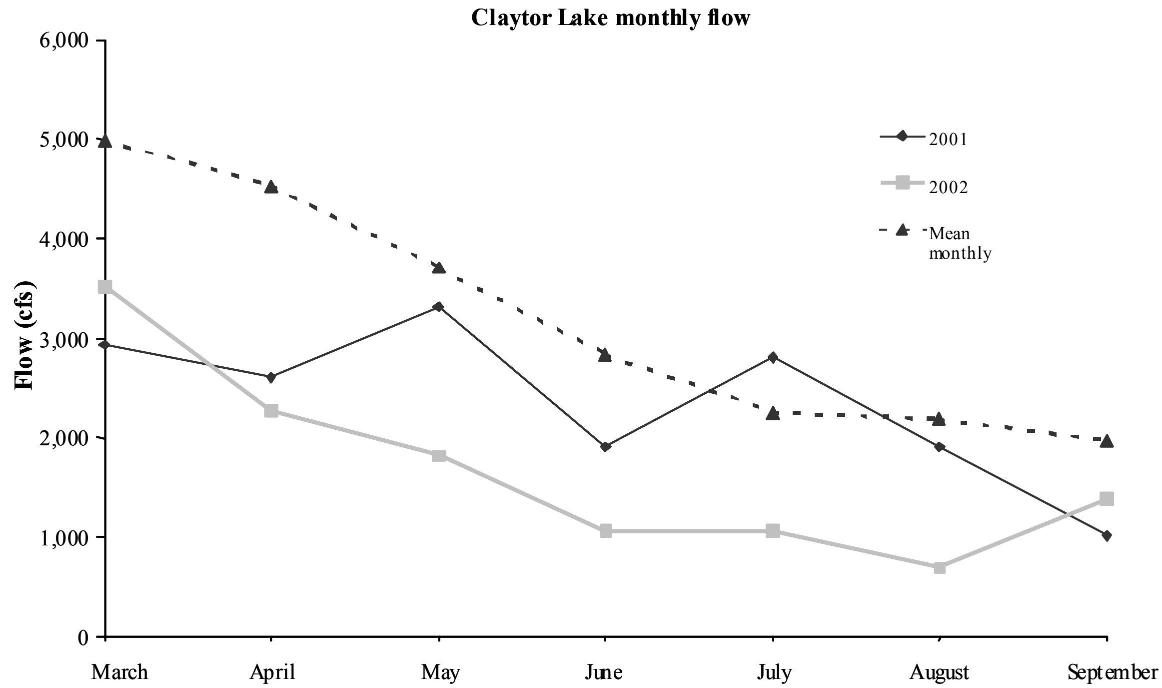


Figure 51. Mean monthly flows into Claytor Lake during 2001 and 2002. Seventy-year average monthly flow is also shown for reference.

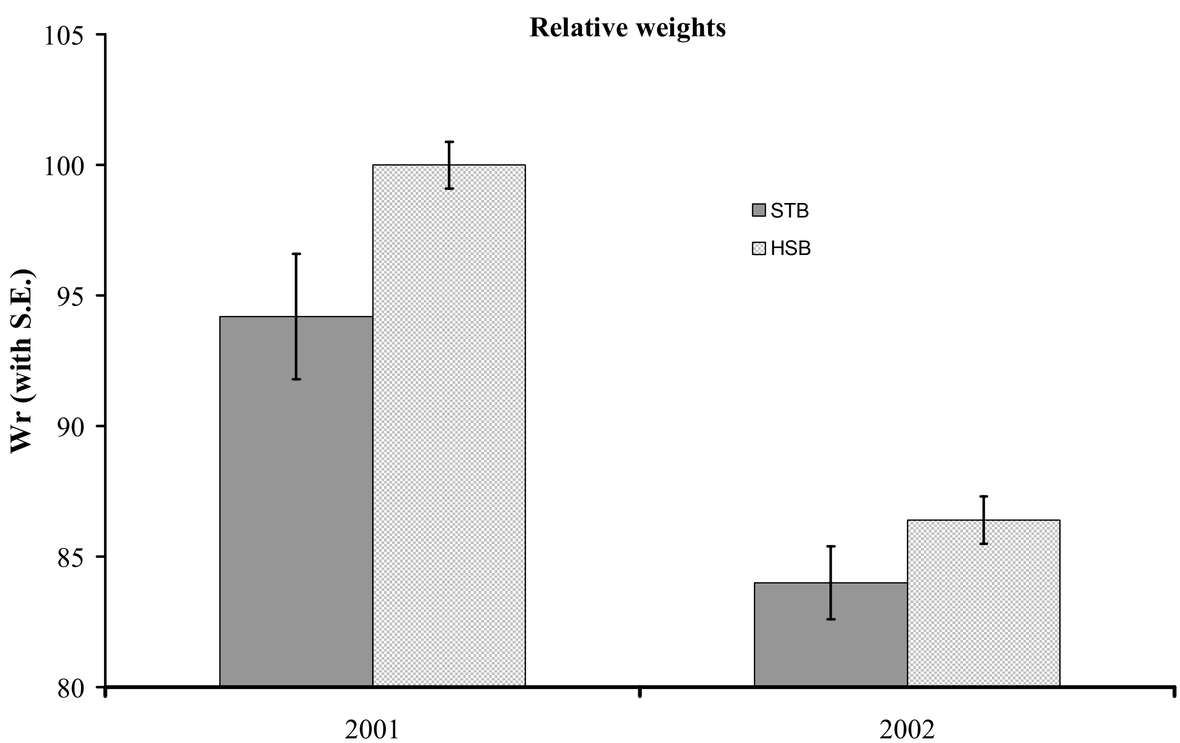


Figure 52. Relative weights (Wr) for STB and HSB from Claytor Lake, Fall 2001 and 2002. Mean Wr and standard errors are shown.

than 5 kg, it is likely that larger fish body condition may have been even poorer than the primarily 1-4 year old fish represented in the gillnet sample.

Habitat use

Habitat use for both STB and HSB was disproportional to its availability in Claytor Lake. During summer stratification, the vertical distribution of STB was determined more by DO than by temperature. Therefore, it can not be said that STB preferred summer temperatures occupied (22.5°C in 2001, 24.9°C in 2002), but rather used these temperatures to avoid low DO levels (<5.0 mg/L). During the summers of 2001 and 2002, STB were found at respective averages of 5.0 mg/L and 4.7 mg/L. If adequate DO levels existed (>2.5 mg/L) and preferred temperatures were available, STB sought temperatures of 15-20°C. However, if DO levels dropped below 2.5 mg/L, STB simply selected the coolest possible water with DO >2.5 mg/L. In many systems, this would represent some sort of refuge area, such as a tailrace releasing cooler water than that of the reservoir occupied by the fish. However, no cool water input thermal refuge areas were identified in this study and both STB and HSB were forced into water in excess of 27°C during summer stratification in 2002 to avoid water <2.5 mg/L.

Average summertime temperatures occupied by STB in Claytor Lake (22.5-24.9°C) were cooler than STB in Lake Whitney, Texas (27-29°C; Farquhar and Gutreuter 1989) and Lake Norman, North Carolina (22-28°C; Van Horn et al. 1996), but warmer than STB in Melton Hill Reservoir, Tennessee (14.1-16.7°C; Bettoli 2000) and STB in Lake Murray, South Carolina (16-18°C; Schaffler et al. 2002). Although the summer temperature average for STB in Claytor Lake was 22.5°C in 2001 and 24.9°C in 2002, similar to findings of Van Horn et al. (1996), STB in Claytor Lake were found during the warmest parts of the summer (late August to early September) to occupy temperatures of up to 27°C. Average summer DO use by STB in Claytor

Lake (4.7-5.0 mg/L) was higher than that found from telemetered fish in Lake Norman (2.3-4.7 mg/L; Van Horn et al. 1996), but similar to that found with fish from J. Strom Thurmond Reservoir, South Carolina (5-6 mg/L; Young and Isely 2002) and Watts Bar Reservoir (>4.0 mg/L; Cheek et al. 1985). It is important to note that, while STB may persist in both Lake Whitney, Texas and Lake Norman, North Carolina, fish rarely grow larger than about 10 kg in either of these reservoirs, whereas fish >10kg are harvested from Lake Melton Hill, Tennessee, Lake Murray, South Carolina, and J. Strom Thurmond Reservoir, South Carolina.

Average summer temperatures occupied by HSB in Claytor Lake (23.8-25.5°C) were cooler than temperatures occupied by telemetered HSB in Clarks Hill Reservoir, Georgia-South Carolina (25-28°C; Windham 1982), Ross Barnett Reservoir, Mississippi (27-29°C; Muncy et al. 1990), and Lake Fairfield, Texas (30-33°C; Piner 1993), but similar to HSB from Spring Lake, Illinois (24-25°C; Douglas and Jahn 1987). Average summer DO habitat used by HSB in Claytor Lake (4.0-5.8 mg/L) was similar to those in Clarks Hill Reservoir, Georgia-South Carolina (>4 mg/L; Windham 1982), Ross Barnett Reservoir, Mississippi (>4 mg/L; Muncy et al. 1990), and Lake Fairfield, Texas (>5.0 mg/L; Piner 1993), but higher than fish from Spring Lake, Illinois (2-5 mg/L; Douglas and Jahn 1987). The temperature and DO habitat used by HSB in Claytor Lake is apparently very good, as temperatures and DO levels used are moderate for HSB from other studies. From the studies of Douglas and Jahn (1987), Muncy et al. (1990), Piner et al. (1993) and Windham (1982), the maximum size and weight of tagged fish was 578 mm TL and 3.4 kg (Ross Barnett Reservoir, Mississippi). However, in Claytor Lake, VDGIF gillnet collections have yielded HSB 660 mm TL and 4.4 kg. During collections for this study, I collected fish up to 787 mm TL and 7.8 kg.

HSI model validation

Although Coutant and Carroll (1980) suggested a temperature preference for STB centered around 22°C and Crance (1984) modeled optimal habitat at 20-25°C, STB in Claytor Lake seemed to prefer cooler temperatures. For instance, in late June of 2002, oxygenated water was available from 17-29°C, STB were found at 18-19°C. This fell within the predicted optimal temperature range from HSI model for STB, as developed from other radio telemetry studies. During this same time period in June, 2002, when oxygenated water was available from 17-29°C, HSB selected water temperatures of 23-25°C. At this time, fish were in the same horizontal locations. From late May until late June (Appendix 3), a range of oxygenated water was available from 17-29°C, and STB and HSB were found to be vertically separated. Similarly, in early summer of 2001, STB were found in 20°C water, when at the same time and approximate same horizontal locations, HSB were found in 21-25°C water. At no other times of the year were a wide range of oxygenated temperatures available to fish, which led to our finding of vertical habitat overlap throughout most of the year in 2001 and 2002. These data were similar to the findings of Young and Isely (2002), who found that STB during summer stratification in Keystone Reservoir, Oklahoma would tolerate suboptimal DO (3.0-4.3 mg/L) in order to inhabit water at 16.5-19.4°C, and Schaffley et al. (2002) who found STB in Lake Murray, South Carolina to inhabit water of 16-18°C even as the DO was <5 mg/L. The optimal temperatures presented within the revised HSI models for STB (15-20°C) and HSB (21.5-25.5°C) were supported by locations of fish during this study, but only during the brief times when these conditions presented themselves simultaneously to STB and HSB.

Striped bass have been suggested to prefer DO levels of >5 mg/L (Crance 1984; Coutant 1985; Young and Isely 2002), whereas HSB have been found to select for habitat >4.5 mg/L

(Douglas and Jahn 1987; DeMauro 1990; Muncy et al. 1990; Piner 1993). In Claytor Lake, DO preference was difficult to determine, but seemed to support the suggested DO optimals. An example of this was in August of 2002, when STB were found in water from 20-23°C (suboptimal temperature), apparently in order to inhabit DO levels that were optimal (>5 mg/L). Similarly, in August of 2002, STB were in water that was considered poor temperature (>25.0°C), but most were found at DO levels of >5 mg/L. HSB also showed a preference for DO levels of >4.5 mg/L. For example, in August of 2002, HSB were found in suboptimal temperatures (>25.5°C), but most fish were found at DO levels of 4-5 mg/L.

The HSI models developed from telemetry data apparently accurately described habitat for STB and HSB in Claytor Lake. If adequate DO levels exist for HSB, they will apparently seek out a preferred temperature of 21.5-25.5°C, while STB will seek out a preferred temperature of 15-20°C. Similar to STB, if DO levels drop below 2 mg/L, HSB will inhabit water in excess of 27°C.

The conditions at which both preferred temperatures and adequate DO exist in Claytor Lake at the same time was only during a brief (about one month) period in the spring. Therefore, adult HSB and STB have the potential to directly compete for both food and space during much of the year in Claytor Lake. The limited data that I have from 2001, suggest that, if appropriate DO levels are maintained in the reservoir, that STB will segregate from HSB by temperature. During summer stratification in Claytor Lake, STB and HSB overlap in their horizontal locations, they may distribute at different depths (temperatures). More research is needed to determine HSI transferability to other systems. Although I considered temperature and DO separately, obtaining an average HSI value would have been easier to interpret. However, the criteria may be weighted disproportionally and if the different values are not weighted accordingly, predictions as to optimal or poor habitat may be erroneous (Rumble and Anderson 1996). For instance, similar to the findings of Piner (1993), DO seemed to be weighted more than temperature for STB during summer stratification of both years, and therefore DO may be of higher importance than temperature. More research is needed to determine if any actual preferences exist between temperature and DO, and how this results in suitability for fish.

Fish distribution

There was a large degree of habitat overlap by STB and HSB in Claytor Lake during this study. Both fishes occupied similar horizontal locations during all seasons, and both participated in similar seasonal migrations. However, STB and HSB appeared to congregate in species-specific schools. Segregation may be driven by social aspects or because of difference in foraging efficiencies specific with the different body shapes of STB and HSB and not purely by habitat availability. Reports from fishermen also confirm that usually either STB or HSB are caught from one area during one time period, but generally not both. A curious example of this occurred in February of 2002 when lake temperatures ranged from about 4-6°C. Fourteen HSB and 7 STB were located on about a 700-m stretch of Claytor Lake. This likely represented the majority of the STB and HSB populations in Claytor Lake, as only one HSB and 3 STB were found anywhere else in the entire reservoir except for this one stretch of shoreline. Although these fish were densely packed in this area, the predominant STB school was located in the upper 500 m stretch, whereas the predominant HSB school was located in the lower 200 m stretch. Therefore, although the species were both located very closely together and even in close proximity to the same shoreline, they were spatially separated. Although I did not collect data from forage fish on Claytor, it is important to note that both STB and HSB were often found in close proximity to schools of forage fish (clupeids) that were evident on the boat-mounted Sonar. Therefore, the distribution and movements of forage fishes also likely influence fish movements.

Both STB and HSB exhibited general seasonal movement patterns. Landlocked STB in the southeast often spawn in early April to late May at temperatures from about 13-18°C (Combs and Peltz 1982; Braschler et al. 1988; Carmichael et al. 1998; Bjorgo et al. 2000), and HSB also in early April to late May at water temperatures of 15-16°C (Bayless 1972; Adornato 1986; Jenkins and Burkhead 1993), In Claytor Lake, both STB and HSB in Claytor Lake were in the upper portion of the reservoir, apparently looking for spawning habitat during March, 2002 when water temperatures were 9-10°C. Although I did not track any fish that were in the river above the reservoir during April of 2002, it is possible that fish migrated and returned without me detecting them. Reports from fishermen indicate that, especially during periods of warm and high flows during April, fish will migrate above Claytor Lake to Buck Dam, a distance of about 37 km. By early April, 2002, surface temperature in the upper portion of Claytor was around 16°C and most fish had returned to the lower half of the reservoir. By late April, no fish were found above about 15 km (9 miles). Although I experienced a problem with the telemetry equipment and only located a total of six fish in late April (2 HSB, 4 STB), reports from anglers confirmed that fish were only being caught in the lower reservoir, and all STB and HSB had apparently left the upper portion of Claytor. Although I did not detect any of my telemetered fish that may have been attempting to spawn at the very upper end of Claytor Lake (Allisonia), I did collect fish during April and May of 2001 and 2002 (mostly HSB) via boat electrofishing. These fish were often ripe and running with milt and were apparently attempting to spawn.

Both STB and HSB utilized the lower portion of Claytor Lake during the summer months. During the summer of 2001, when fish were in deeper water (18-20 m), they were found suspended and often not related to any particular physical feature of Claytor Lake. During the summer of 2002, fish were generally in shallower water (2-10 m) and were often found either on or in close proximity to submerged structure such as islands, points, and flats. During this time, fish were found within 1 m from the bottom.

During September of both years, when surface water temperatures cooled to about 23°C, both STB and HSB distributed throughout much of the reservoir, and most fish moved both up the reservoir and into Peak Creek. During late fall and early winter, fish remained dispersed throughout the lower 16 km (10 mi) of the main body of Claytor Lake and into Peak Creek. Both STB and HSB congregated in an apparent pre-spawn staging location about 14.5 km (9 mi) above the dam during February.

Movement rates

Bi-weekly tracking

During the summer of 2001, the average STB minimum daily movement rate (1.5 km/d) was much higher than reported from other reservoirs (0.1-0.2 km/d) (Cheek et al 1985; Wilkerson and Fisher 1997; Schaffler et al. 2002). However, during the summer of 2002, when habitat conditions were more degraded, STB movement rates in Claytor were much less than 2001 (0.25 km/d) and similar to other studies. Both summer stress from degraded habitat and the reduction of habitat available likely influenced STB movement. HSB daily movement was always less than the 4.4 km/d reported by Jones and Rogers (1988). Summertime movement in 2001 averaged 0.49 km/d, whereas it was similar to STB in the summer of 2002 (0.29 km/d).

Excluding minimum daily movement rates from Spring 2001 (0.8 km/day), movement rates for STB in seasons other than summer were lower in Claytor Lake (0.2-0.5 km/day) than STB from Watts Bar Reservoir, Tennessee (0.7-1.0 km/d; Cheek et al. 1985). However, they were similar to movement rates from Lake Murray, South Carolina, which ranged from 0.1-0.4 km/d (Schaffler et al. 2002). Although Schaffler et al. (2002) also found the lowest STB movement during the winter, STB moved more in winter (0.5 km/d) than in any other season of 2002. Although movement rates differed between seasons, they did not differ within each season between STB and HSB. Based on activity patterns, HSB may be as likely to emigrate from Claytor Lake as STB.

Diel movement

Fish primarily moved during crepuscular periods, which is consistent with other findings (Hampton et al. 1988) that also found that STB move more at night than during the day during periods of warm water temperature. However, neither STB nor HSB in this study showed a difference in hourly movement rates between day and night. Mean hourly movement rates of STB in Claytor Lake (0.2-0.3 km/h) were similar to the average hourly movement rates found by Schaffler et al. (2002) (0.2 km/h). Although Douglas and Jahn (1987) found HSB hourly movement to be only about 0.05 km/h in Spring Lake, Illinois, HSB in Claytor Lake averaged similar hourly movement at 0.3-0.4 km/h.

It is interesting to note that both the minimum daily movement rates and hourly movement rates are similar. Similar to findings from Schaffler et al. (2002), hourly movement rates in Claytor Lake were sometimes higher than movement rates calculated for the normal 2-week sample intervals. Therefore, movement rates reported from periodic (even daily) telemetry studies likely greatly underestimate the amount of actual movement for both STB and HSB. For instance, if the average hourly movement rate for STB in Claytor Lake (0.2 km/day) was expanded to a 24-h period, a daily movement rate of 4.8 km/day would be reported, higher than reported from any inland STB population.

Exploitation

The inability to catch, tag, and release large numbers of STB and HSB, and possible low angler return rate of captured fish, impeded my ability to describe harvest on Claytor Lake. However, I was able to provide estimates for annual harvest for STB (4.7-41.5%) and HSB (9.8-18.3%) from Claytor Lake. The average annual harvest from Claytor Lake was 14.0% for HSB and 25.8% for STB. These rates are lower than those found for other Virginia reservoirs. Hightower et al. (2001) estimated a 28-52% annual harvest from Lake Gaston and Dan Wilson (VDGIF, personal communication) found a 53.5% annual harvest from Smith Mountain Lake (SML). If an instantaneous natural mortality rate of 0.14 is assumed (Hightower et al. 2001) and a corresponding annual natural mortality of 13.1% is realized, it is important to note that annual fishing mortality on Claytor Lake exceeds natural mortality. This is useful to managers for support of current or proposed fishing regulations. It is clear that a substantial portion of the anglers at Claytor Lake target STB and HSB and a successful fishery for fish <10kg has been maintained by stocking.

Some limitations exist with interpretation of these results, however. I was unable to tag fish at discrete time intervals; instead I tagged a small number of fish in the spring of 2001 and tagged fish throughout the fall of 2002 and the winter and spring of 2002. Therefore, tagging was operating concurrently with harvest. Also, the tag reporting rate estimation that I was able to generate (10%) was likely a gross underestimation of actual tag returns. The reporting rate that I did apply (49.3%) came from SML striped bass anglers and was likely more realistic. Although I visited boat ramps in the early morning or late evening to limit contact with non-anglers, the possiblity exists that some people received tags that were not fishermen. I simply left window tags on cars with boat trailers in the boat-ramp parking lots surrounding Claytor, whereas tags in SML were handed personally to anglers. This may have more closely simulated actual capture of the fish. Several anglers also voiced their displeasure with receiving tag rewards, where they had to go through the bureaucratic system of the University and often did not receive their reward for over a month. This likely reduced the enthusiasm to report subsequent tag captures.

Although most STB angling effort is believed to be in the summer (46%) (Copeland 2002), most reported STB and HSB harvest from this study was reported from the fall of 2001 and spring of 2002. This is also contrary to the creel survey conducted on Claytor Lake (Copeland 2002), which found that 75% of the yearly harvest of STB occurs in the summer months. According to Claytor's creel survey from the late 1990s, about 29% of the STB angling effort is directed in the spring, while fall angling represents about 22%. The discrepancy between the creel survey and this study may be because the creel survey only interviewed anglers fishing during the daytime hours, and many STB and HSB anglers fish only at night. Alternatively, the warm stressful summertime conditions in 2002, as reported by this study, may have resulted in less fish feeding and less subsequent harvest by anglers.

Emigration

Because of the low tag return rate coupled with the small sample size of tagged moronids from Claytor Lake, I was unable to generate accurate rates of fish migration through Claytor dam. Only one tagged fish was recovered from the tailrace. No juvenile STB or HSB were electrofished in the tailrace. Few adult fish were captured in the tailrace, suggesting low rates of emigration through Claytor dam. To estimate detection probabilities for fish passage through Claytor dam, it is useful to provide some estimates. If I tagged 1200 fish in Claytor Lake and 5% of them emigrated through the dam and stayed in the tailrace throughout an entire year, each fish had a 35% chance of getting harvested from the tailrace, and each tag had a 25% probability of being reported, I would only expect to get 5 tag returns from the original 1200 fish. These are only speculative numbers, but are meant to illustrate the point that detection of fish migrating from the reservoir is a challenging undertaking.

No radio-tagged fish were found in the tailrace that had come from Claytor Lake. More than half of the radio-tagged fish that were caught and tagged in the tailrace remained in the small area directly below Claytor dam through August 2002, and one additional tagged fish was harvested from the tailrace. The whereabouts of the rest of the tags are unknown, but these fish may have been harvested, migrated downstream, or the tags may have lost battery power. In addition, the carcasses of tagged fish that died in the tailrace may have washed downstream and settled in an unknown location.

Extensive electrofishing in the tailrace by myself and other researchers from VDGIF failed to sample many moronids, either during this study or previously. However, reports from anglers indicate that a fishery does exist, and large (>8 kg) fish are periodically caught in the tailrace area. One angler has kept a fishing diary for the past 20 years, and has consistently caught STB, primarily in the spring but throughout the year, in Claytor's tailrace.

Most of the fish I tagged in Claytor's tailrace inhabited the area throughout the summer. Because biologists have sampled few STB or HSB in the tailrace, and large-scale losses of moronids have not been reported from Claytor Lake, a large proportion of STB and HSB likely do not emigrate. While it is demonstrated that fish do escape from the reservoir, it is unknown whether the fish in the tailrace passed through the dam as juveniles or adults, although no juveniles were collected throughout this study from the tailrace. Results from this study indicate that at least some proportion of the adult population survives the passage through Claytor dam and contributes to the fishery below. More research is certainly needed to place better parameters on the actual numbers of adult fish lost from Claytor Lake.

SUMMARY AND CONCLUSIONS

1. This is the first directed study of behavior of STB and HSB coexistent in a reservoir. The comparative habitat use, movements, and exploitation of these two stocked moronids were investigated.

2. Based on published radio telemetry studies, preferred striped bass (STB) habitat in Claytor Lake was defined as 15-20°C and ≥5.0 mg/L, suboptimal or summertime refugia habitat was defined as 20.1-25°C or ≥2.5 but less than 5.0 mg/L, and poor habitat was that <2.5 mg/L or >25°C. Preferred hybrid striped bass (HSB) habitat in Claytor Lake was defined as 21.5-25.5°C and ≥5.0 mg/L, suboptimal or summertime refugia habitat was defined as 25.6-27.0°C or ≥2.0 but less than 5.0 mg/L, and poor habitat was that <2.0 mg/L or >27°C.

3. As determined by radio telemetry of STB (n-26) and HSB (n=33), similar vertical (depth) habitats were occupied by both STB and HSB in Claytor Lake throughout most of the study period. However, the two species occupied different vertical habitats during the spring of 2001 and 2002 when preferred temperatures were available and DO levels were >2.0 mg/L. During the summer of 2001, STB also were in deeper and cooler water than HSB.

4. Late July to late August of 2002 represented the most critical habitat limitation in Claytor Lake. Hybrid striped bass lost their entire preferred habitat during this period of time, but suboptimal habitat ranged from 10-45%, whereas no preferred and <1% of suboptimal habitat was available during this time period for STB. Relative weight of both STB and HSB decreased from 2001 to 2002, possibly as a consequence of more severely degraded habitat in 2002.

5. Selection for optimal or suboptimal DO seemed to influence summertime habitat selection more than temperature in Claytor Lake during 2001 for both STB and HSB. However, in 2001, DO habitat was selected over temperature by STB, but temperature was selected over DO by HSB.

6. The horizontal distribution of radio-tagged STB and HSB was determined by locating fish twice monthly from June-December of 2001, once monthly from January-April, 2002, and twice monthly from May-December, 2002. Radio tagged fish were 46-68 cm total length (TL) (HSB) and 53-94 cm TL (STB), and were collected during the spring and fall of 2001, and the winter and spring of 2002.

7. Both STB and HSB exhibited similar movement rates. Minimum daily movement rates over seasons averaged from about 0.2-1.5 km day, as determined from twice-per-month tracking. Movement rates were generally higher in the summer of 2001 (1.5 km/d for STB, 0.5 km/day for HSB) than in the summer of 2002 (0.2 km/d for STB, 0.3 km/day for HSB), possibly because of the more severely degraded habitat during the warmest months of 2002. Movement rates during this study were lowest in the fall of 2001 (STB 0.2 km/d, HSB 0.3 km/d) and the summer of 2002 (STB 0.2 km/d, HSB 0.3 km/d).

8. Seasonal movement patterns of STB and HSB were also similar. Both exhibited an upstream migration in the spring, into the upper end of Claytor Lake and into Peak Creek. No telemetered fish were found in the river above Claytor Lake, although HSB (primarily) and STB were collected in April and May from Allisonia, the riffle marking the upper boundary of Claytor Lake. Fish returned to the lower end of the reservoir in May of 2001and 2002, where they resided until the water began to cool in September. From late September until the beginning of the springtime migration, both STB and HSB ranged throughout the lower reservoir. Although general locations were similar between STB and HSB, they were most often found in species-specific schools and may segregate socially. Definitive biological centers of activity were not identified for STB or HSB during this study.

9. Hourly movement rates were similar to minimum daily movement rates, averaging 0.2 to 0.4 km/h. Therefore, daily movement rates from twice a month tracking likely grossly underestimate actual daily movement. Hourly movement rates peaked during the crepuscular periods, but fish generally moved throughout the entire 24-h period, albeit in a stop and go manner. No difference was found in hourly movement between STB and HSB.

10. Both STB and HSB from Claytor Lake were tagged with internal anchor tags. Difficulty with collecting fish coupled with a probable low tag-return rate limited the effectiveness of this study to determine seasonal or annual exploitation. However, during this study, reported STB and HSB harvest peaked in the spring and fall periods of time. As calculated from this study, annual harvest was 14.0% for STB and 25.8% for HSB.

11. The Claytor Lake tailrace was searched periodically in 2002 to attempt to find adult STB or HSB that were tagged in the reservoir, but had escaped Claytor Lake through the dam. Only one fish was found, an adult HSB. In addition, adult STB (n=2) and HSB (n=8) were collected from and radio-tagged in the tailrace area during April of 2002. By August of 2002, the majority of these fish still remained in the tailrace, in spite of poor water quality (temp >23.0°C, DO<2.0 mg/L). By December of 2002, only three fish remained, including both STB. No radio tagged fish were found to move from Claytor Lake to the tailrace. It appears that large-scale emigration from Claytor Lake does not likely occur.

12. Dam operations were found to influence Claytor Lake summertime habitat. During stratification, STB and HSB habitat is at depths that are susceptible to loss from the reservoir (i.e., penstock depths). Different patterns of stratification (depth of the thermocline and amount of DO habitat available in and below the metalimnion) will result in different potential for habitat loss. Habitat loss was likely minimal in 2002 due to the shallow thermocline and anoxic metalimnion, but was likely greater in 2001 because of the large oxygenated metalimnion which was located at depths near the dam intakes. Habitat lost through the dam appeared to be replenished with incoming flow through the reservoir.

13. Gillnets proved the most efficient collecting technique for both STB and HSB. Hook and line sampling was useful, but took much more time. Survival of gillnetted fish appeared good when gillnets were placed in high fish-density areas identified from boat mounted Sonar readings, were checked frequently (<30 min), fish were quickly tagged and released, and nets were set during the colder months (surface temperature <10°C) survival of gillnetted fish appeared good.

The results of this study indicate that low abundance of large (>6 kg) STB in Claytor Lake is not likely the result of over-exploitation, but may be due to inadequate summer habitat, especially for these larger fish. This is also important, as some anglers have believed forage to be the limiting factor for STB growth, leading to the illegal stocking and establishment of gizzard shad in Claytor Lake. In contrast, HSB do not seem to be limited by habitat in Claytor Lake, as HSB refuge habitat persisted throughout the entire study. This may contribute to the increased relative abundance of HSB over STB reported by Bonds (2000).

Artificial aeration in Claytor Lake would likely be the only alternative to improving STB habitat in Claytor to the point of producing a trophy fishery. As this is an expensive endeavor and perhaps not a realistic option, the trophy potential for STB in Claytor Lake will likely never develop. Habitat in Claytor Lake does, however, support large number of STB <10 kg. Because HSB have only been stocked in large numbers since 1993, the trophy fishery for HSB may not be fully developed yet. Survival of adult HSB seems to be high, and they may actually provide a better return for anglers. However, the perception by VDGIF that HSB are more sedentary and less susceptible to emigration from Claytor Lake may be unwarranted.

Under current conditions (run-of-the-river), Claytor Lake summer habitat for STB and HSB is eroded by dam operations, but can be replenished to an unknown degree by reservoir inflow. Hydropeaking operations may exacerbate the current problem, leading to both larger loss of habitat and greater potential for loss of fish through the turbines, particularly if summer inflow is low. Because habitat becomes critical during the warmest months in Claytor, moronid research efforts should be directed at changes in habitat and patterns of habitat use associated with changes in dam operations (i.e., run-of-the-river operations vs. hydropeaking).

Continued research on Claytor Lake is warranted. Exploitation rates for STB and HSB from this study are questionable due to the small sample size and low return rates. Tagging efforts on Smith Mountain Lake have been successful with the enlistment of numbers of dedicated STB fishermen who are both tagging fish and reporting tag captures. Similar efforts on Claytor Lake would verify harvest estimate mortality rates generated from this study and possibly estimate the numbers of fish lost via catch-and-release mortality.

The degree of emigration of adult STB and HSB from Claytor Lake remains somewhat of a mystery. The use of stationary, recording radio-tag receiver/loggers might prove useful to detect radio tagged fish passage through the reservoir and into the tailrace. Although I radio-tagged fish in the tailrace, I did not extensively search the river further than 2 km downstream. Research directed at the annual movements by fish in the tailrace would be useful to determine if fish in the tailrace during the spring have come from Claytor Lake, or have migrated upstream from Bluestone Reservoir, WV, the next reservoir down the New River. In addition, the transferability of the newly constructed HSI models for STB and HSB needs to be independently tested by researchers working with telemetry equipment in other reservoirs.

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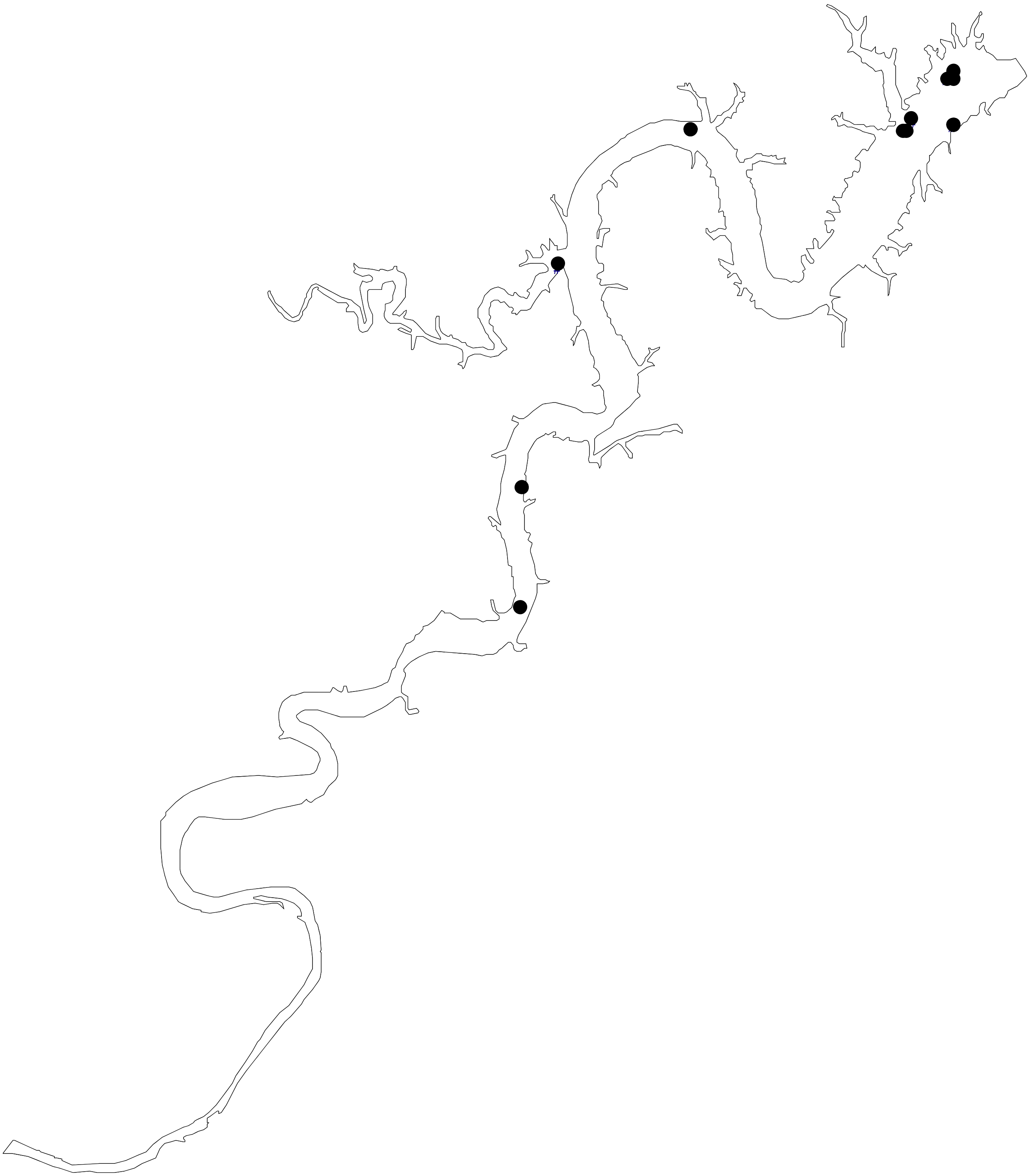
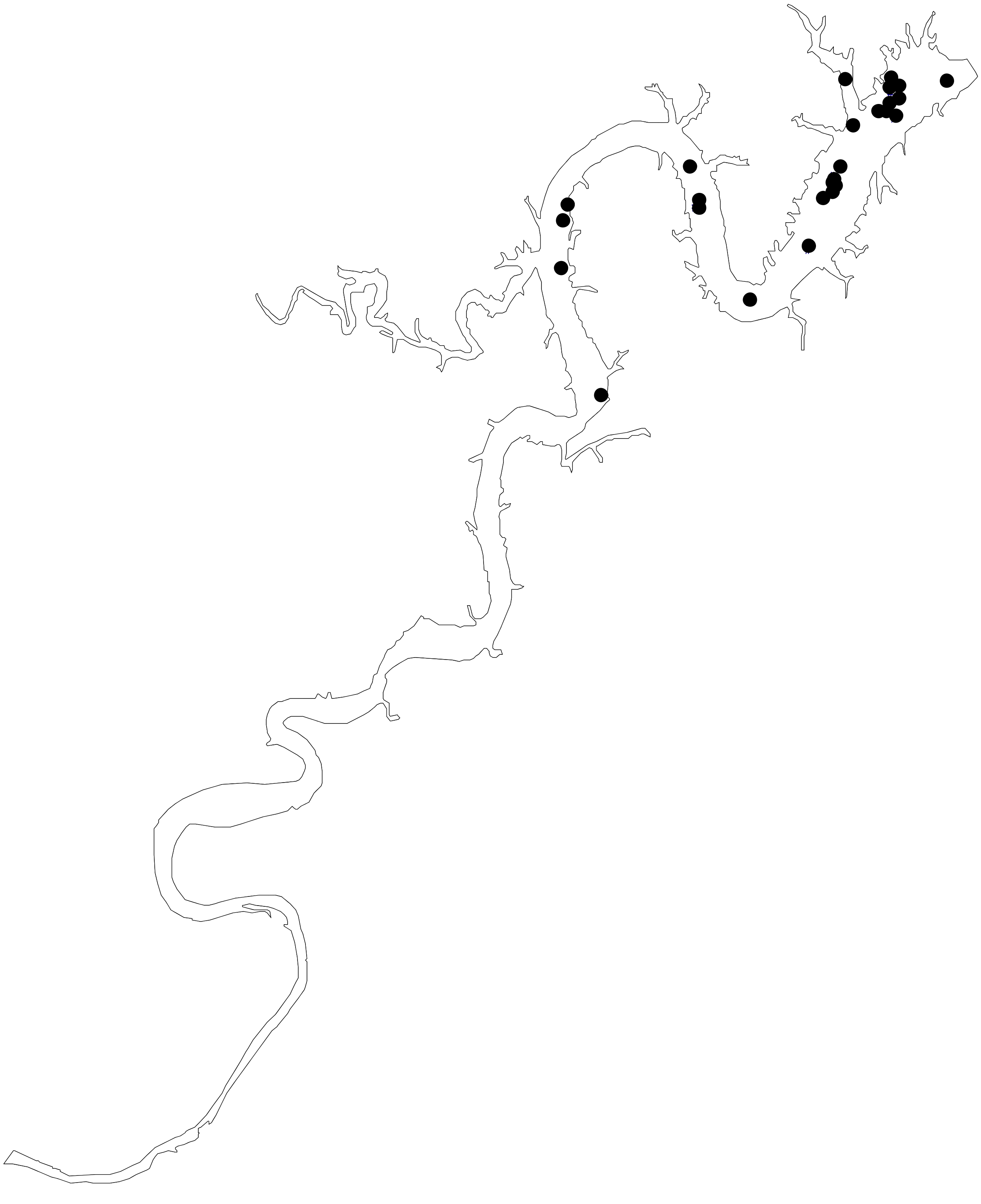
Appendix 1. Monthly horizontal fish locations.

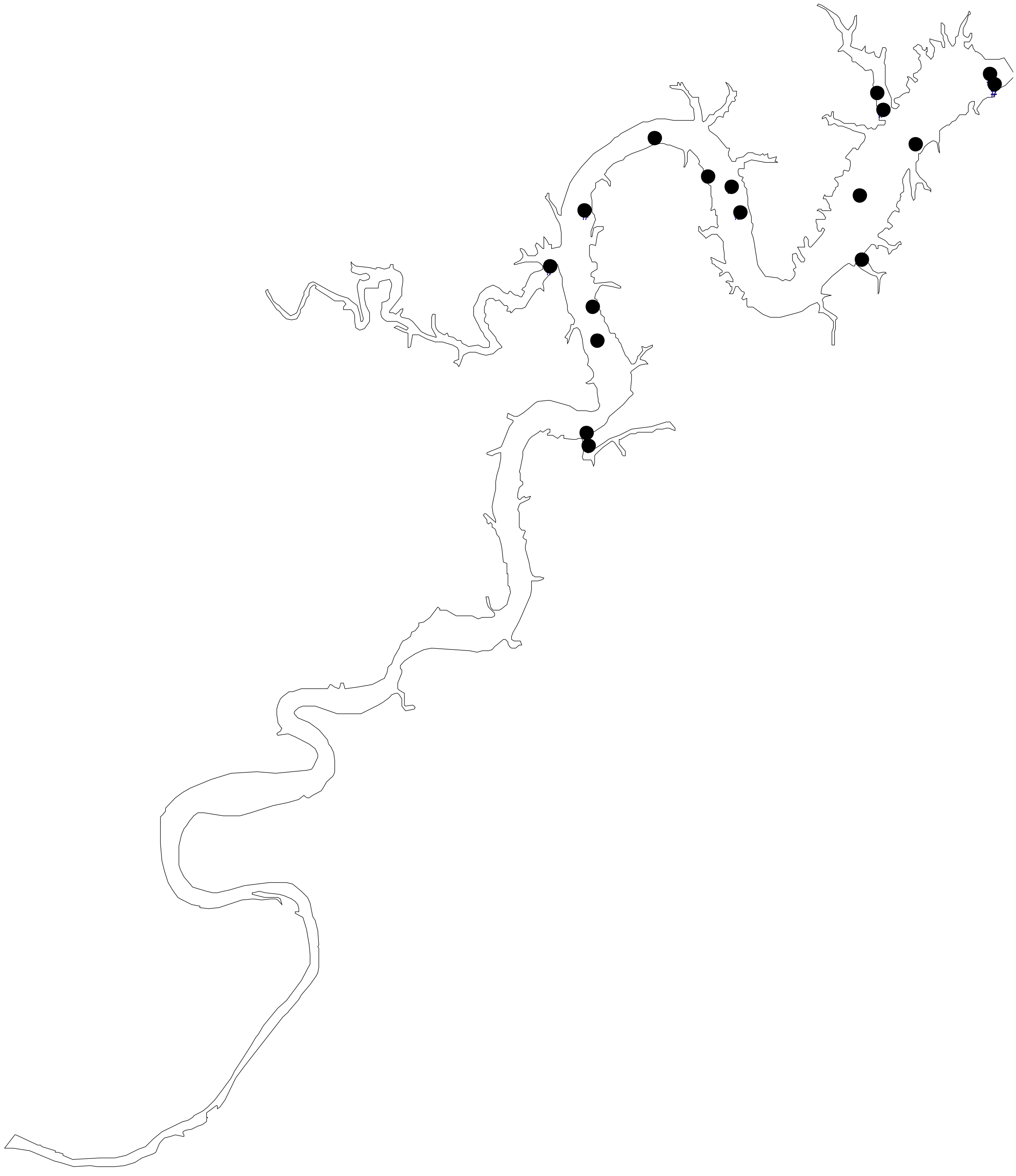
Hybrid striped bass locations May 2001.



Striped bass locations May 2001.



Hybrid striped bass locations June 2001.



Striped bass locations June 2001.

Hybrid striped bass locations July 2001.

Striped bass locations July 2001.

Hybrid striped bass locations August 2001.

Striped bass locations August 2001.

Hybrid striped bass locations September 2001.

Striped bass locations September 2001.

Hybrid striped bass locations October 2001.

Striped bass locations October 2001.

Hybrid striped bass locations November 2001.

Striped bass locations November 2001.

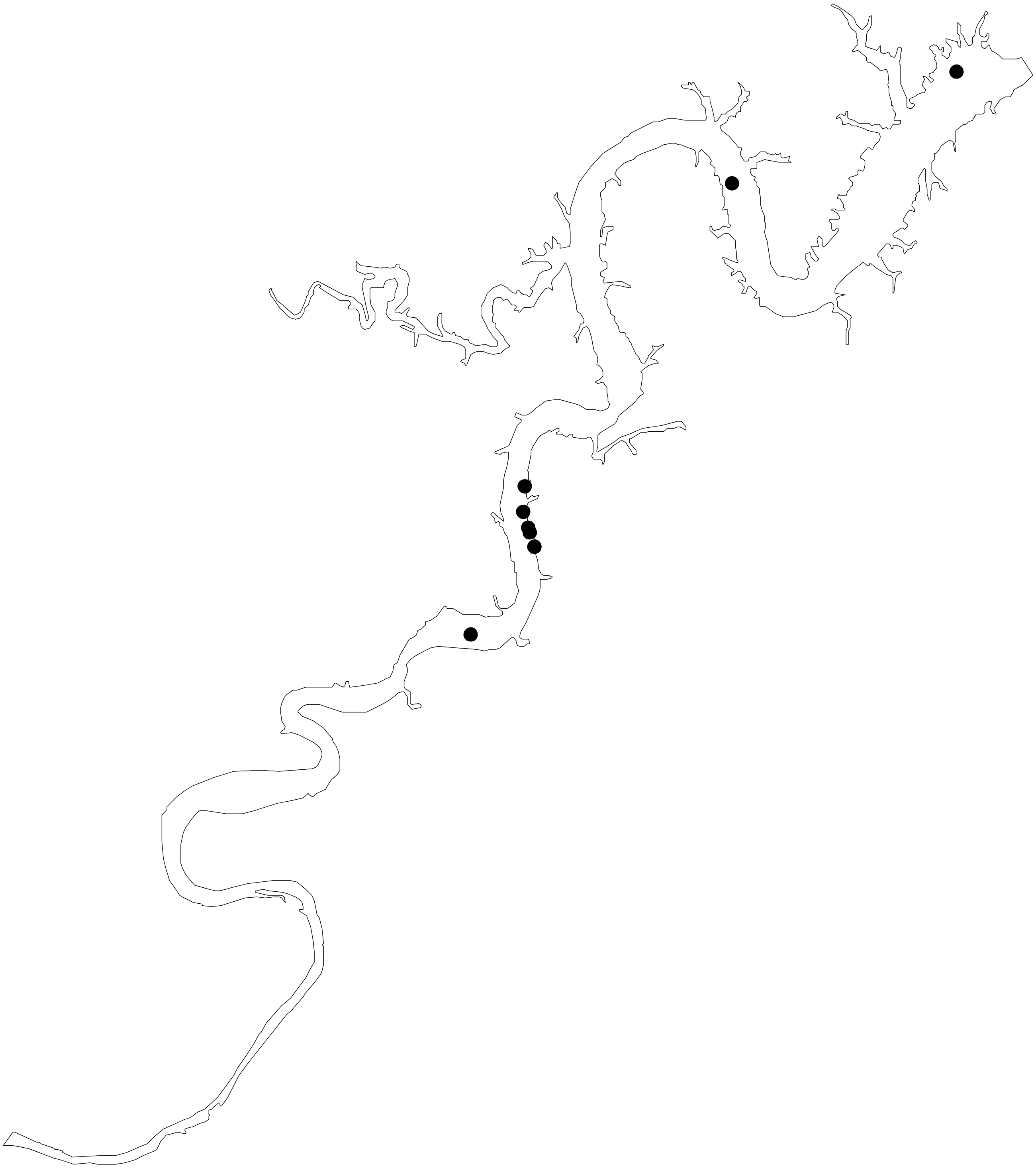
Hybrid striped bass locations December 2001.

Striped bass locations December 2001.

Hybrid striped bass locations January 2002.

Striped bass locations January 2002.

Hybrid striped bass locations February 2002.



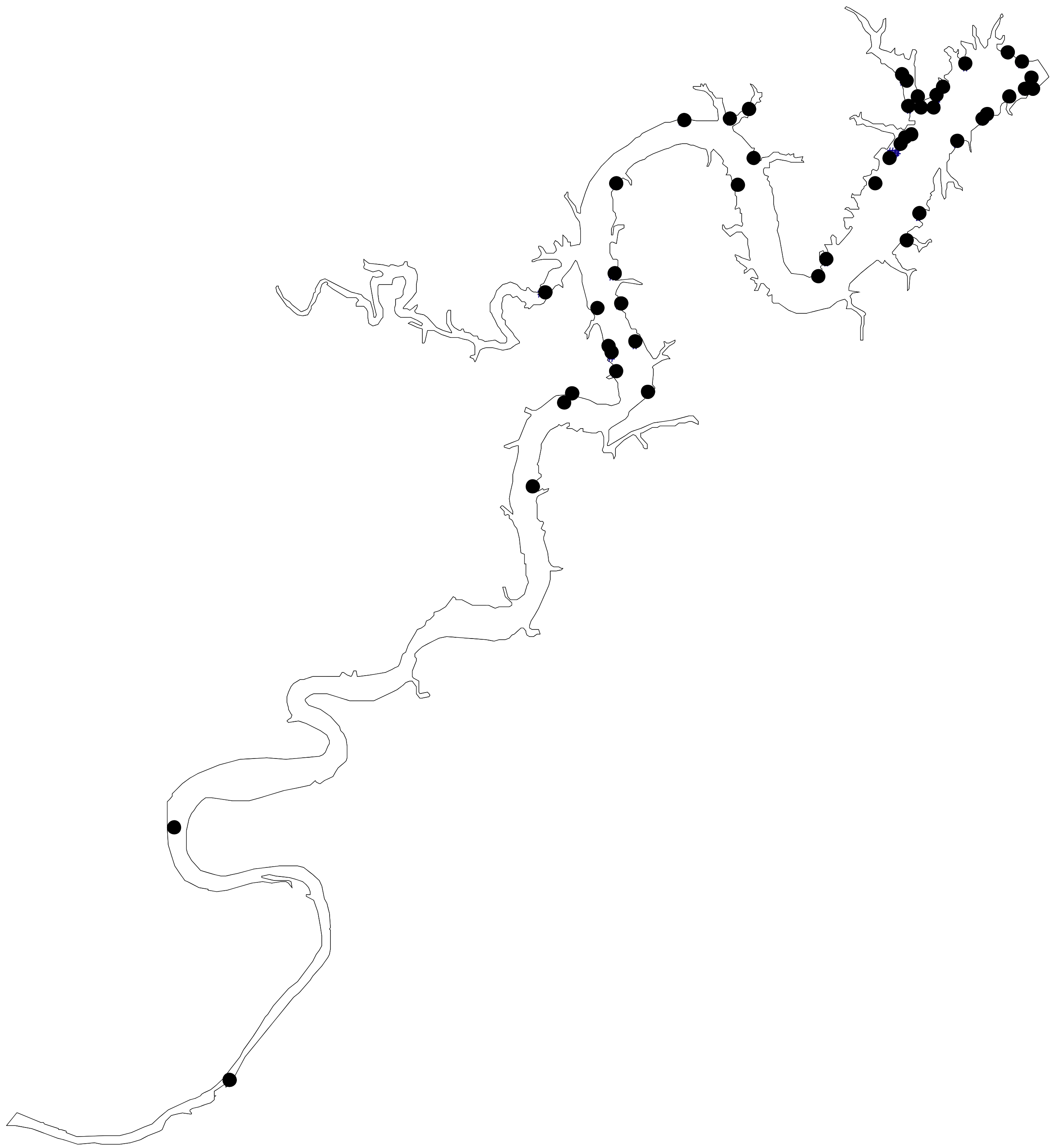
Striped bass locations February 2002.

Hybrid striped bass locations March 2002.

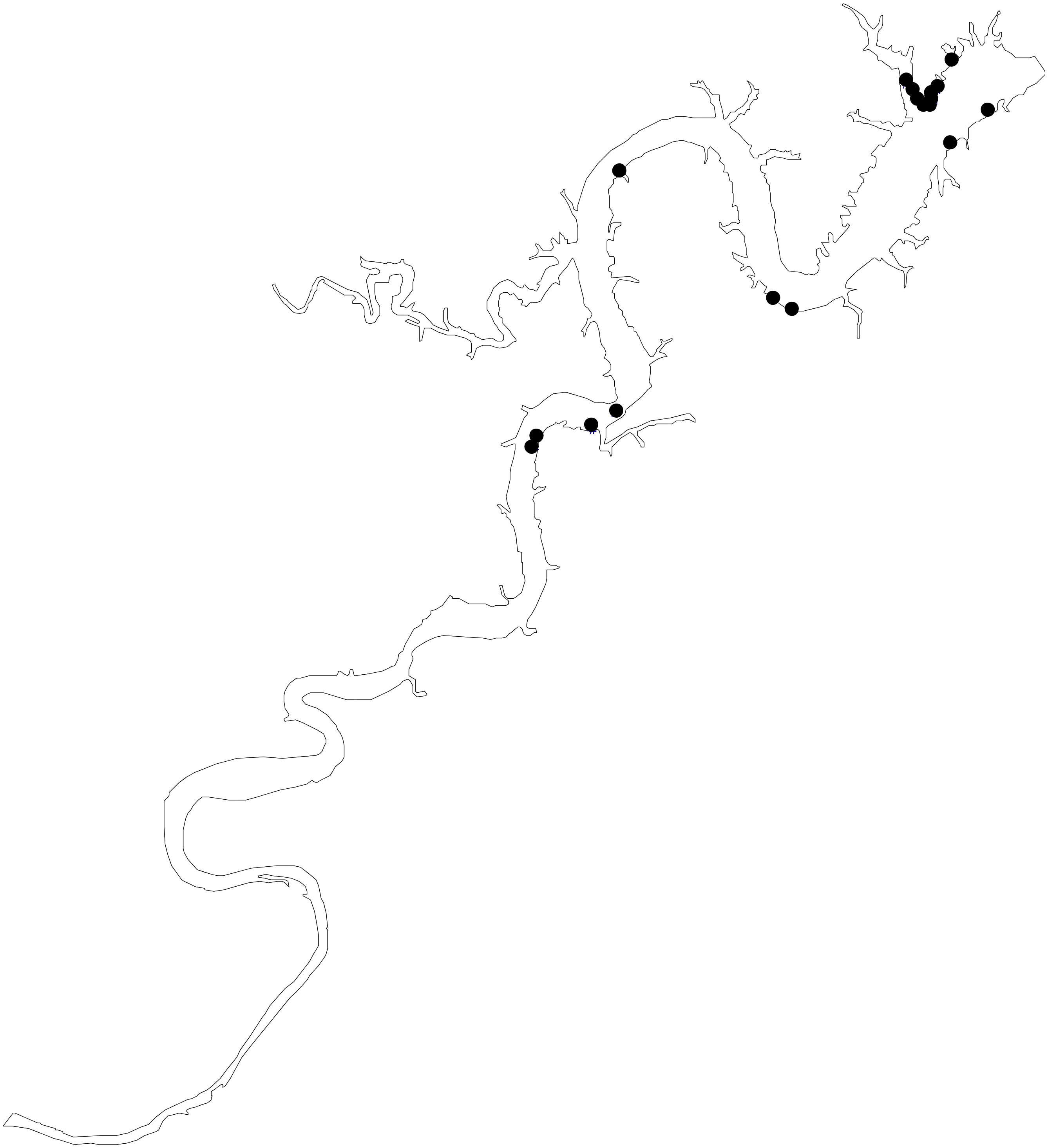
Striped bass locations March 2002.

Hybrid striped bass locations April 2002.

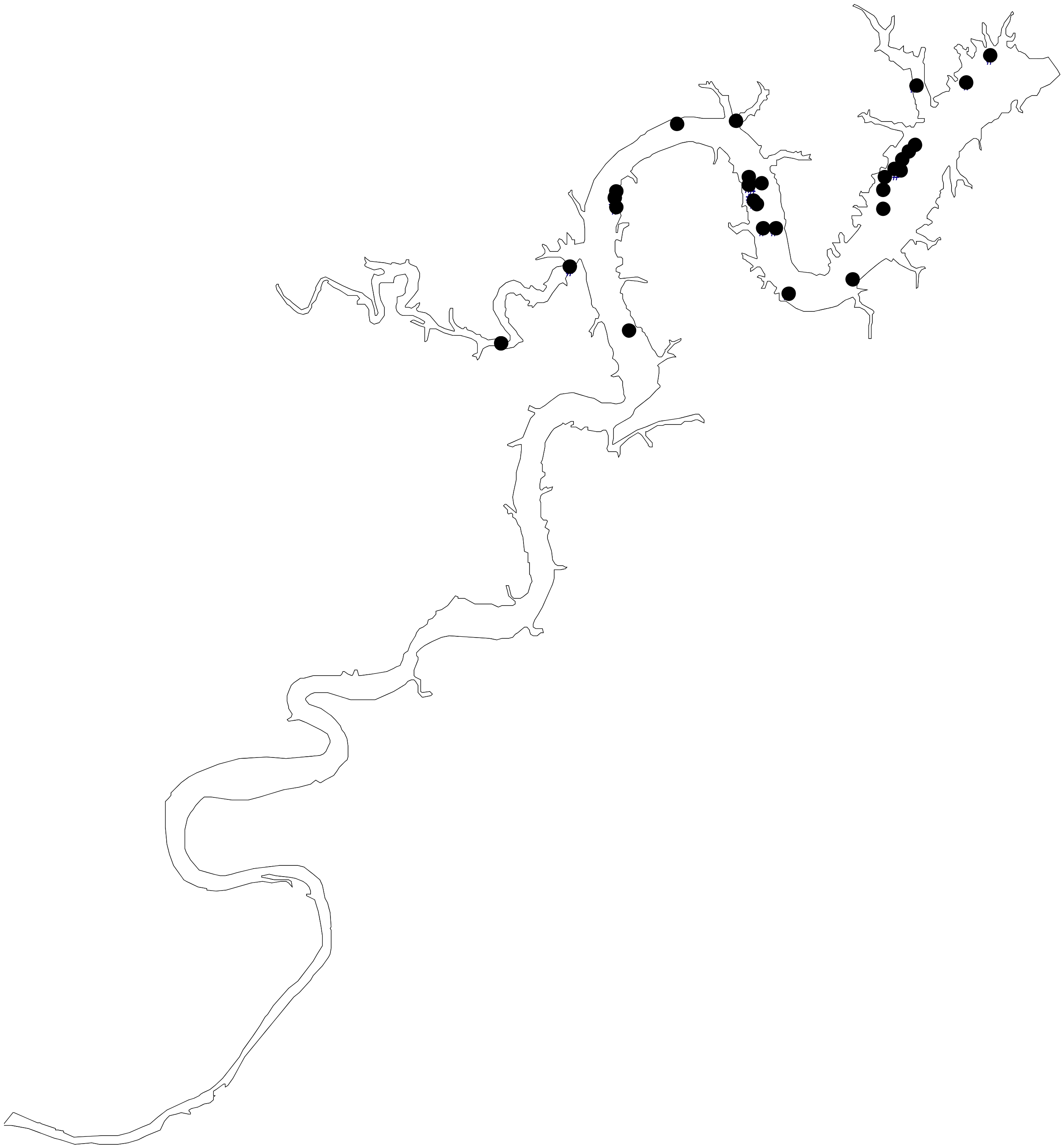
Striped bass locations April 2002.



Hybrid striped bass locations May 2002.

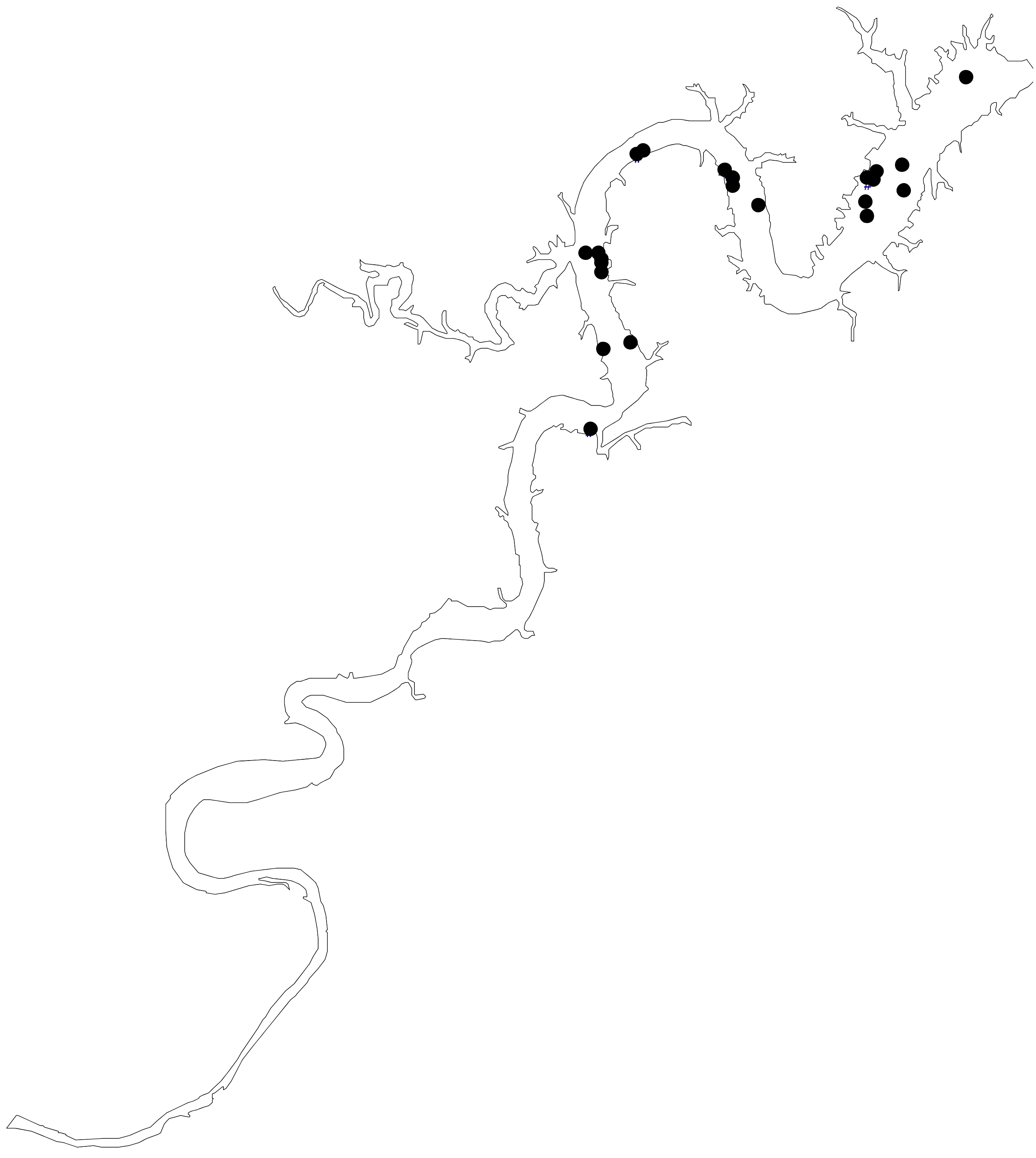


Striped bass locations May 2002.



Hybrid striped bass locations June 2002.

Striped bass locations June 2002.



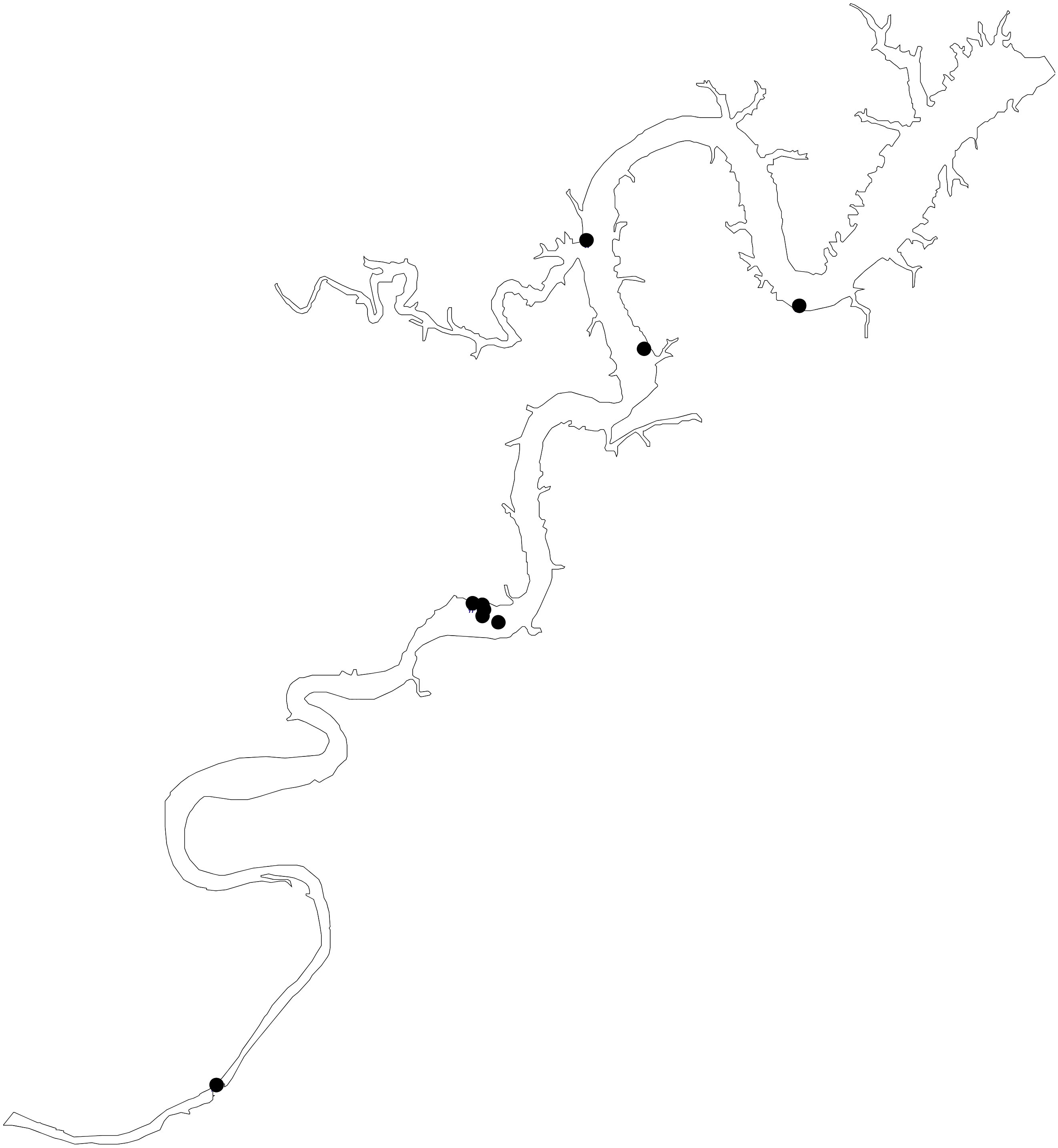
Hybrid striped bass locations July 2002.

Striped bass locations July 2002.

Hybrid striped bass locations August 2002.

Striped bass locations August 2002.

Hybrid striped bass locations September 2002.



Striped bass locations September 2002.

Hybrid striped bass locations October 2002.

Striped bass locations October 2002.

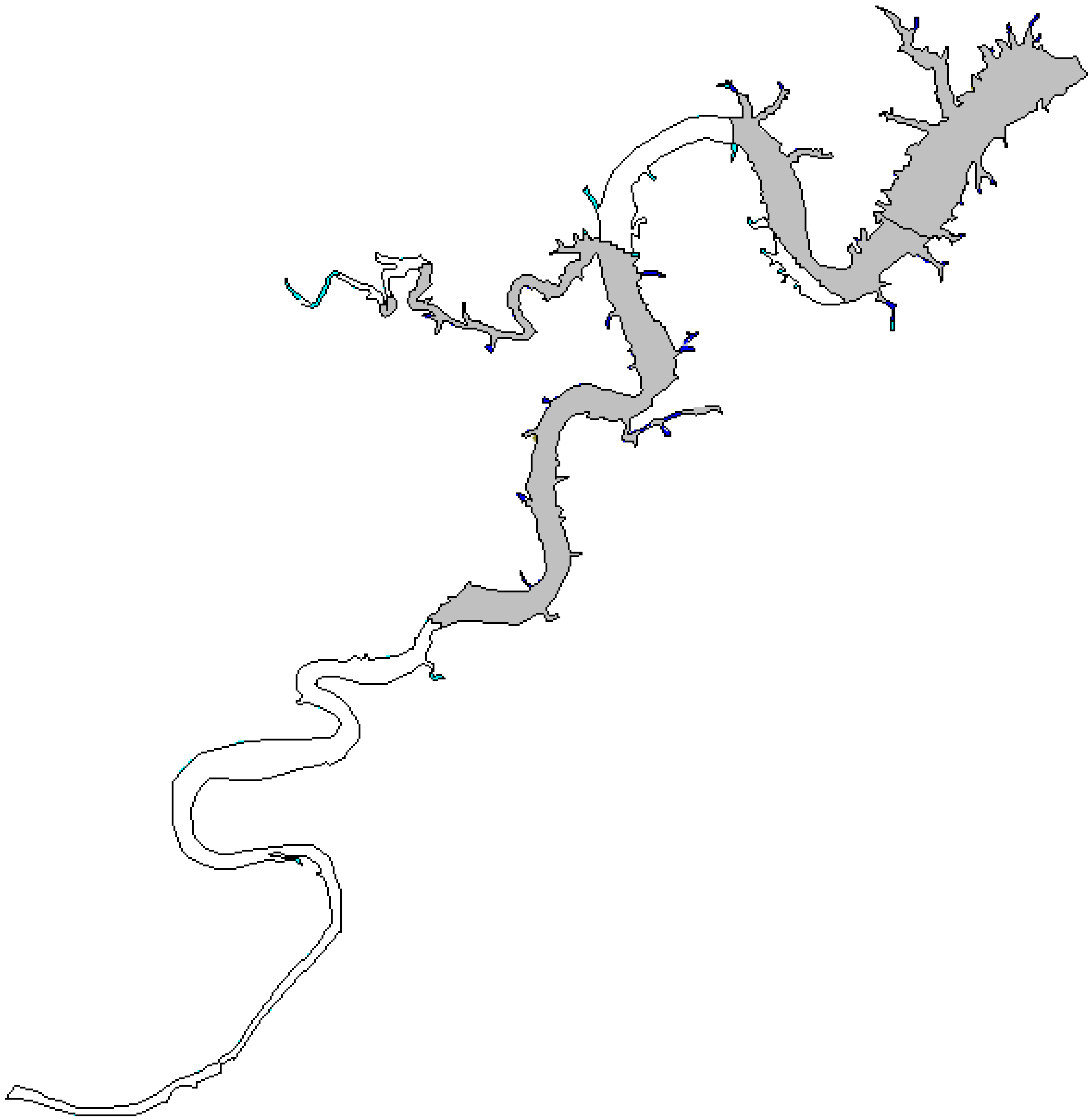
Hybrid striped bass locations November 2002.

Striped bass locations November 2002.

Hybrid striped bass locations December 2002.

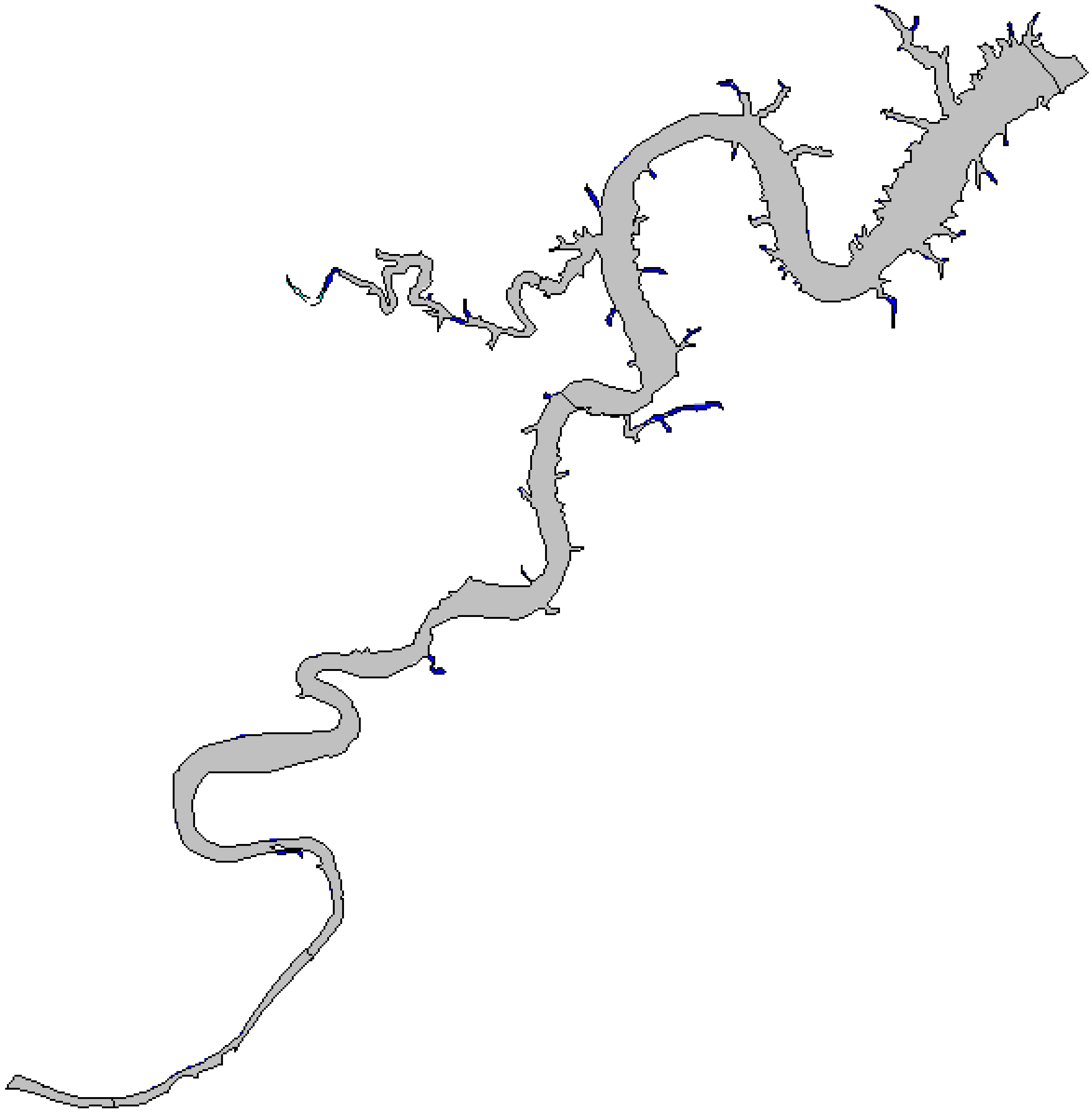
Striped bass locations December 2002.

Appendix 2. Utilization distributions for STB and HSB from Claytor Lake. Kernel-estimated 95% confidence bounds for each fish are represented by shaded areas.



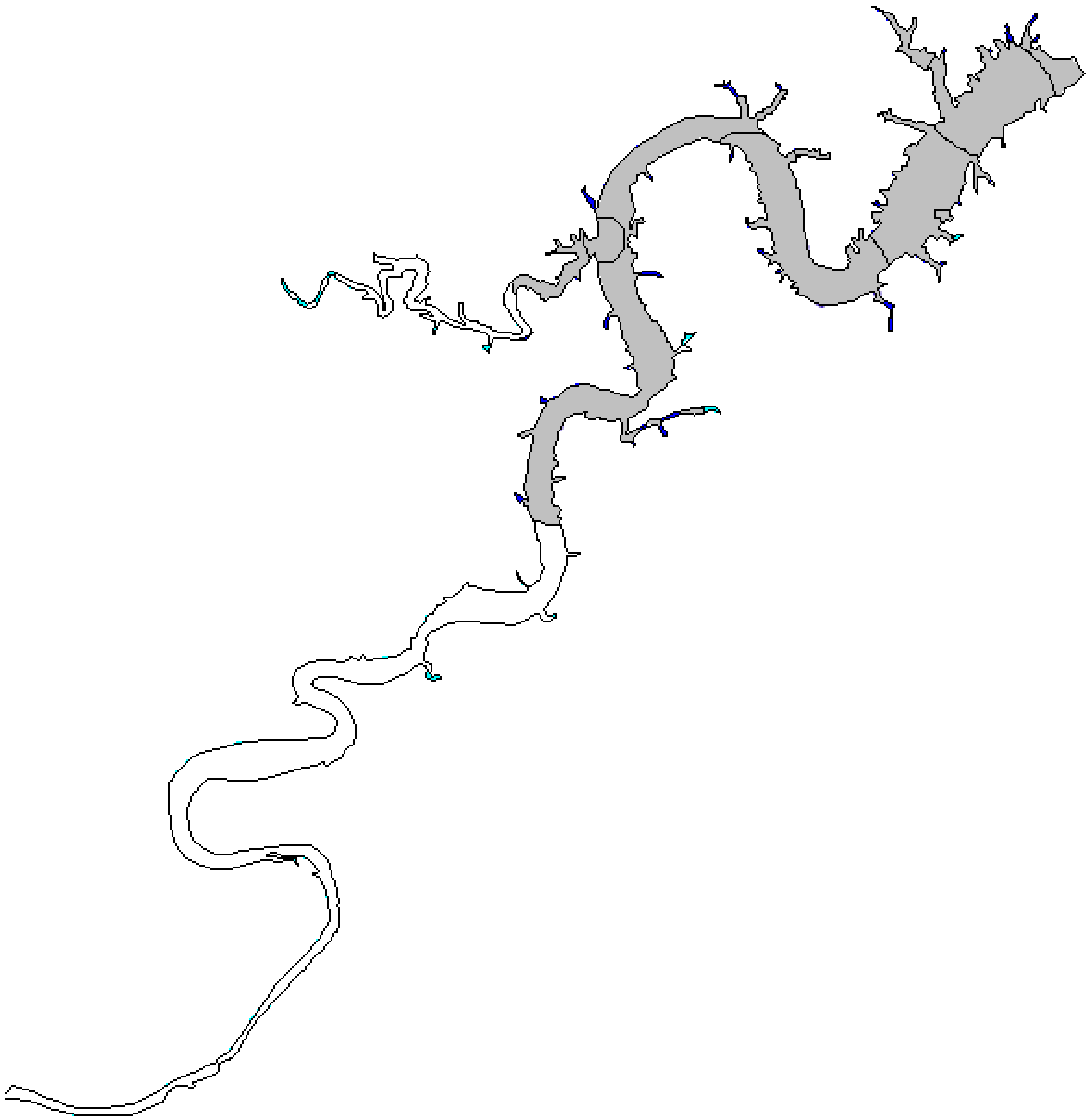
Utilization distribution for STB # 48. 091. Fish was located 4 times over the following seasons. Shaded areas represent 95% kernel estimated confidence bounds.

	2001			2002			
	Spring	Summer	Fall	Winter	Spring	Summer	Fall
Seasons					**X**		



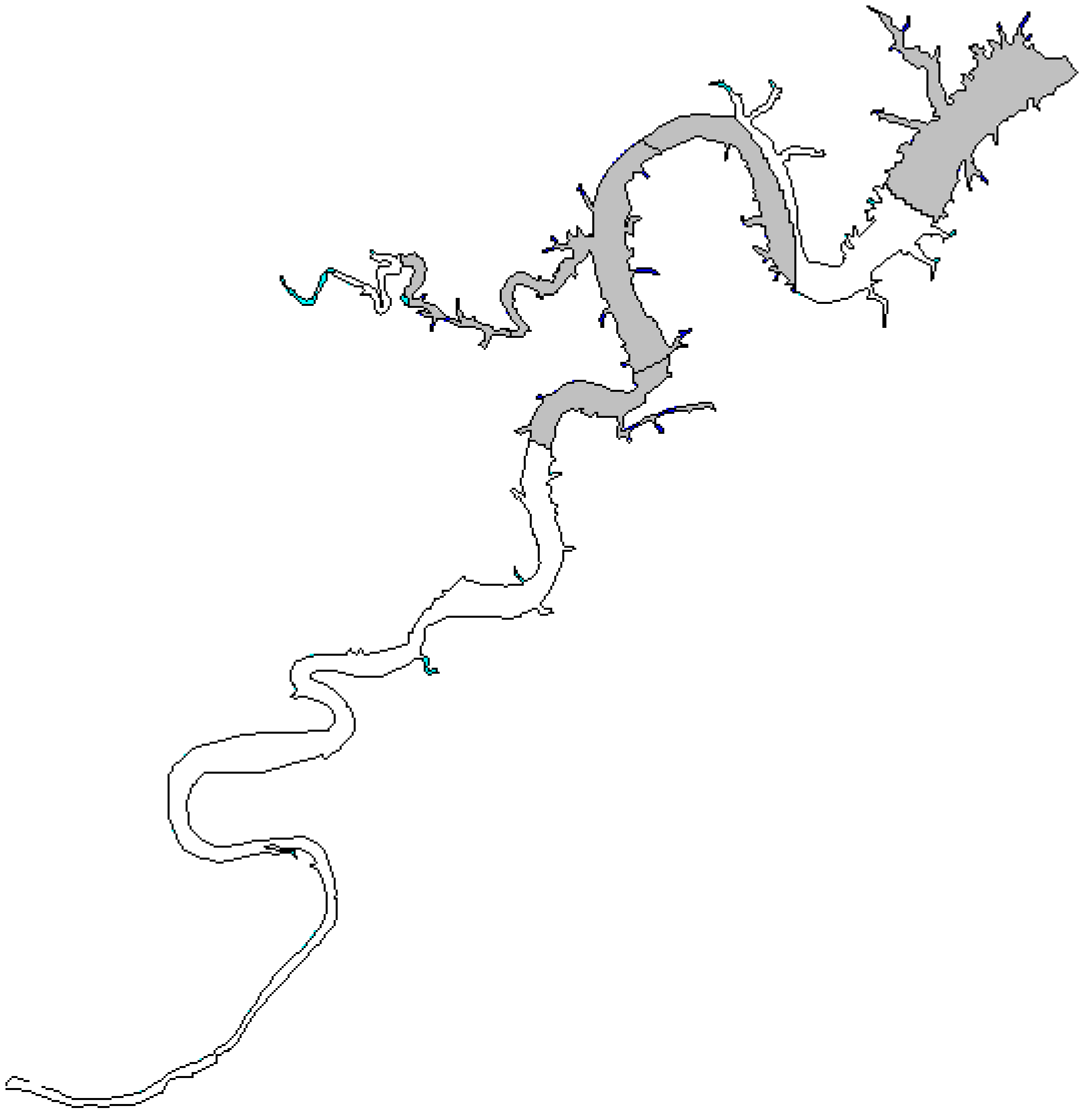
Utilization distribution for STB # 48. 171. Fish was located 15 times over the following seasons. Shaded areas represent 95% kernel estimated confidence bounds.

	2001			2002			
	Spring	Summer	Fall	Winter	Spring	Summer	Fall
Seasons					**X**	**X**	**X**



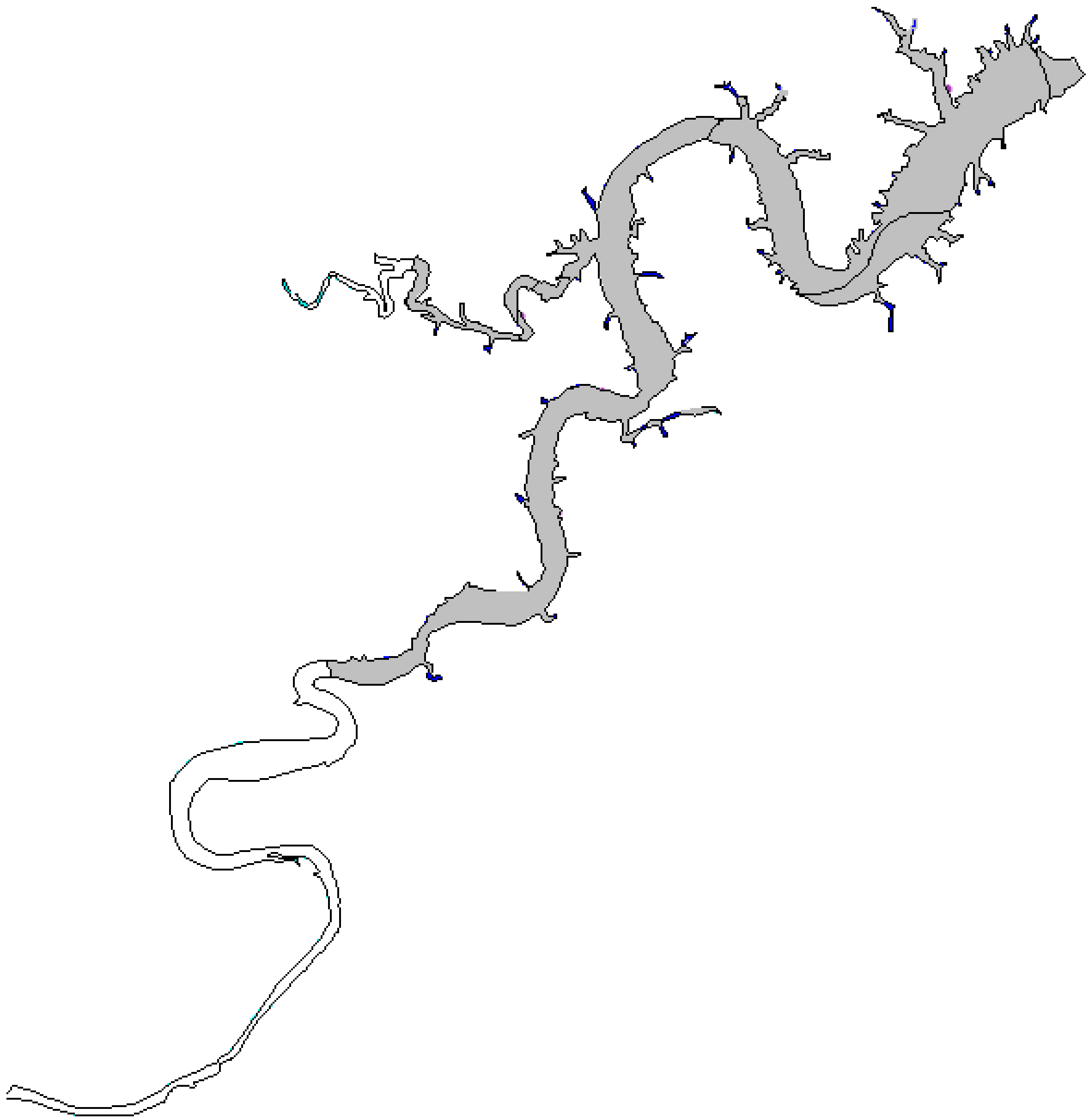
Utilization distribution for STB # 48. 191. Fish was located 14 times over the following seasons. Shaded areas represent 95% kernel estimated confidence bounds.

	2001			2002			
	Spring	Summer	Fall	Winter	Spring	Summer	Fall
Seasons					**X**	**X**	**X**



Utilization distribution for STB # 48. 222. Fish was located 4 times over the following seasons. Shaded areas represent 95% kernel estimated confidence bounds.

	2001			2002			
	Spring	Summer	Fall	Winter	Spring	Summer	Fall
Seasons	X						



Utilization distribution for STB # 48. 461. Fish was located 14 times over the following seasons. Shaded areas represent 95% kernel estimated confidence bounds.

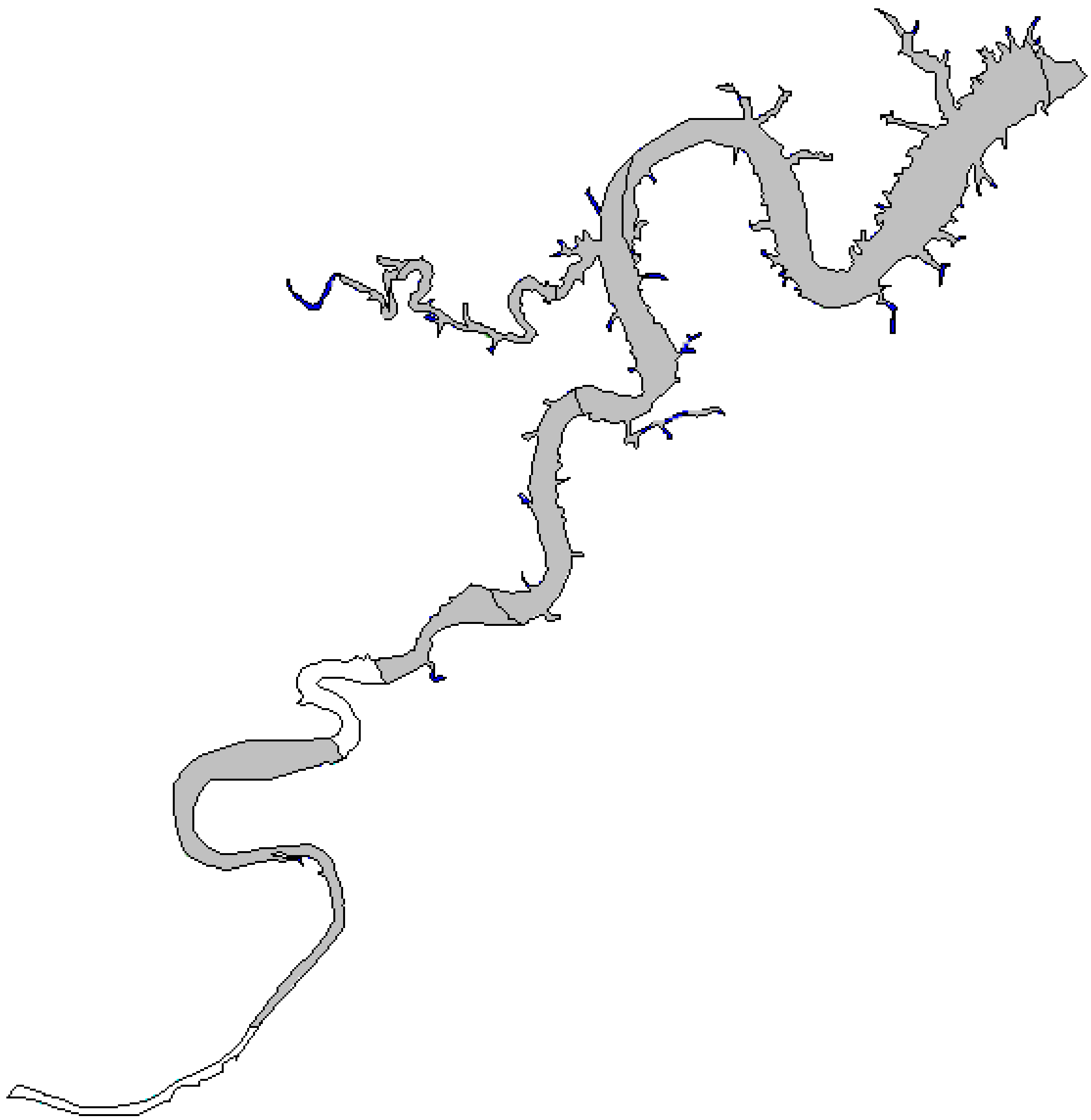
	2001			2002			
	Spring	Summer	Fall	Winter	Spring	Summer	Fall
Seasons			**X**	**X**	**X**	**X**	

Utilization distribution for STB # 48. 491. Fish was located 20 times over the following seasons. Shaded areas represent 95% kernel estimated confidence bounds.

	2001			2002			
	Spring	Summer	Fall	Winter	Spring	Summer	Fall
Seasons	**X**	**X**	**X**	**X**	**X**		

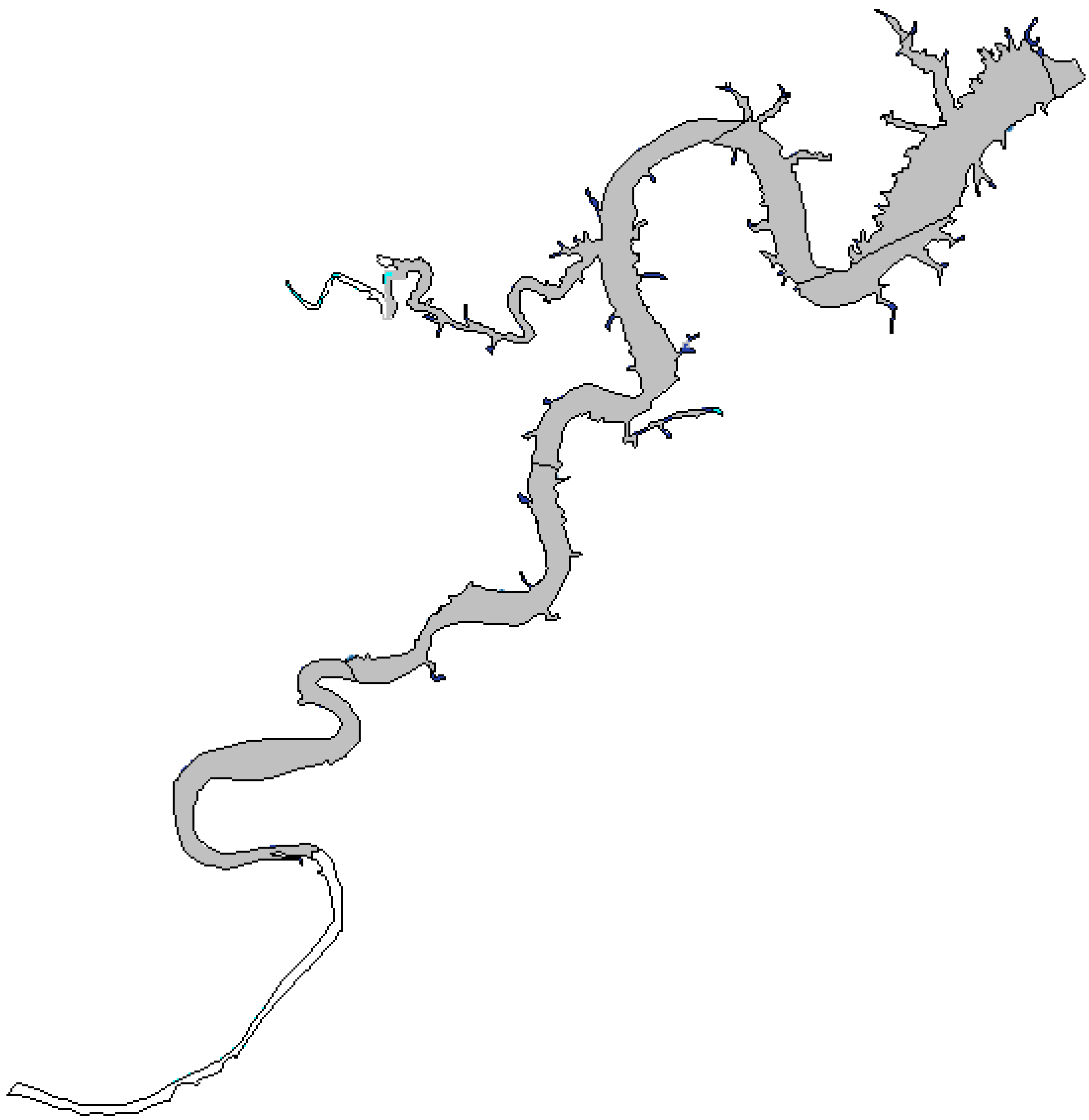
Utilization distribution for STB # 48.501. Fish was located 16 times over the following seasons. Shaded areas represent 95% kernel estimated confidence bounds.

	2001			2002			
	Spring	Summer	Fall	Winter	Spring	Summer	Fall
Seasons					**X**	**X**	**X**



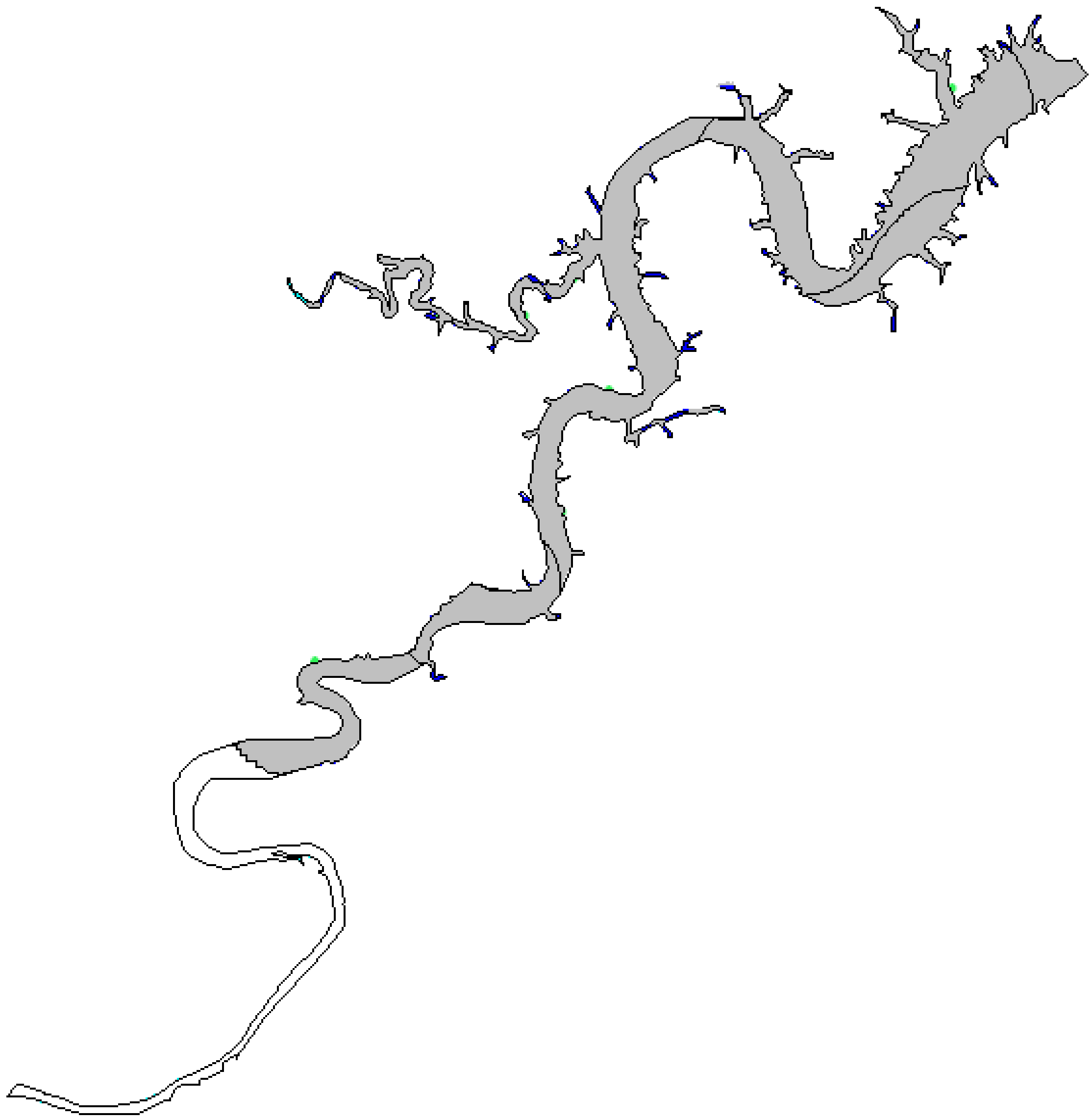
Utilization distribution for STB # 48. 521. Fish was located 11 times over the following seasons. Shaded areas represent 95% kernel estimated confidence bounds.

	2001			2002			
	Spring	Summer	Fall	Winter	Spring	Summer	Fall
Seasons			**X**	**X**	**X**	**X**	**X**



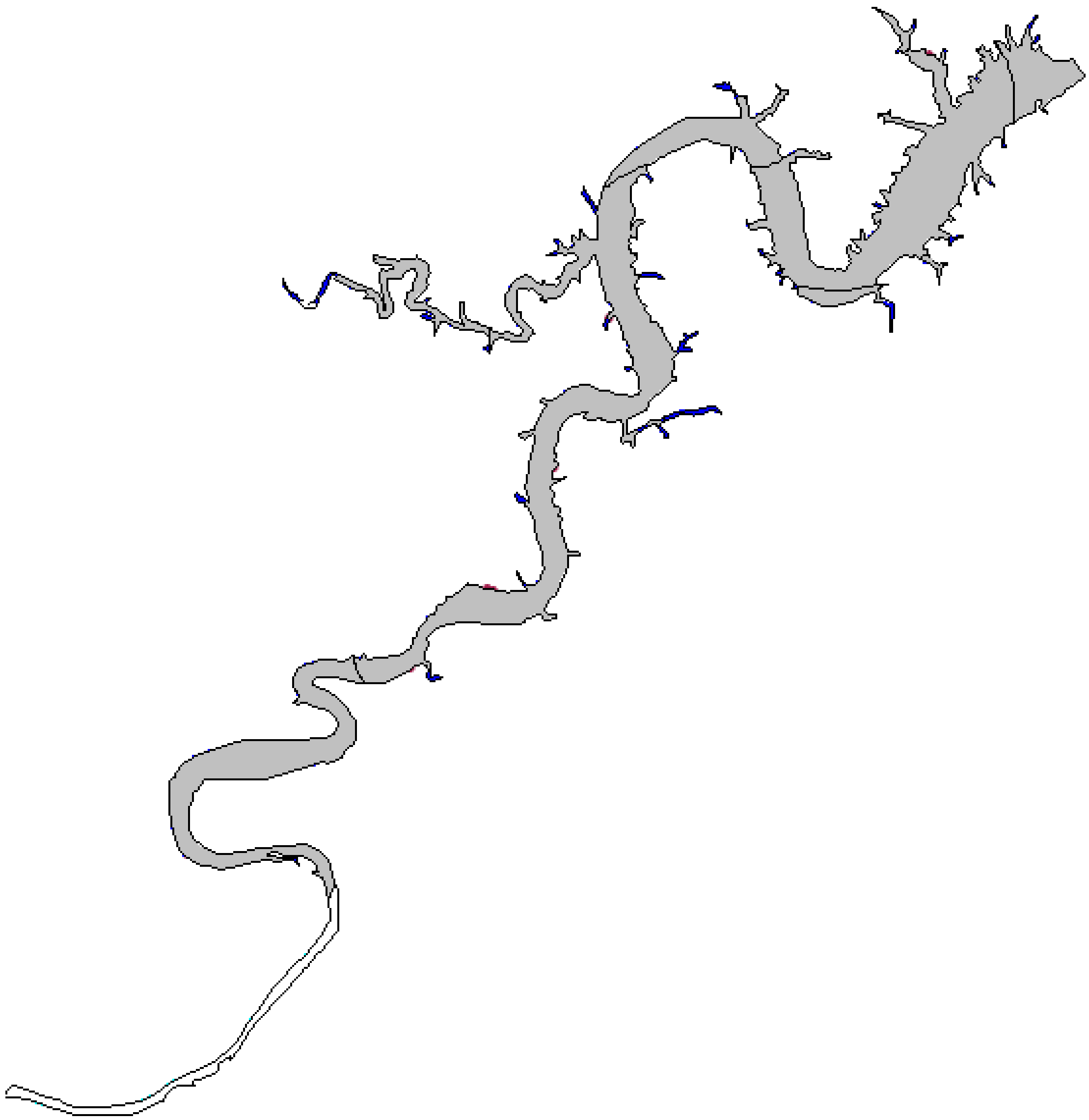
Utilization distribution for STB # 48. 531. Fish was located 20 times over the following seasons. Shaded areas represent 95% kernel estimated confidence bounds.

	2001			2002			
	Spring	Summer	Fall	Winter	Spring	Summer	Fall
Seasons	**X**	**X**	**X**	**X**			



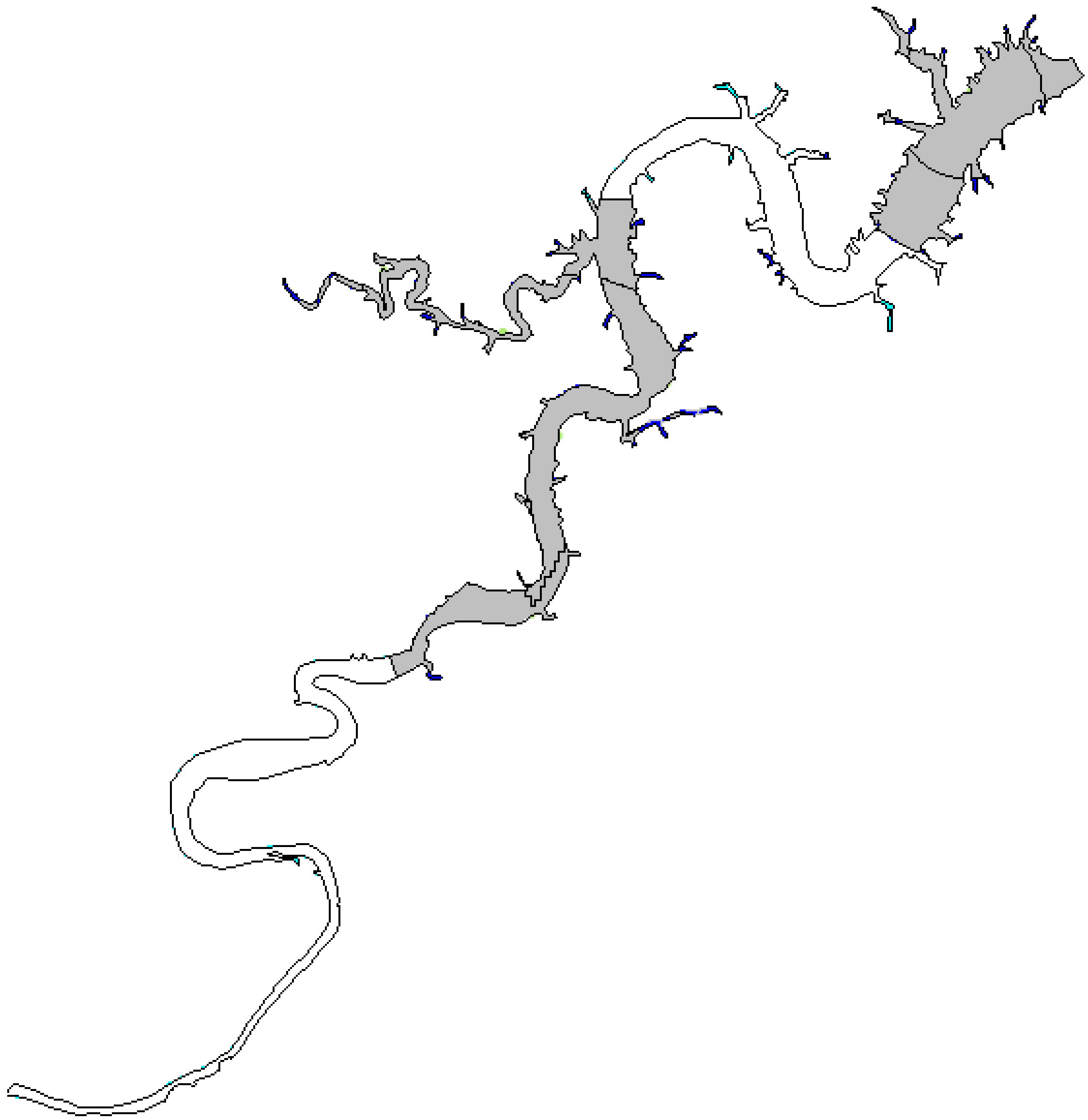
Utilization distribution for STB # 48. 561. Fish was located 21 times over the following seasons. Shaded areas represent 95% kernel estimated confidence bounds.

	2001			2002			
	Spring	Summer	Fall	Winter	Spring	Summer	Fall
Seasons			**X**	**X**	**X**	**X**	**X**



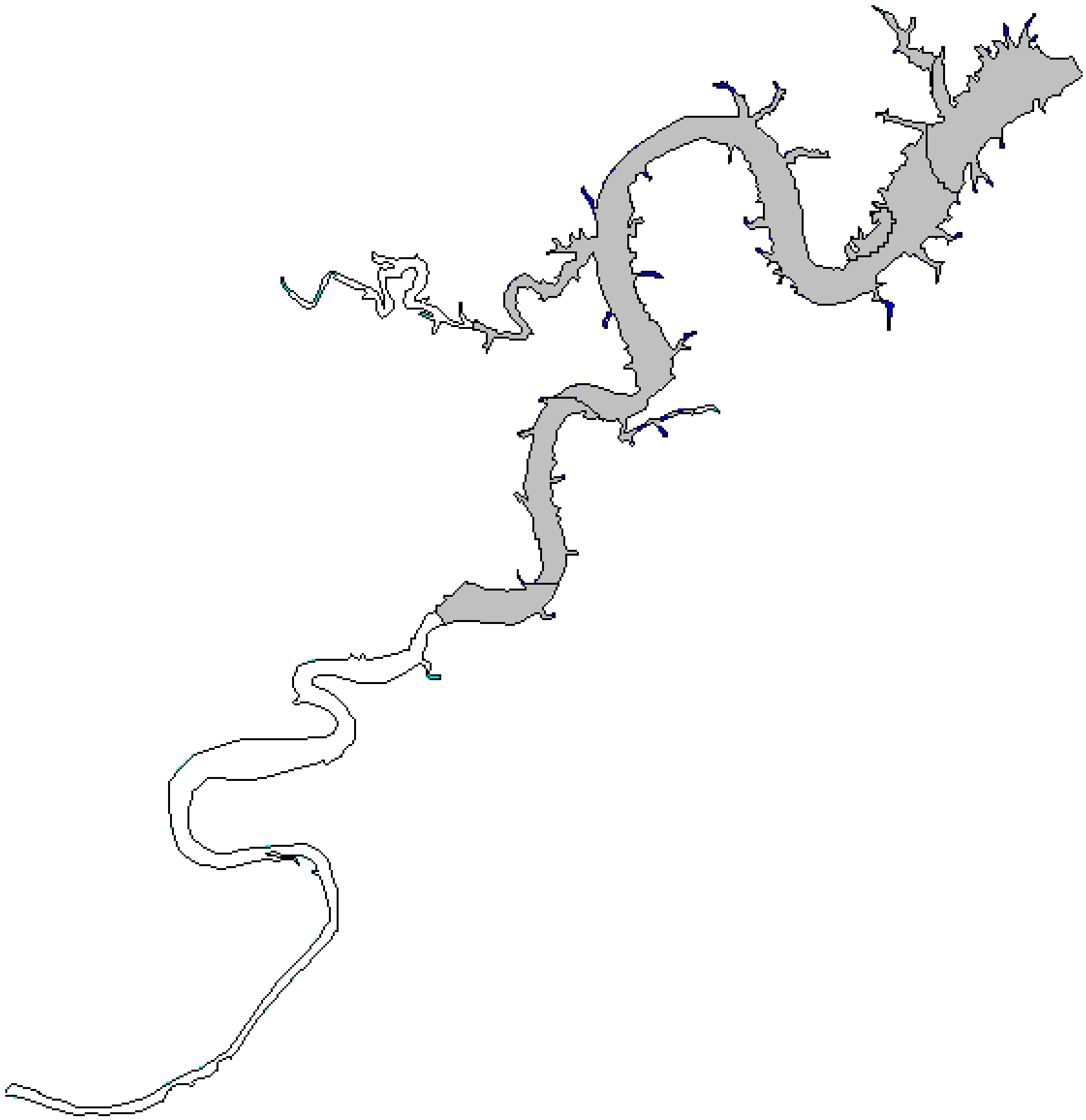
Utilization distribution for STB # 48. 581. Fish was located 21 times over the following seasons. Shaded areas represent 95% kernel estimated confidence bounds.

	2001			2002			
	Spring	Summer	Fall	Winter	Spring	Summer	Fall
Seasons			**X**	**X**	**X**	**X**	**X**



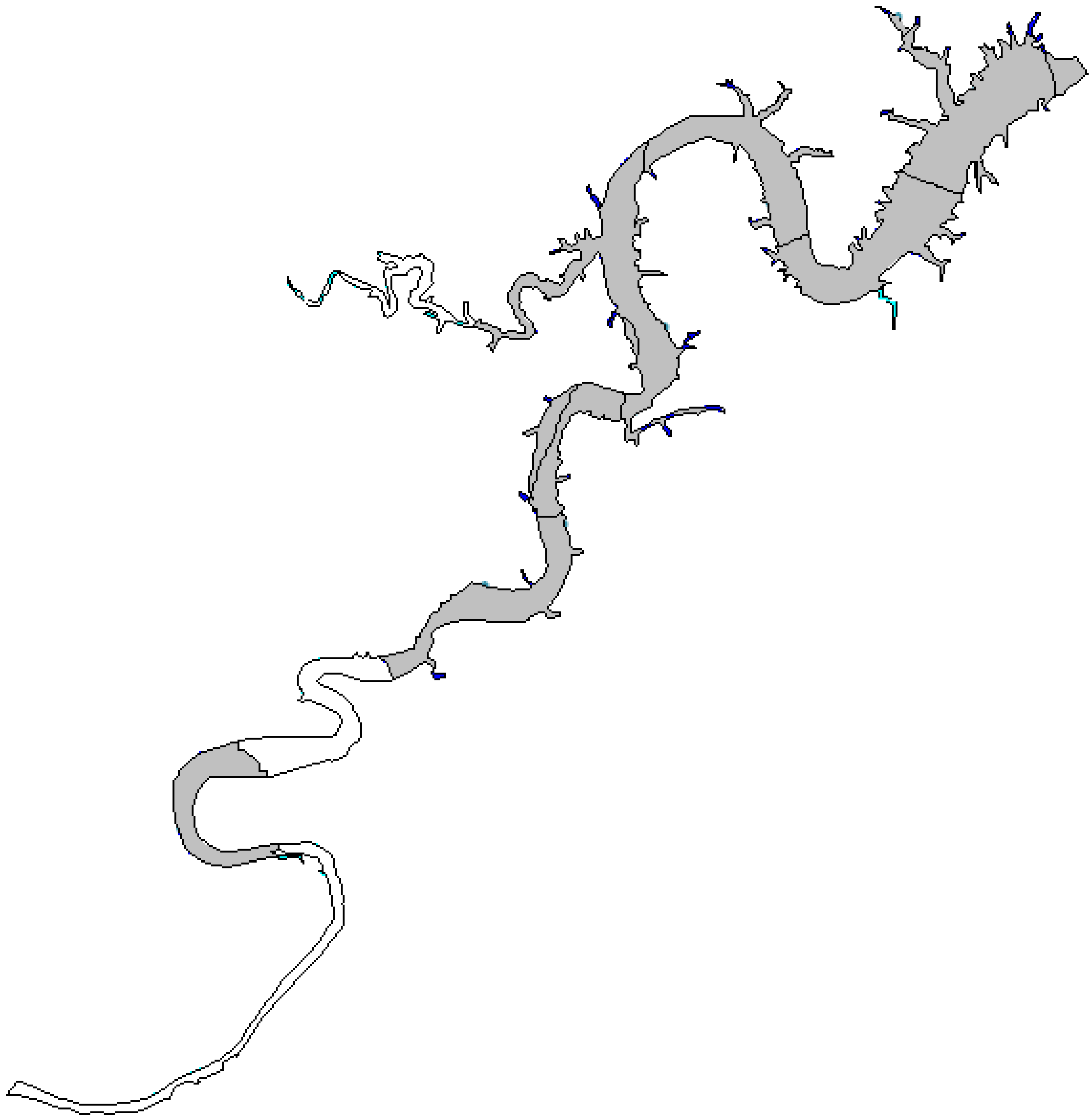
Utilization distribution for STB # 48. 881. Fish was located 12 times over the following seasons. Shaded areas represent 95% kernel estimated confidence bounds.

	2001			2002			
	Spring	Summer	Fall	Winter	Spring	Summer	Fall
Seasons					**X**	**X**	**X**



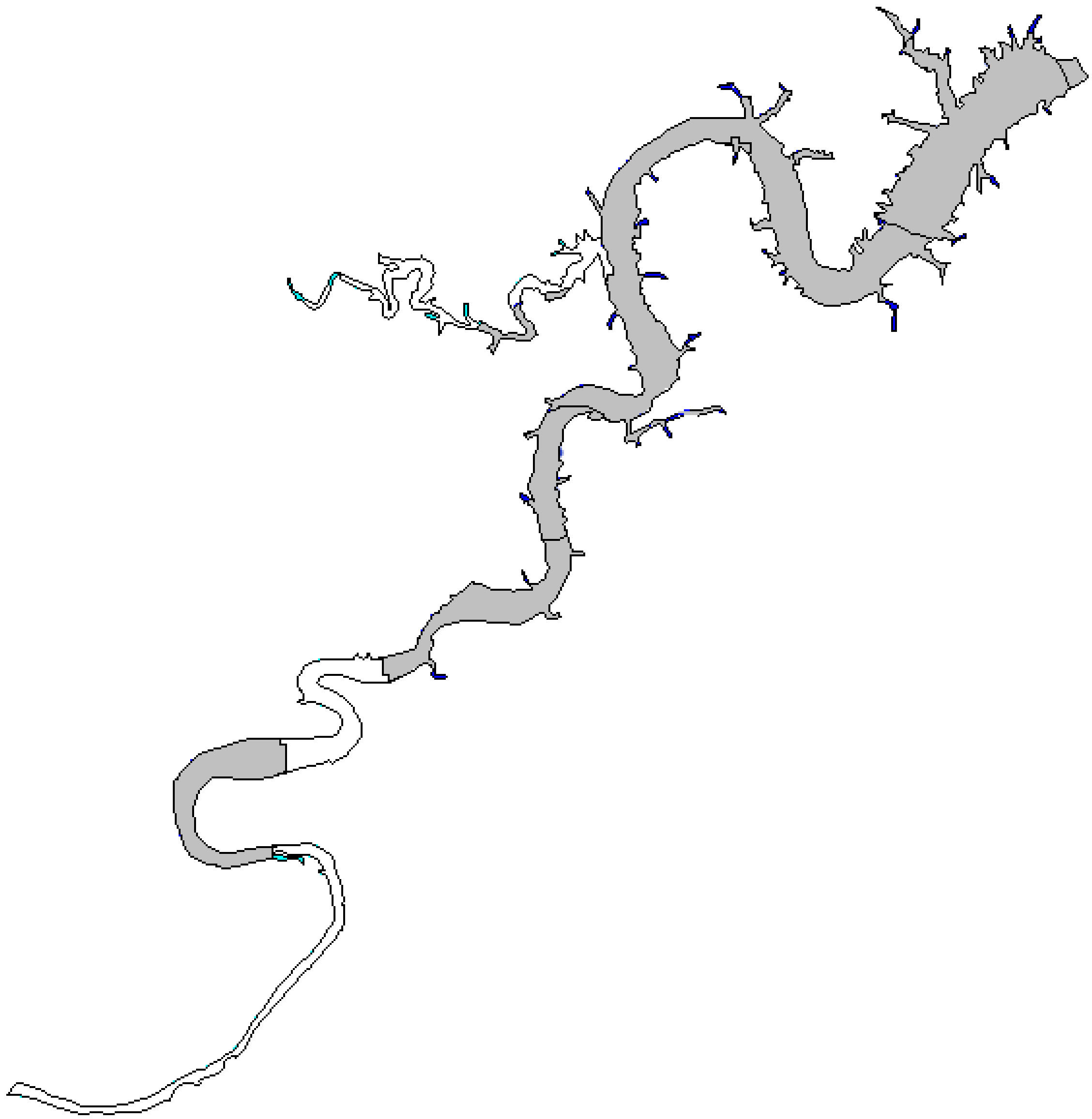
Utilization distribution for STB # 48.892. Fish was located 20 times over the following seasons. Shaded areas represent 95% kernel estimated confidence bounds.

	2001			2002			
	Spring	Summer	Fall	Winter	Spring	Summer	Fall
Seasons	**X**	**X**	**X**	**X**			



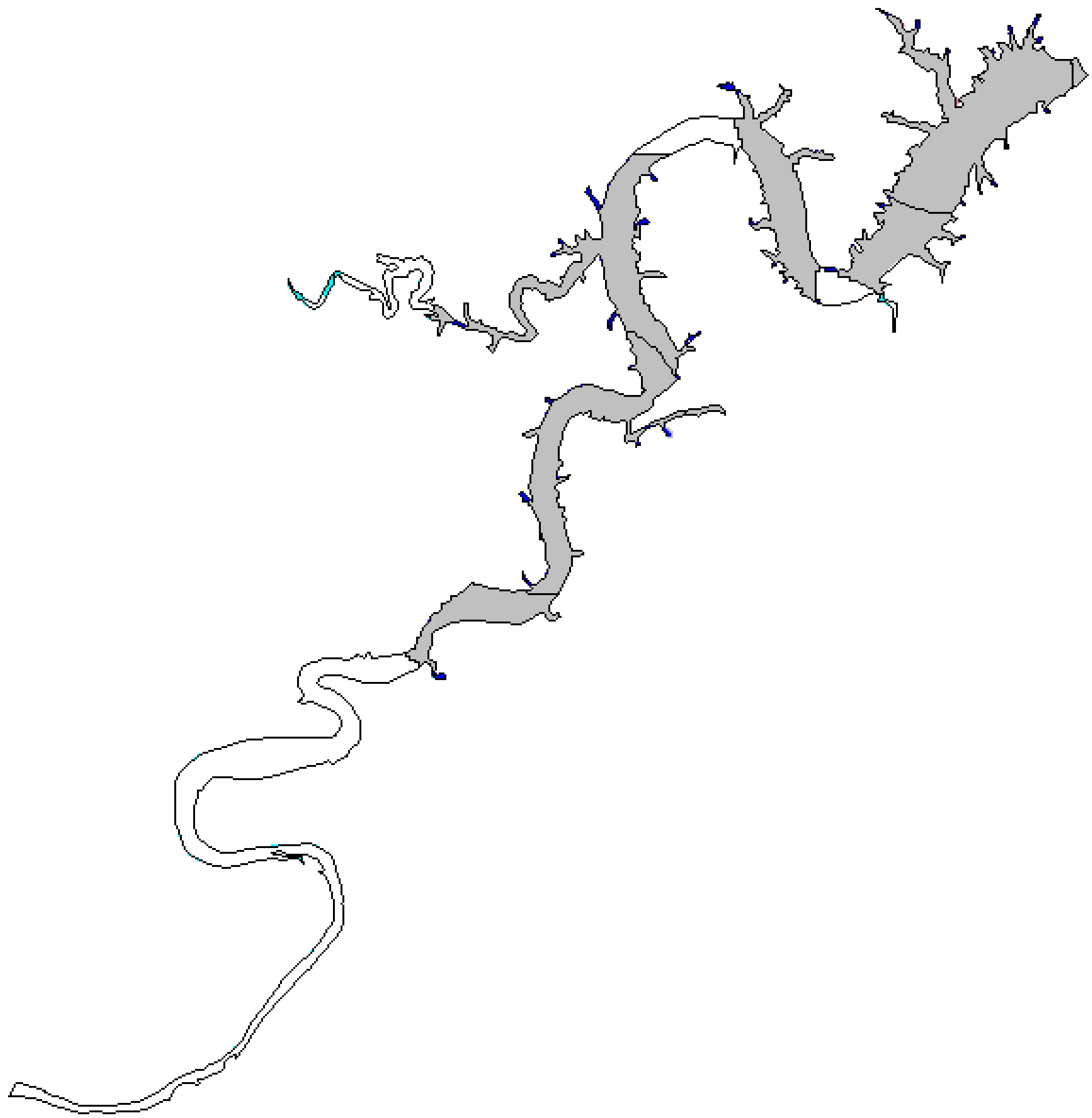
Utilization distribution for STB # 48.911. Fish was located 27 times over the following seasons. Shaded areas represent 95% kernel estimated confidence bounds.

	2001			2002			
	Spring	Summer	Fall	Winter	Spring	Summer	Fall
Seasons	**X**	**X**	**X**	**X**	**X**		



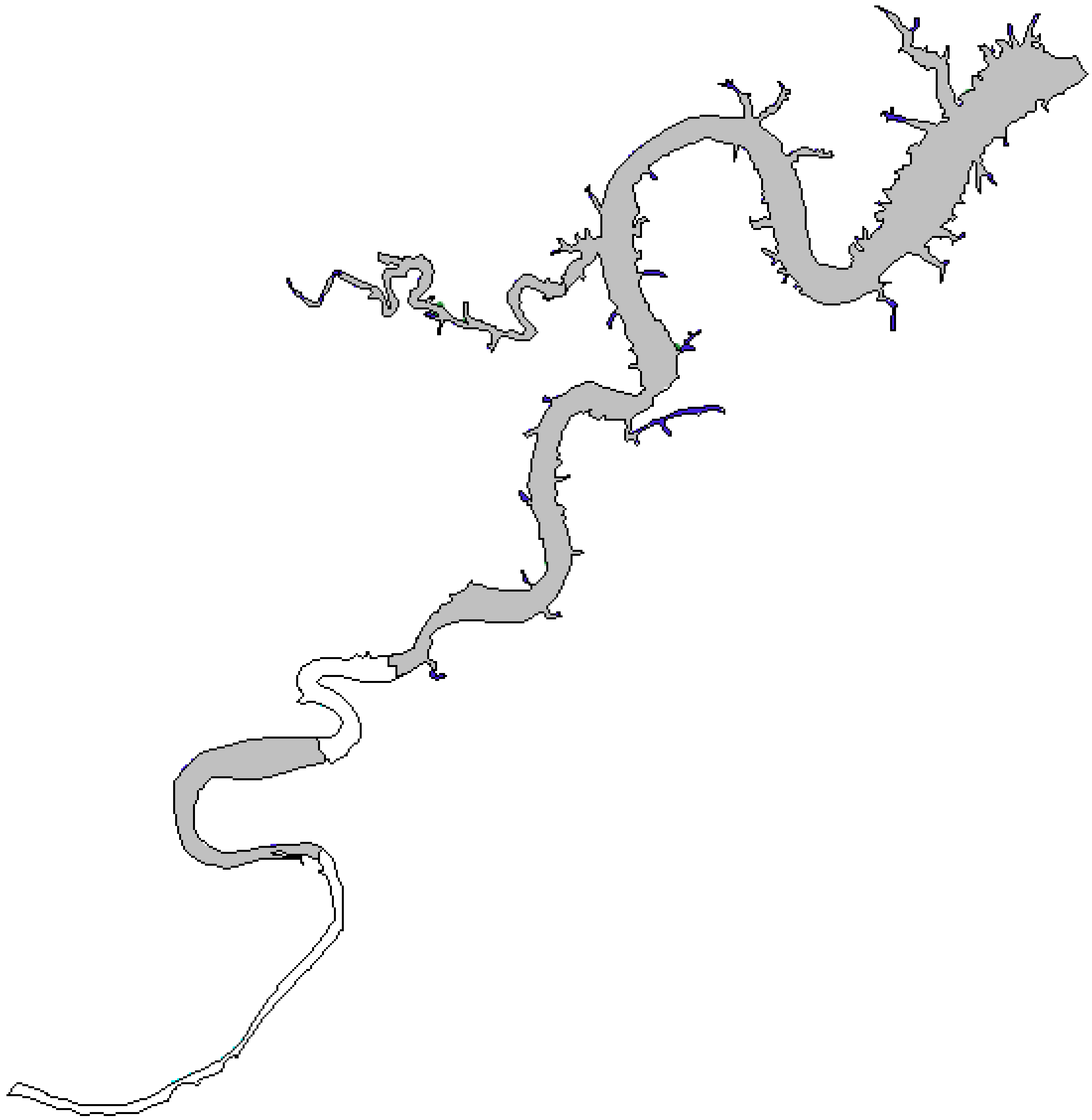
Utilization distribution for STB # 48.951. Fish was located 20 times over the following seasons. Shaded areas represent 95% kernel estimated confidence bounds.

	2001			2002			
	Spring	Summer	Fall	Winter	Spring	Summer	Fall
Seasons	**X**	**X**	**X**	**X**	**X**		**X**



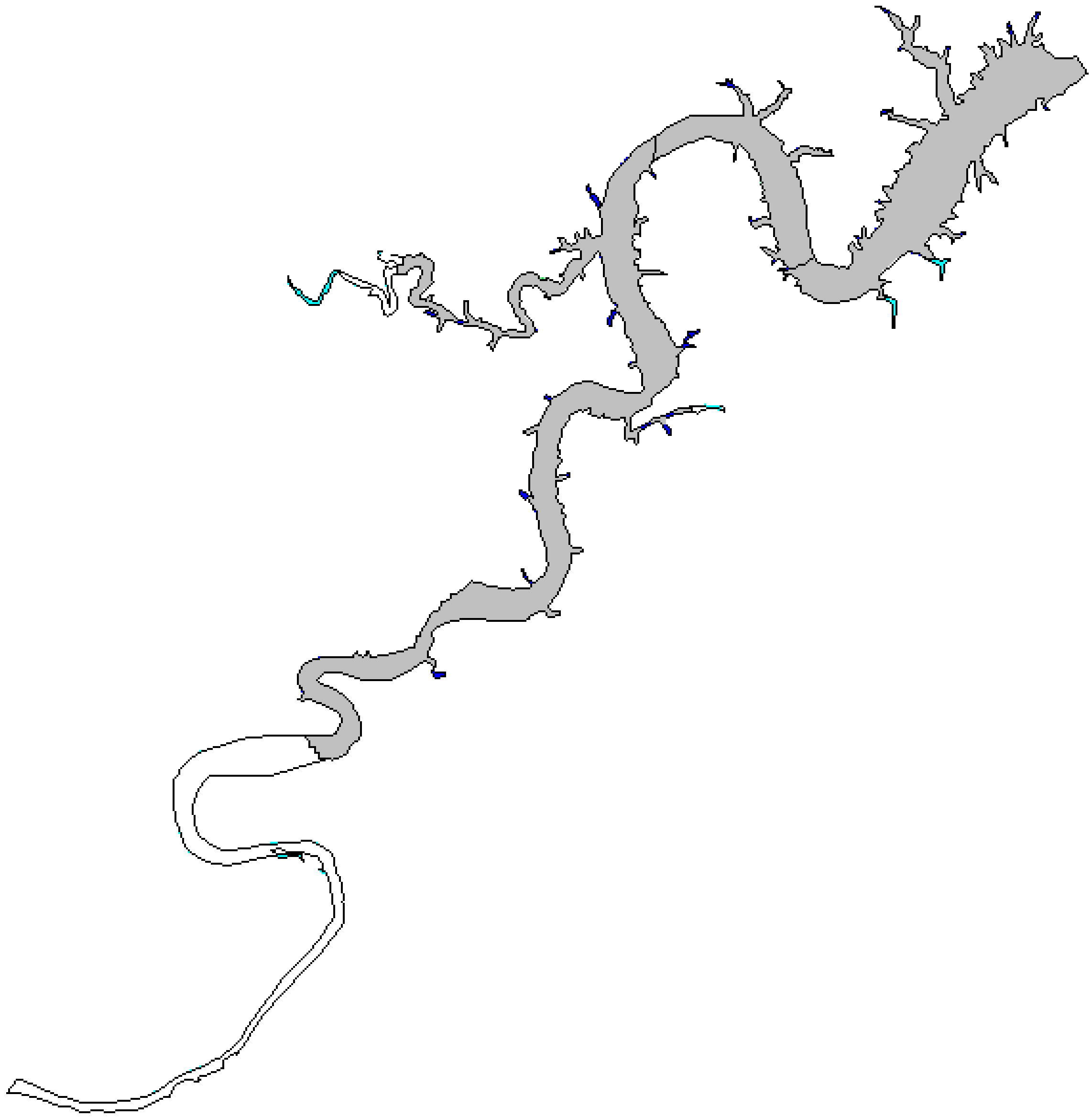
Utilization distribution for STB # 48.961. Fish was located 6 times over the following seasons. Shaded areas represent 95% kernel estimated confidence bounds.

	2001			2002			
	Spring	Summer	Fall	Winter	Spring	Summer	Fall
Seasons				**X**	**X**		**X**



Utilization distribution for STB # 48.981. Fish was located 21 times over the following seasons. Shaded areas represent 95% kernel estimated confidence bounds.

	2001			2002			
	Spring	Summer	Fall	Winter	Spring	Summer	Fall
Seasons			**X**	**X**	**X**	**X**	**X**

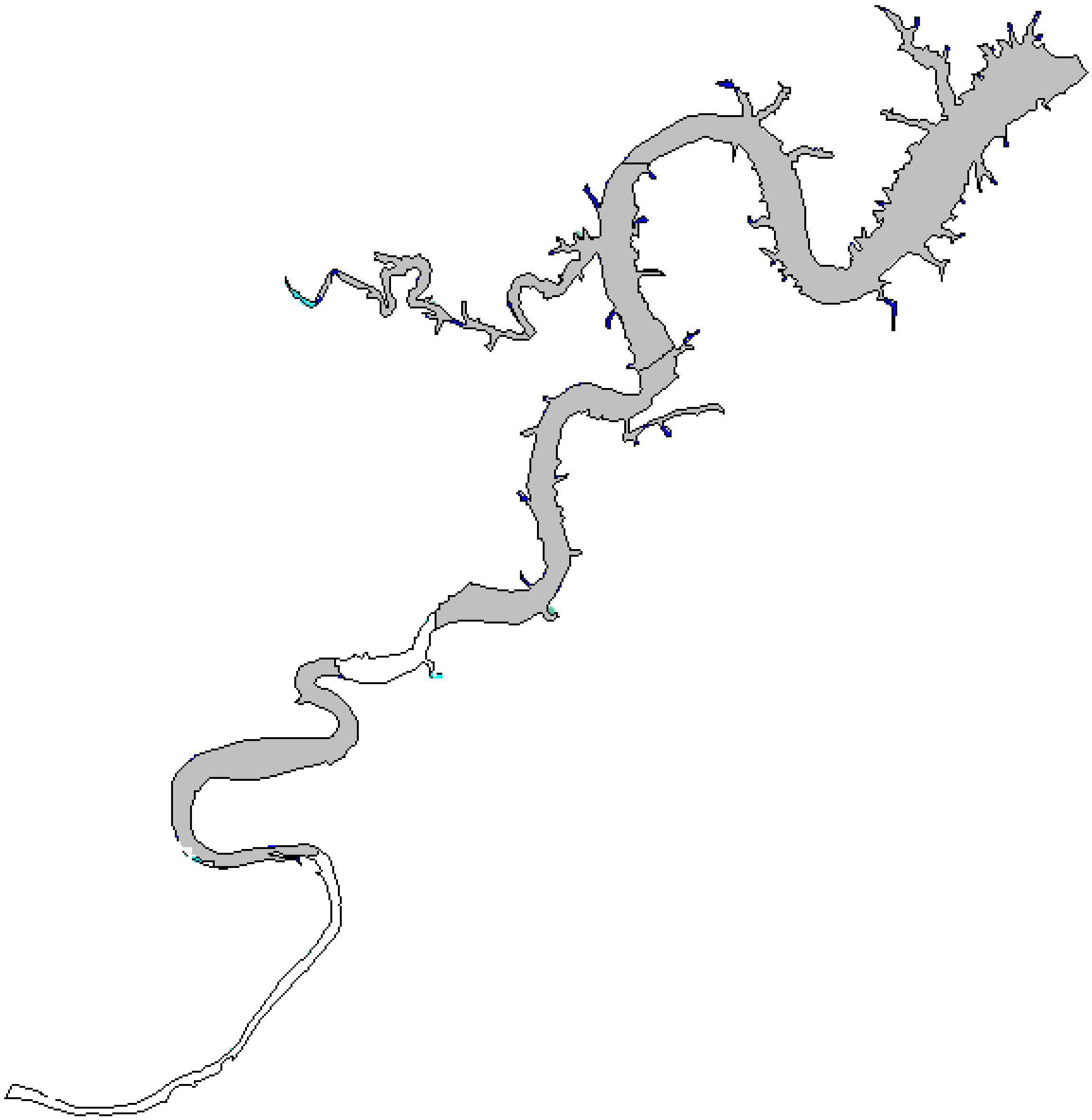


Utilization distribution for STB # 49.015. Fish was located 9 times over the following seasons. Shaded areas represent 95% kernel estimated confidence bounds.

	2001			2002			
	Spring	Summer	Fall	Winter	Spring	Summer	Fall
Seasons			**X**	**X**	**X**		

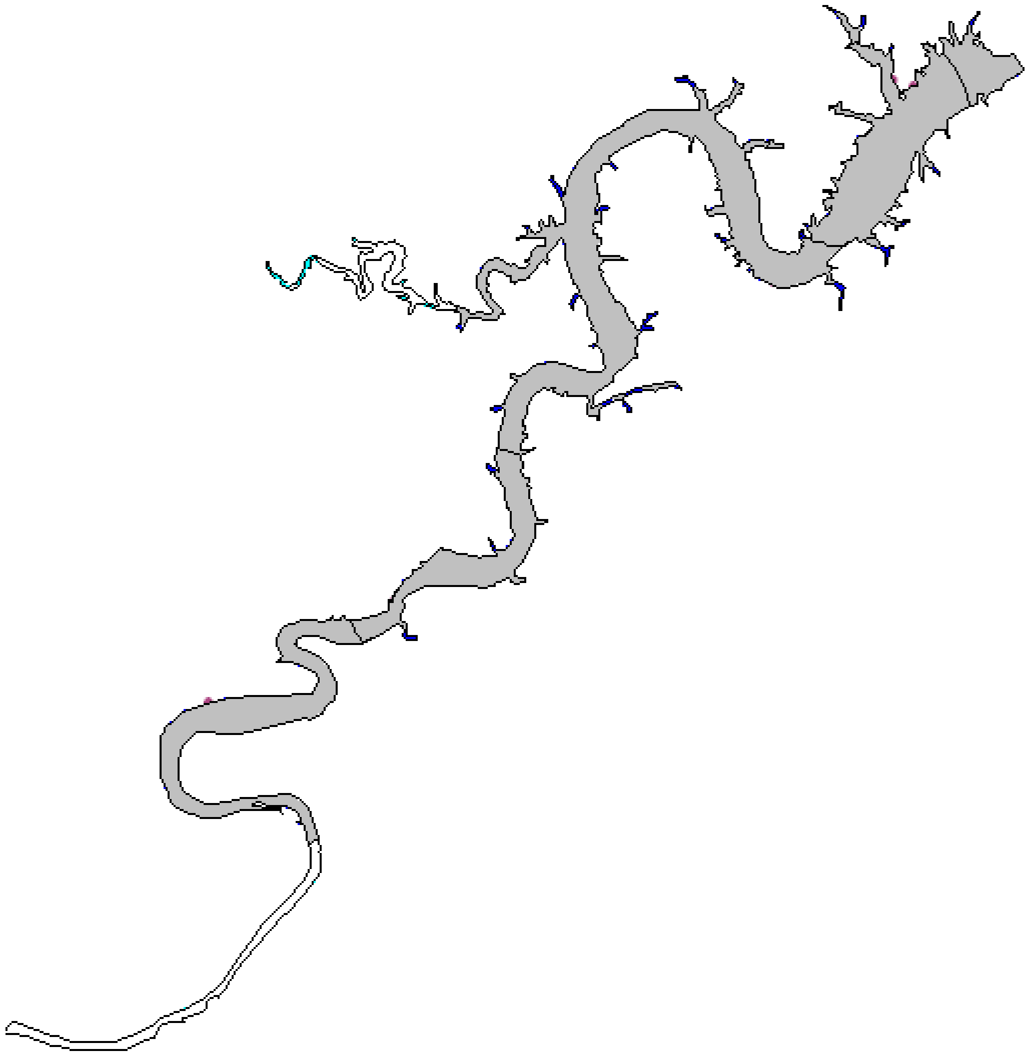
Utilization distribution for STB # 49.065. Fish was located 19 times over the following seasons. Shaded areas represent 95% kernel estimated confidence bounds.

	2001			2002			
	Spring	Summer	Fall	Winter	Spring	Summer	Fall
Seasons				**X**	**X**	**X**	**X**



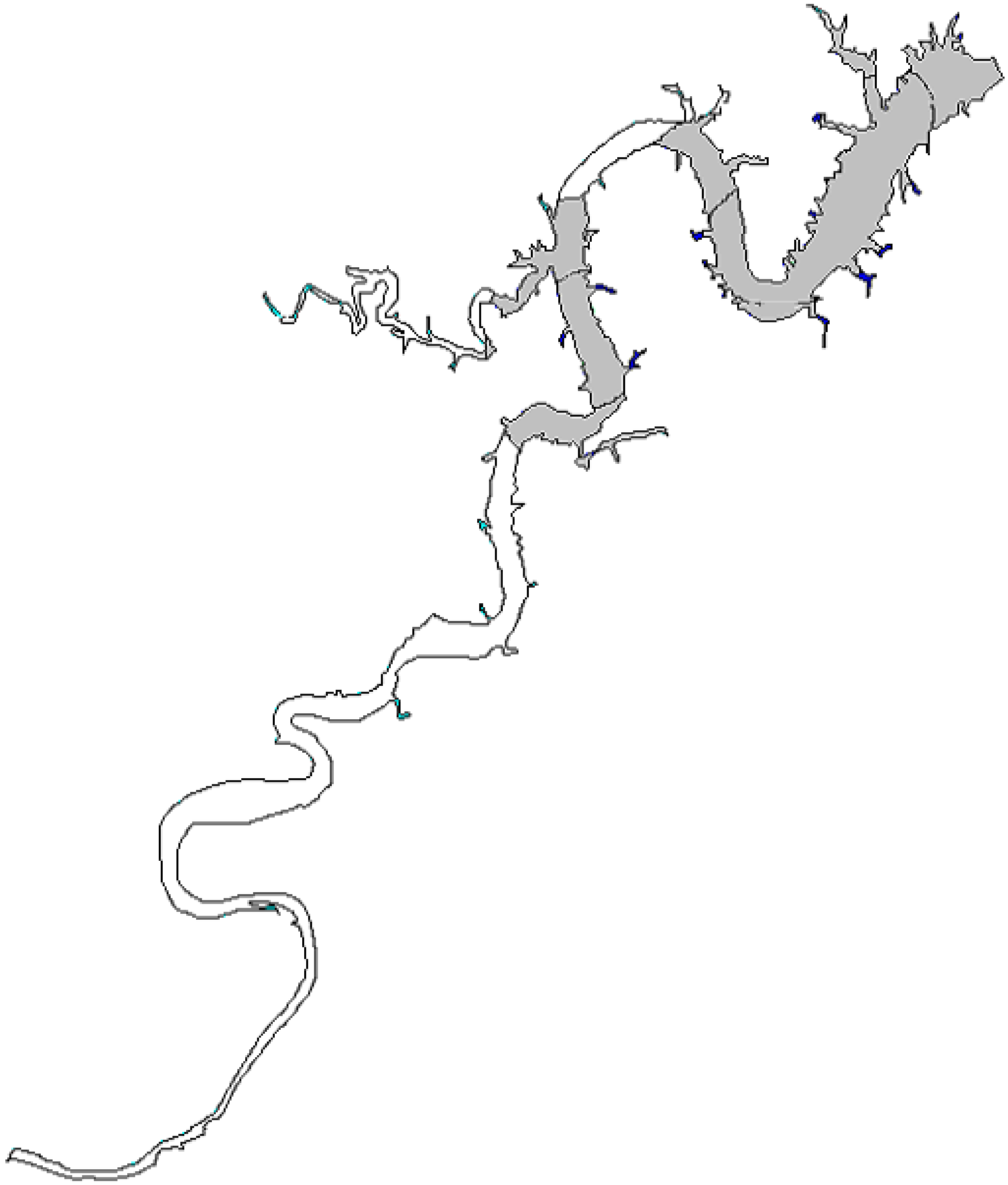
Utilization distribution for STB # 49.075. Fish was located 14 times over the following seasons. Shaded areas represent 95% kernel estimated confidence bounds.

	2001			2002			
	Spring	Summer	Fall	Winter	Spring	Summer	Fall
Seasons				**X**	**X**	**X**	**X**



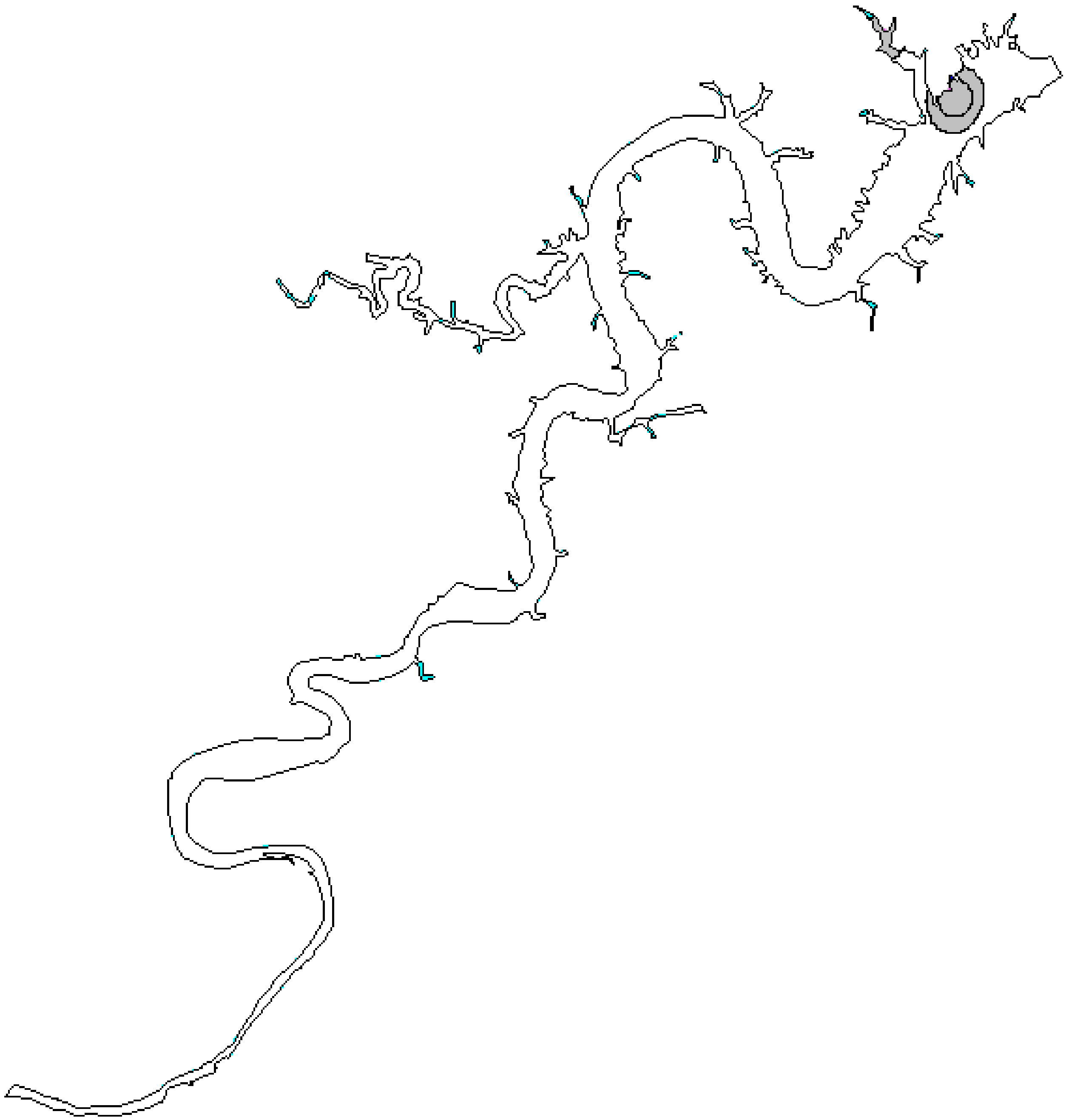
Utilization distribution for STB # 49.085. Fish was located 15 times over the following seasons. Shaded areas represent 95% kernel estimated confidence bounds.

	2001			2002			
	Spring	Summer	Fall	Winter	Spring	Summer	Fall
Seasons				**X**	**X**	**X**	**X**



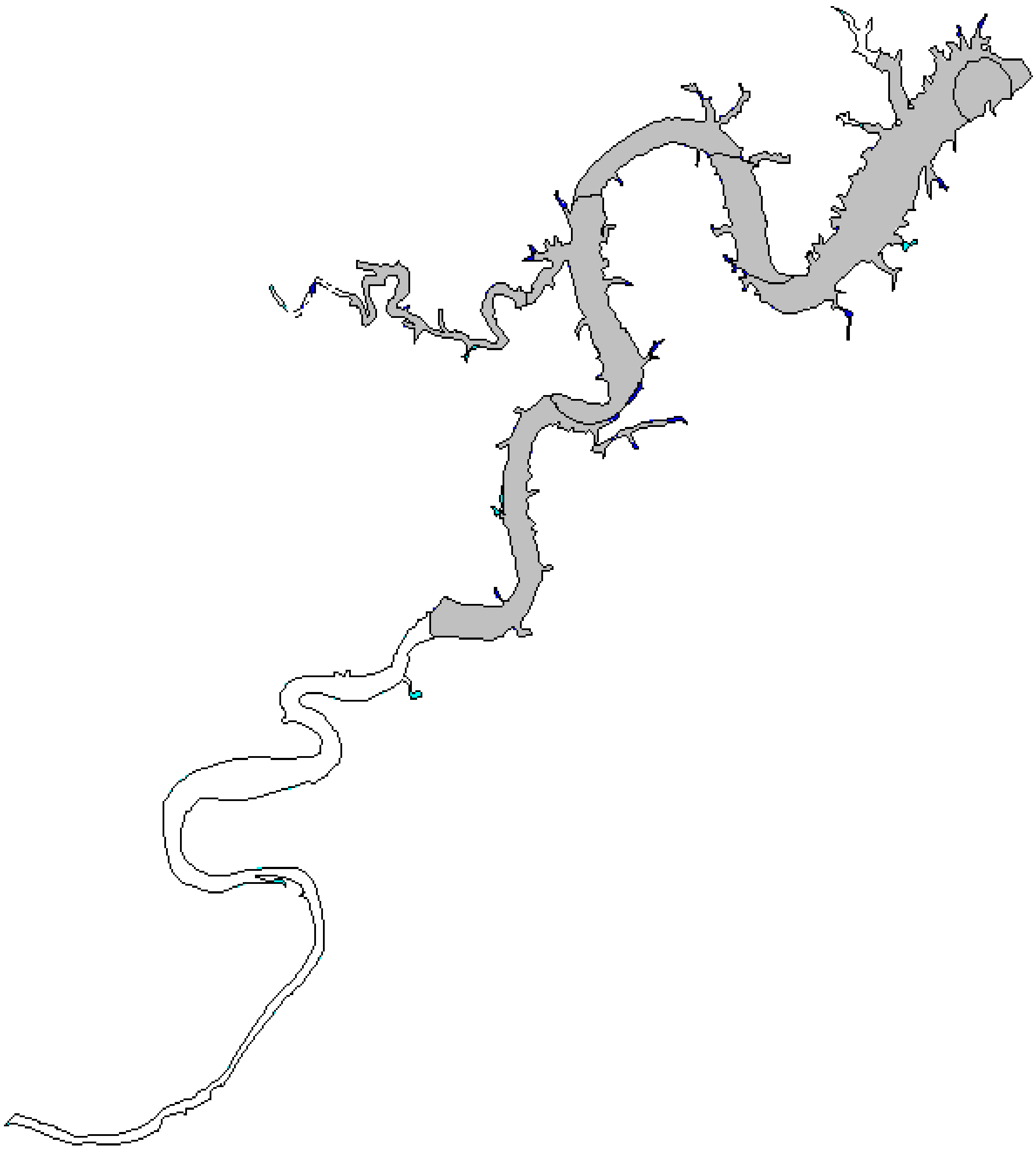
Utilization distribution for HSB # 48.021. Fish was located 7 times over the following seasons. Shaded areas represent 95% kernel estimated confidence bounds.

	2001			2002			
	Spring	Summer	Fall	Winter	Spring	Summer	Fall
Seasons	**X**	**X**					



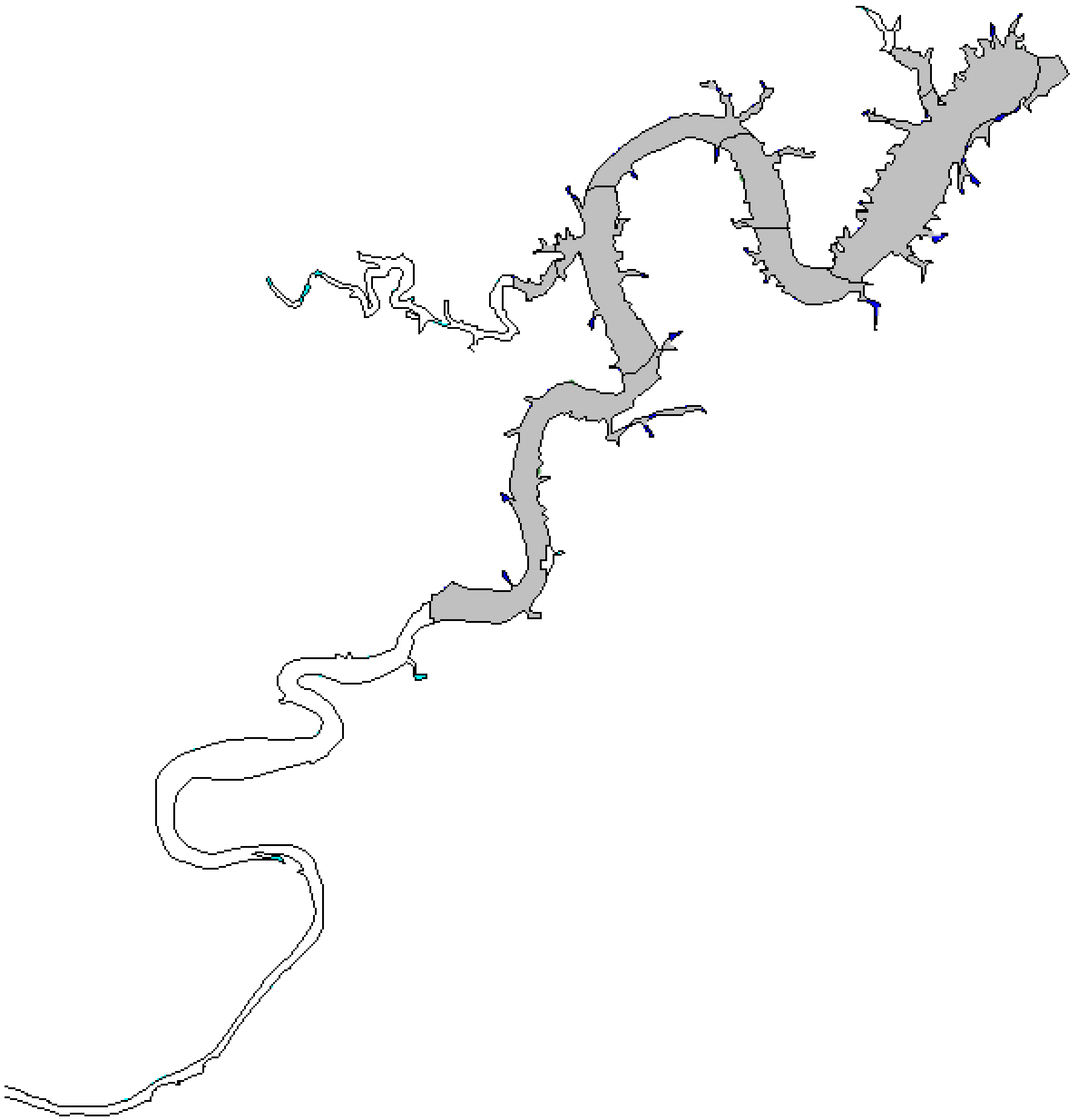
Utilization distribution for HSB # 48. 051. Fish was located 6 times over the following seasons. Shaded areas represent 95% kernel estimated confidence bounds.

	2001			2002			
	Spring	Summer	Fall	Winter	Spring	Summer	Fall
Seasons	**X**						



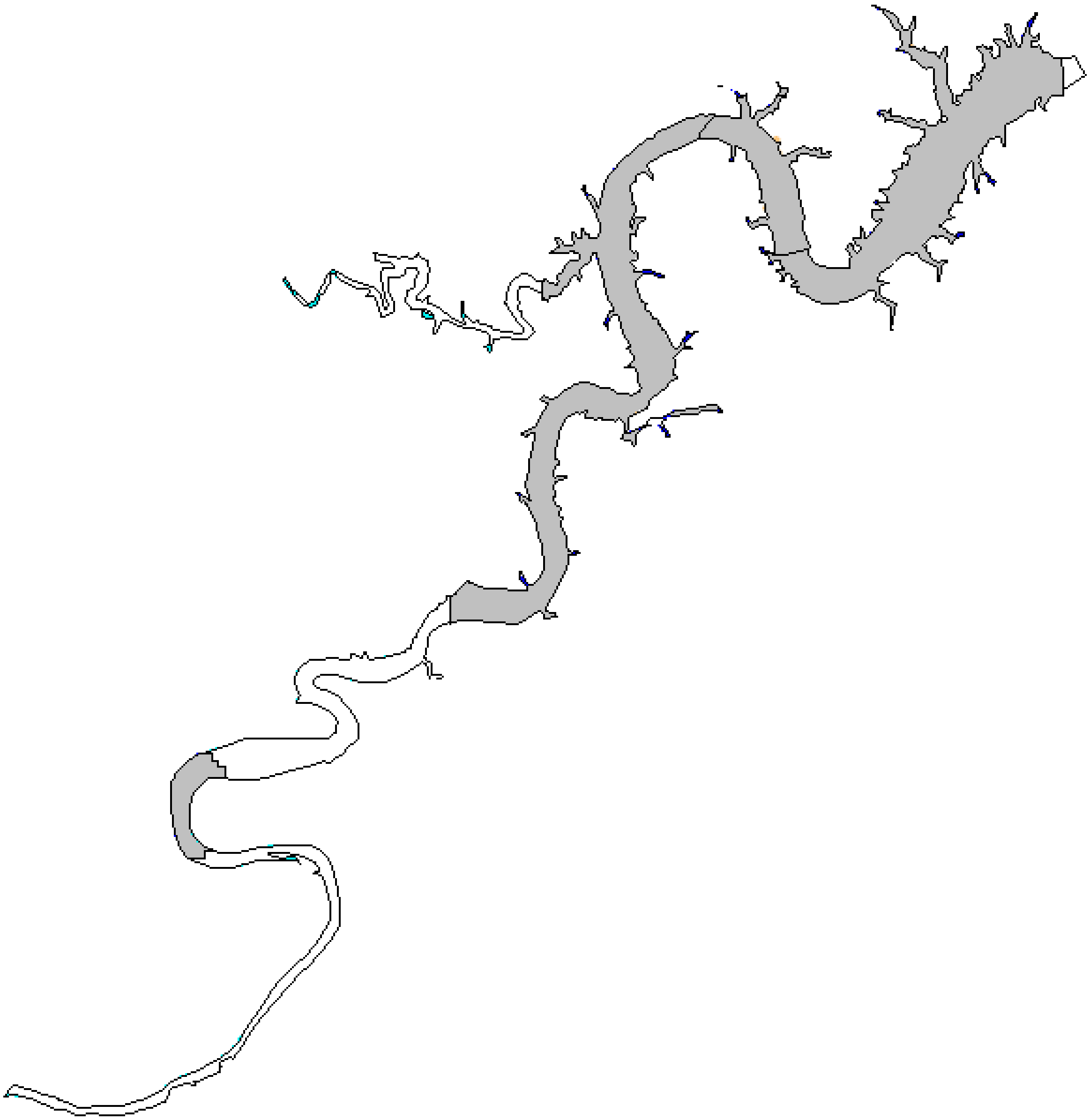
Utilization distribution for HSB # 48.071. Fish was located 21 times over the following seasons. Shaded areas represent 95% kernel estimated confidence bounds.

	2001			2002			
	Spring	Summer	Fall	Winter	Spring	Summer	Fall
Seasons			X	X	X	X	X



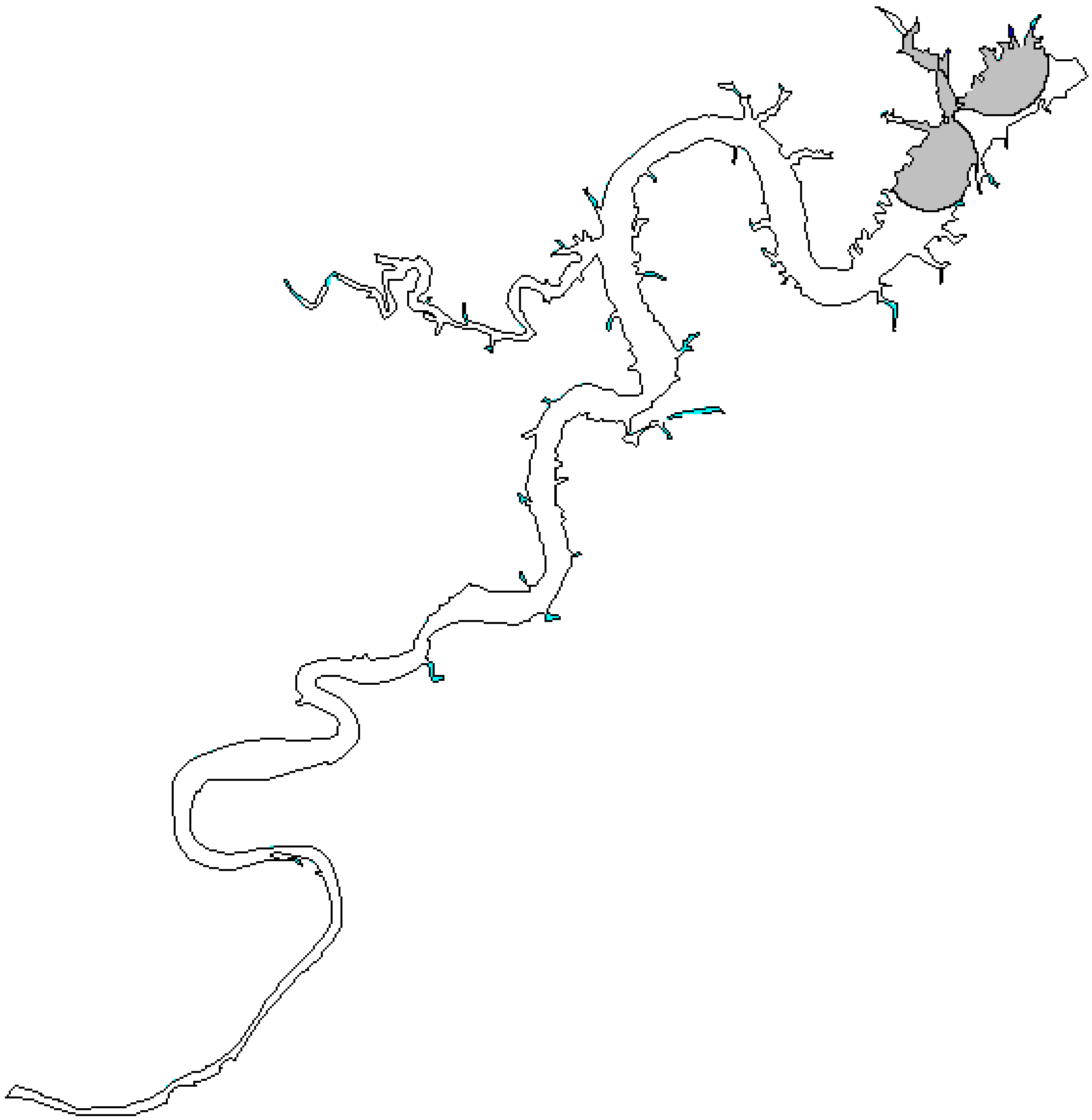
Utilization distribution for HSB # 48.081. Fish was located 43 times over the following seasons. Shaded areas represent 95% kernel estimated confidence bounds.

	2001			2002			
	Spring	Summer	Fall	Winter	Spring	Summer	Fall
Seasons	**X**	**X**	**X**	**X**	**X**	**X**	



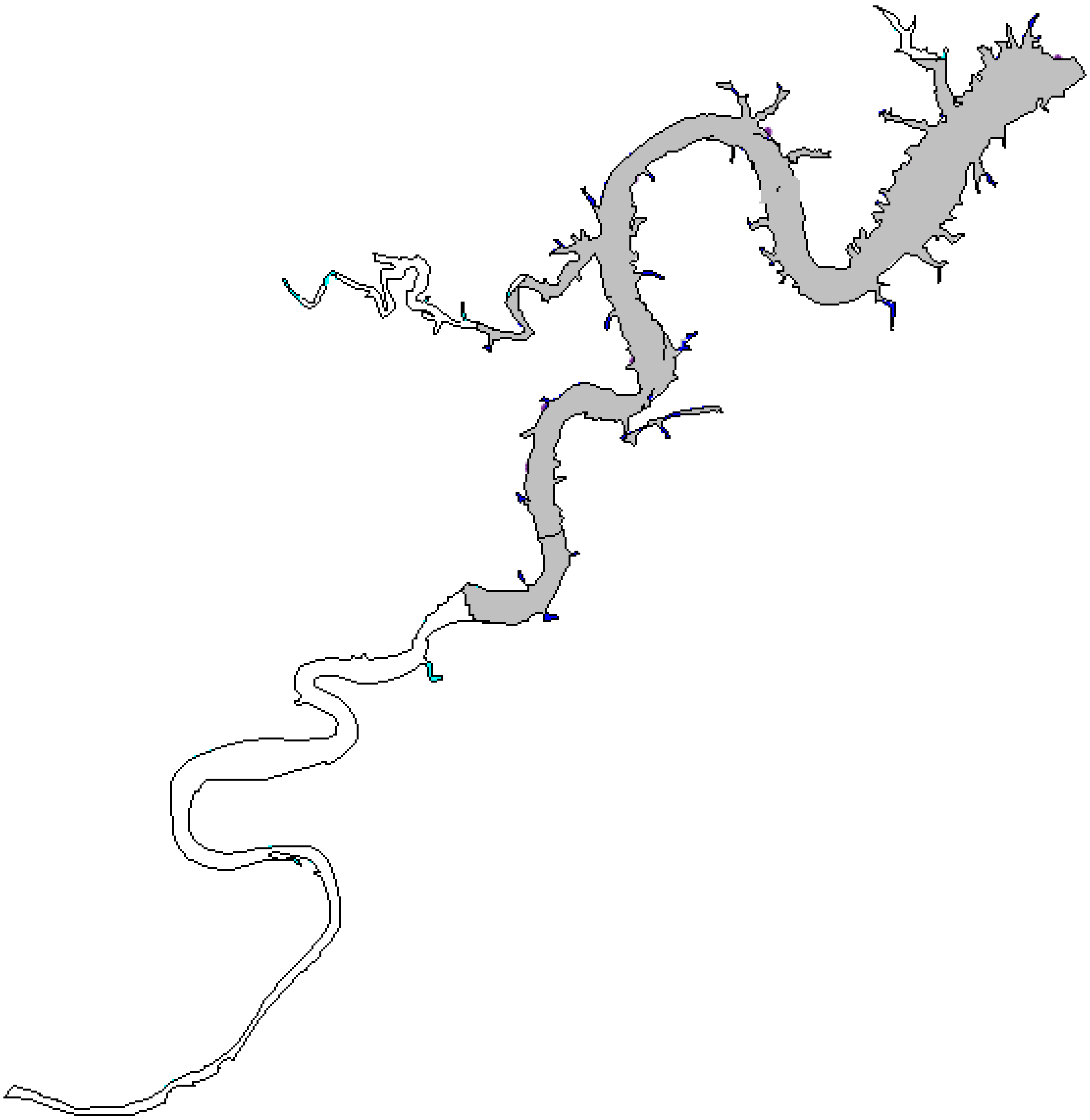
Utilization distribution for HSB # 48.101. Fish was located 30 times over the following seasons. Shaded areas represent 95% kernel estimated confidence bounds.

	2001			2002			
	Spring	Summer	Fall	Winter	Spring	Summer	Fall
Seasons	**X**	**X**	**X**	**X**	**X**		



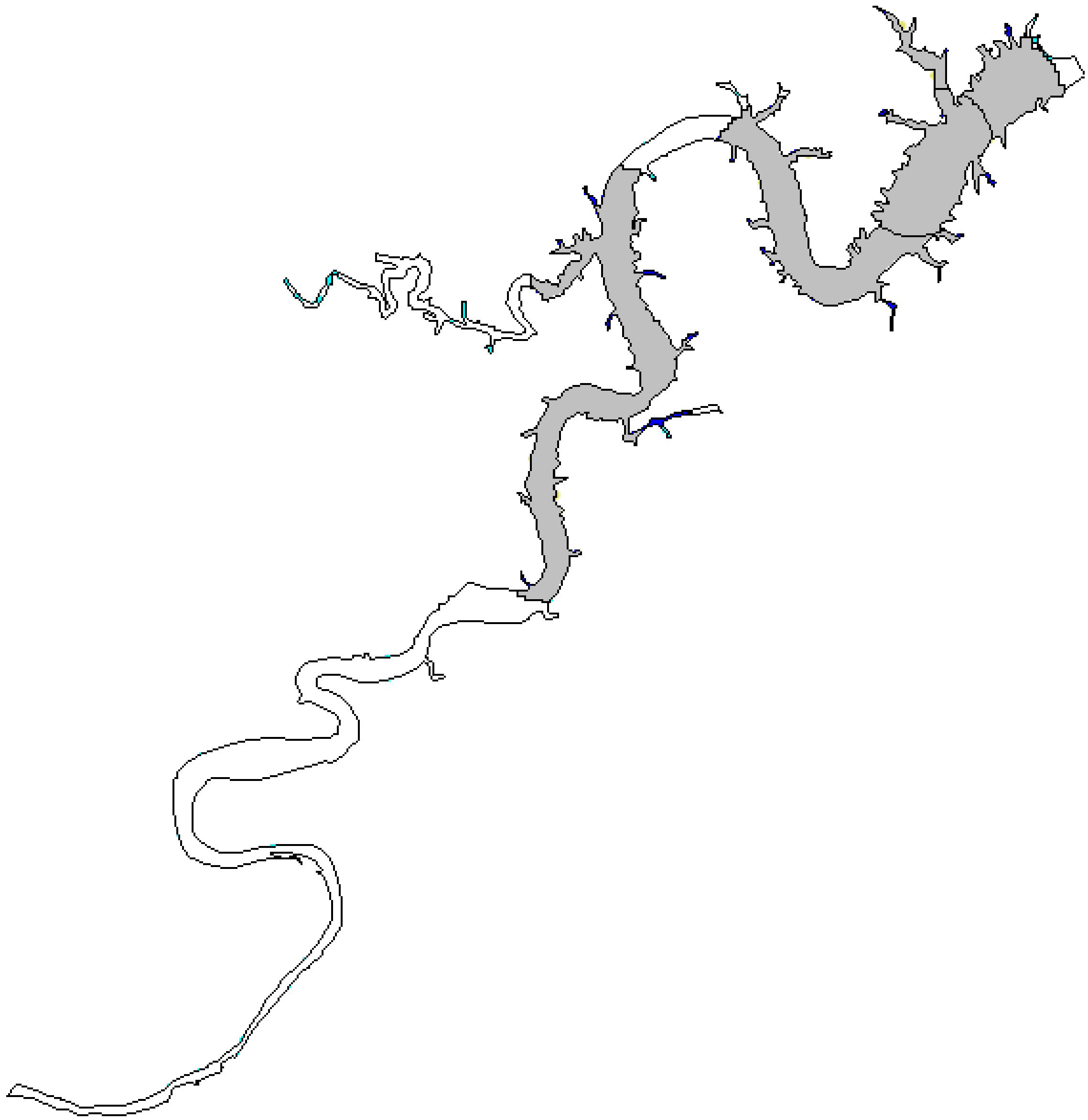
Utilization distribution for HSB # 48.141. Fish was located 4 times over the following seasons. Shaded areas represent 95% kernel estimated confidence bounds.

	2001			2002			
	Spring	Summer	Fall	Winter	Spring	Summer	Fall
Seasons	**X**	**X**					



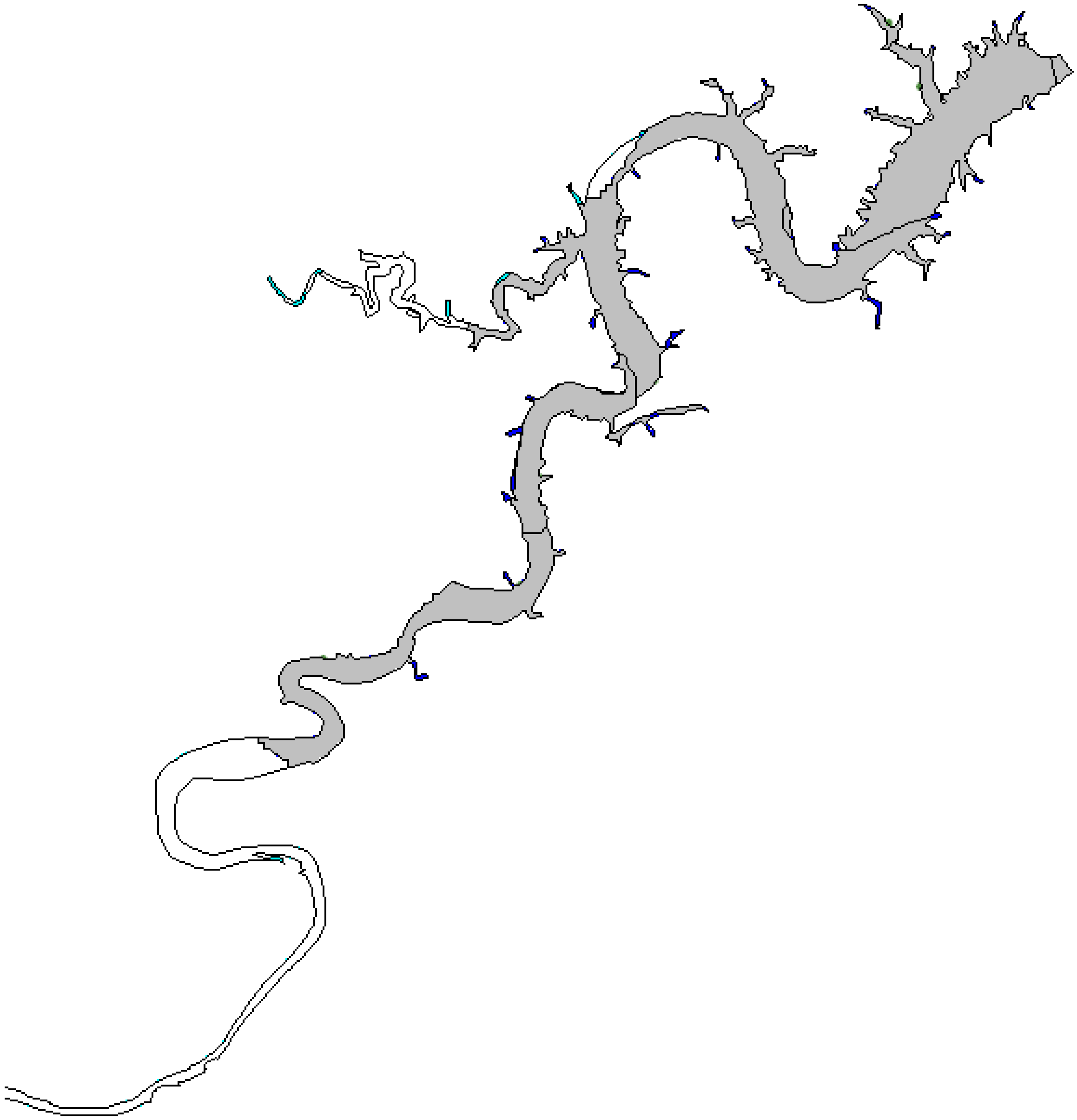
Utilization distribution for HSB # 48.151. Fish was located 16 times over the following seasons. Shaded areas represent 95% kernel estimated confidence bounds.

	2001			2002			
	Spring	Summer	Fall	Winter	Spring	Summer	Fall
Seasons					**X**	**X**	**X**



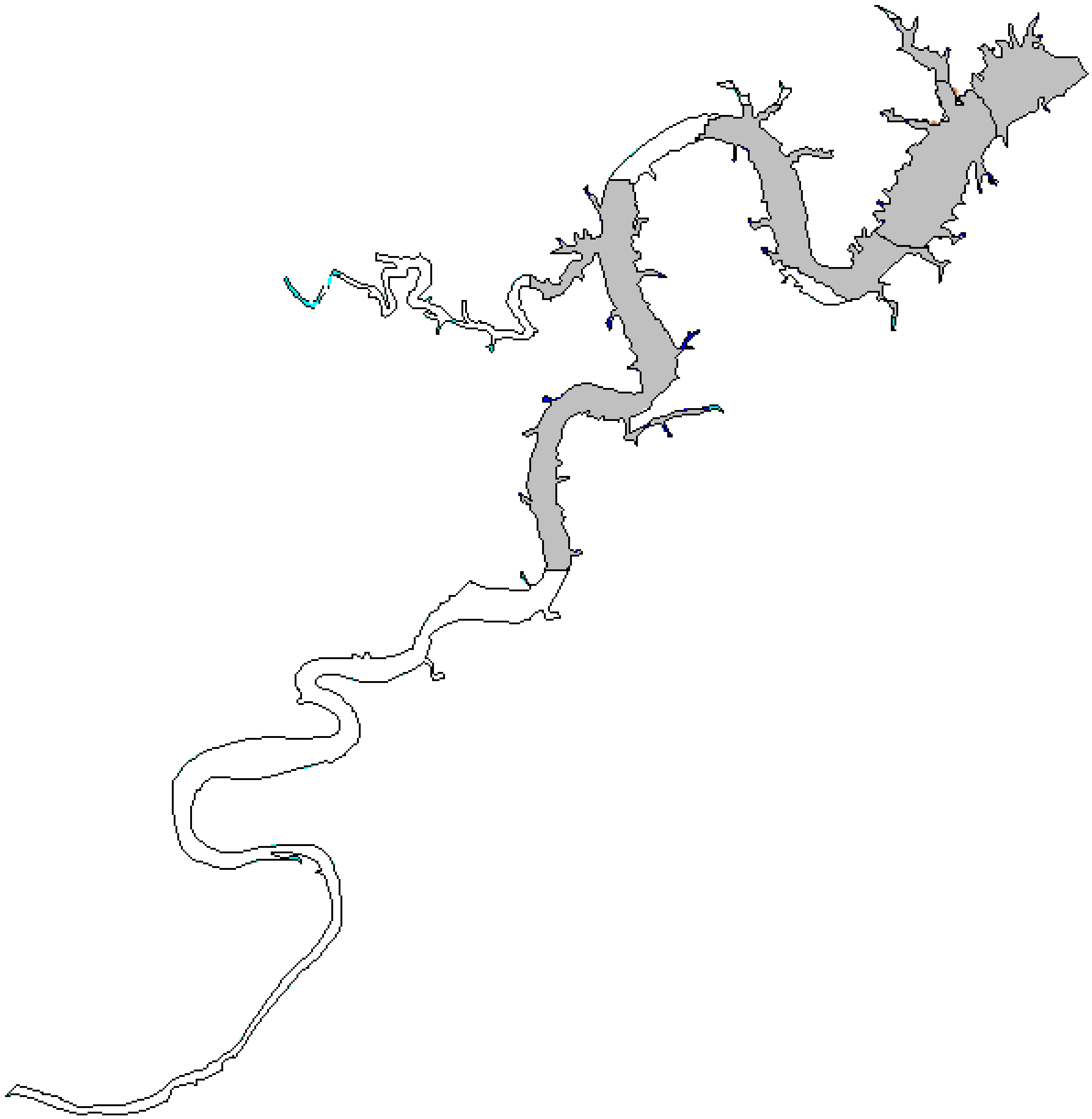
Utilization distribution for HSB # 48.181. Fish was located 36 times over the following seasons. Shaded areas represent 95% kernel estimated confidence bounds.

	2001			2002			
	Spring	Summer	Fall	Winter	Spring	Summer	Fall
Seasons	**X**	**X**	**X**	**X**	**X**	**X**	



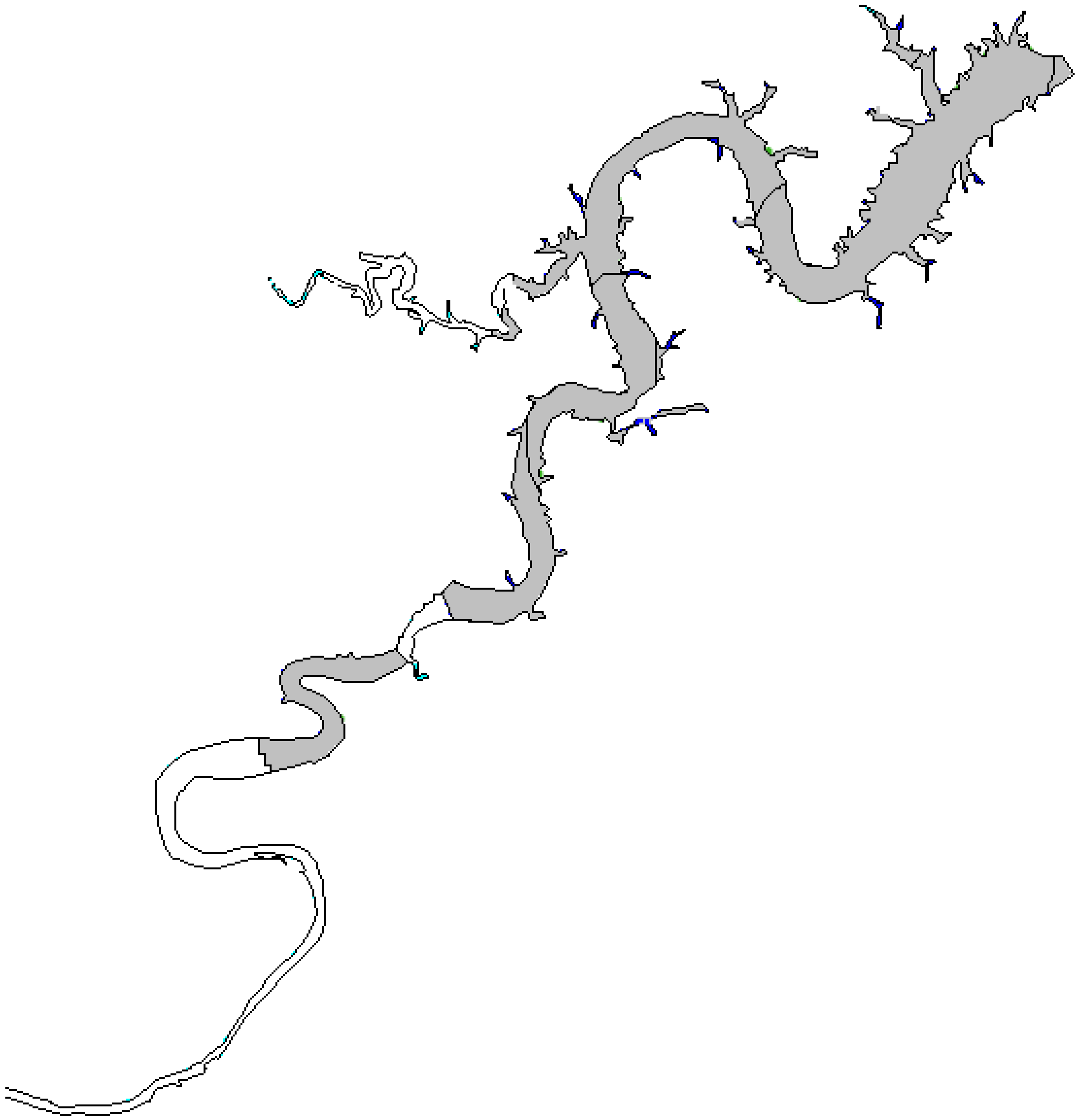
Utilization distribution for HSB # 48.201. Fish was located 35 times over the following seasons. Shaded areas represent 95% kernel estimated confidence bounds.

	2001			2002			
	Spring	Summer	Fall	Winter	Spring	Summer	Fall
Seasons	**X**	**X**	**X**	**X**	**X**		



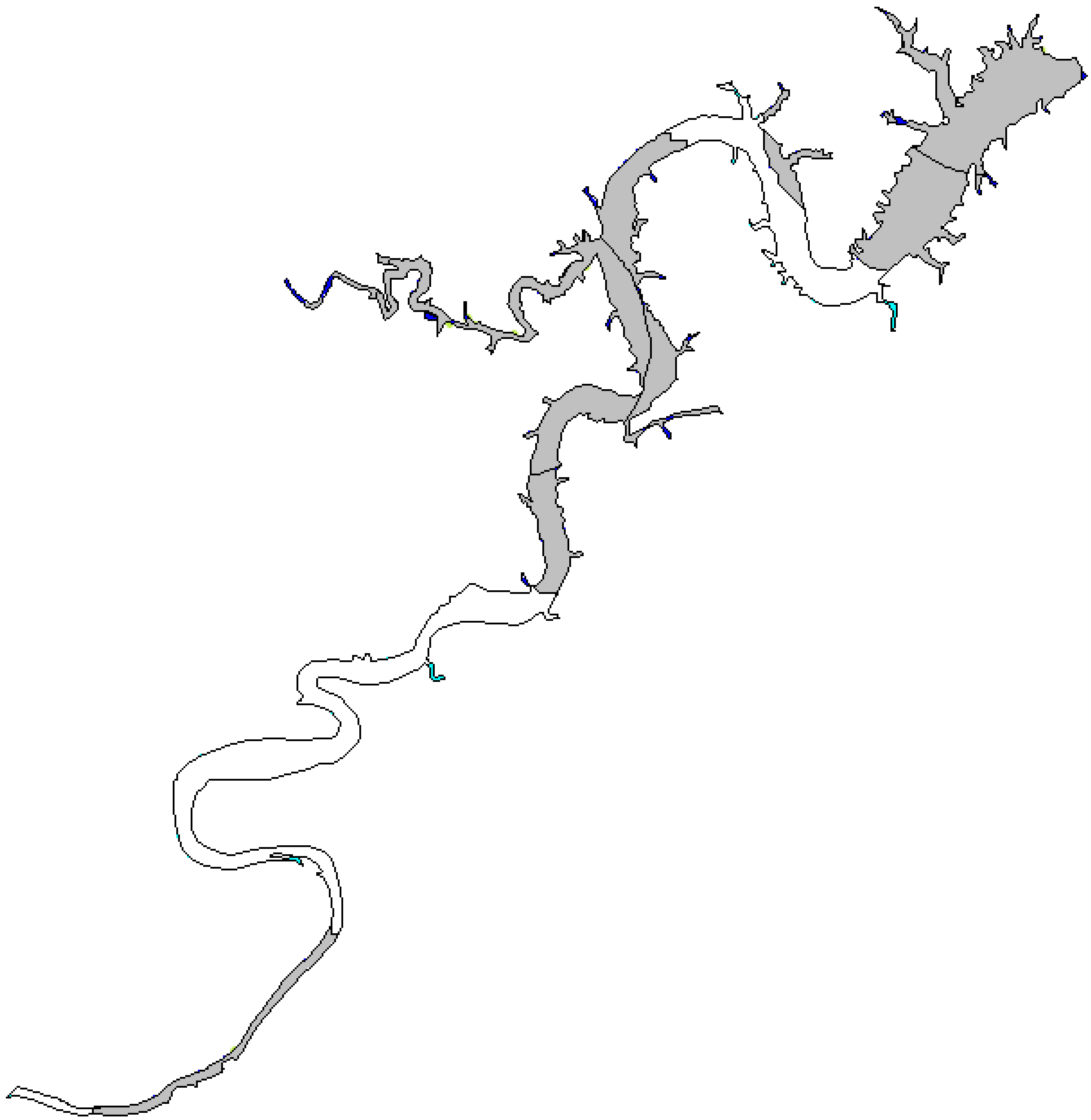
Utilization distribution for HSB # 48.231. Fish was located 15 times over the following seasons. Shaded areas represent 95% kernel estimated confidence bounds.

	2001			2002			
	Spring	Summer	Fall	Winter	Spring	Summer	Fall
Seasons			**X**	**X**	**X**	**X**	



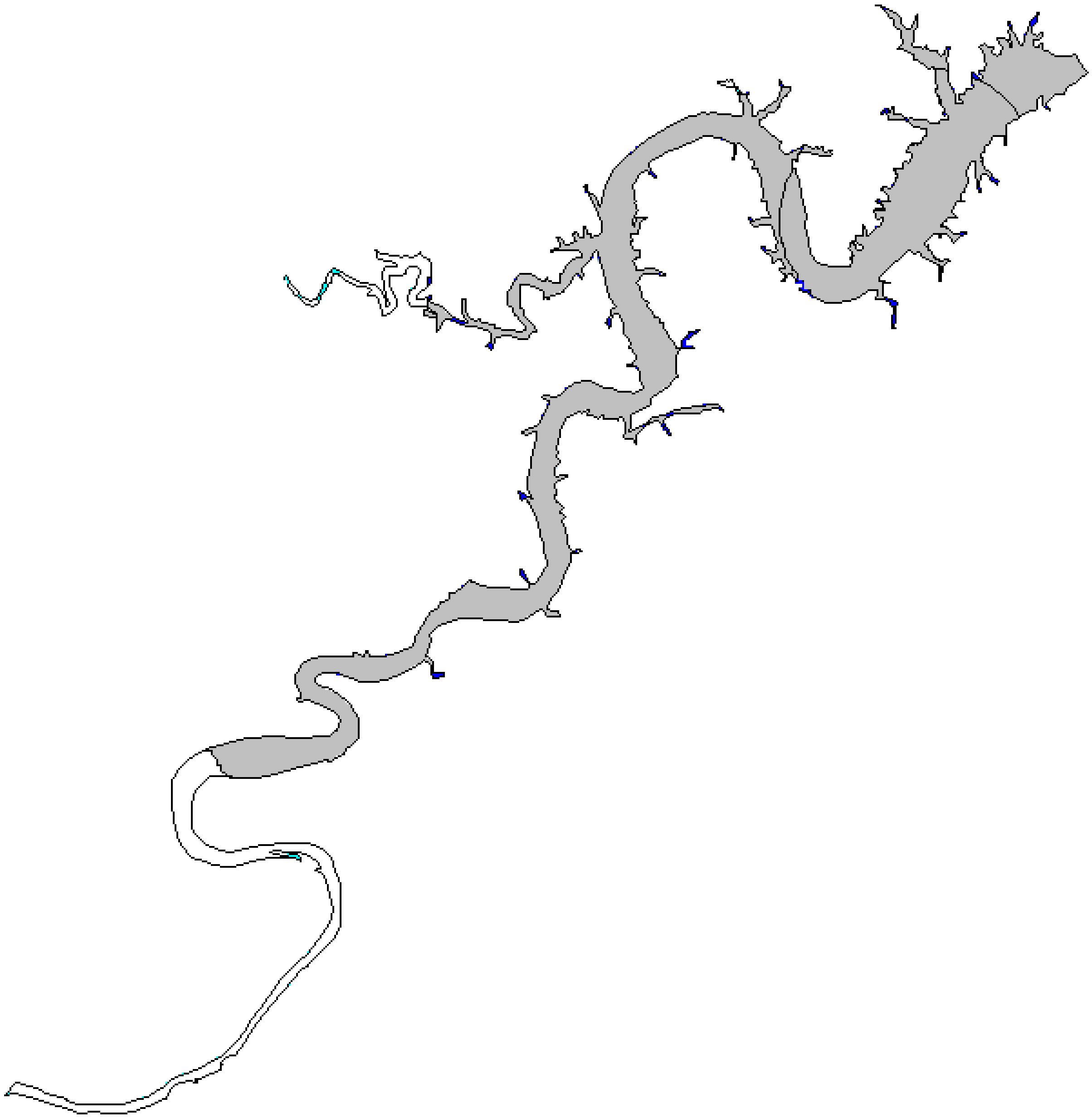
Utilization distribution for HSB # 48.241. Fish was located 31 times over the following seasons. Shaded areas represent 95% kernel estimated confidence bounds.

	2001			2002			
	Spring	Summer	Fall	Winter	Spring	Summer	Fall
Seasons	**X**	**X**	**X**	**X**	**X**	**X**	



Utilization distribution for HSB # 48.251. Fish was located 13 times over the following seasons. Shaded areas represent 95% kernel estimated confidence bounds.

	2001			2002			
	Spring	Summer	Fall	Winter	Spring	Summer	Fall
Seasons					**X**	**X**	**X**

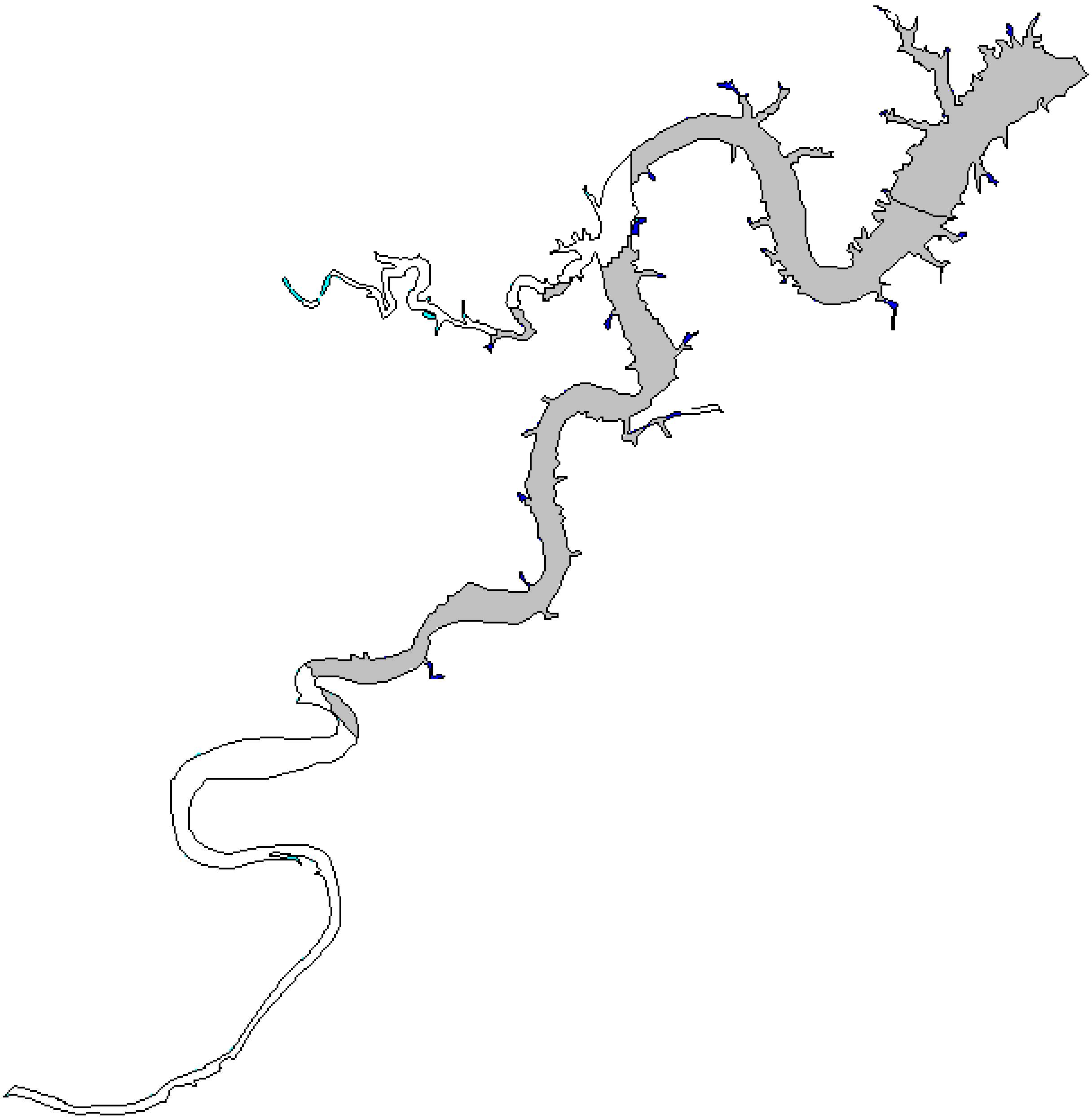


Utilization distribution for HSB # 48.621. Fish was located 7 times over the following seasons. Shaded areas represent 95% kernel estimated confidence bounds.

	2001			2002			
	Spring	Summer	Fall	Winter	Spring	Summer	Fall
Seasons			**X**	**X**			

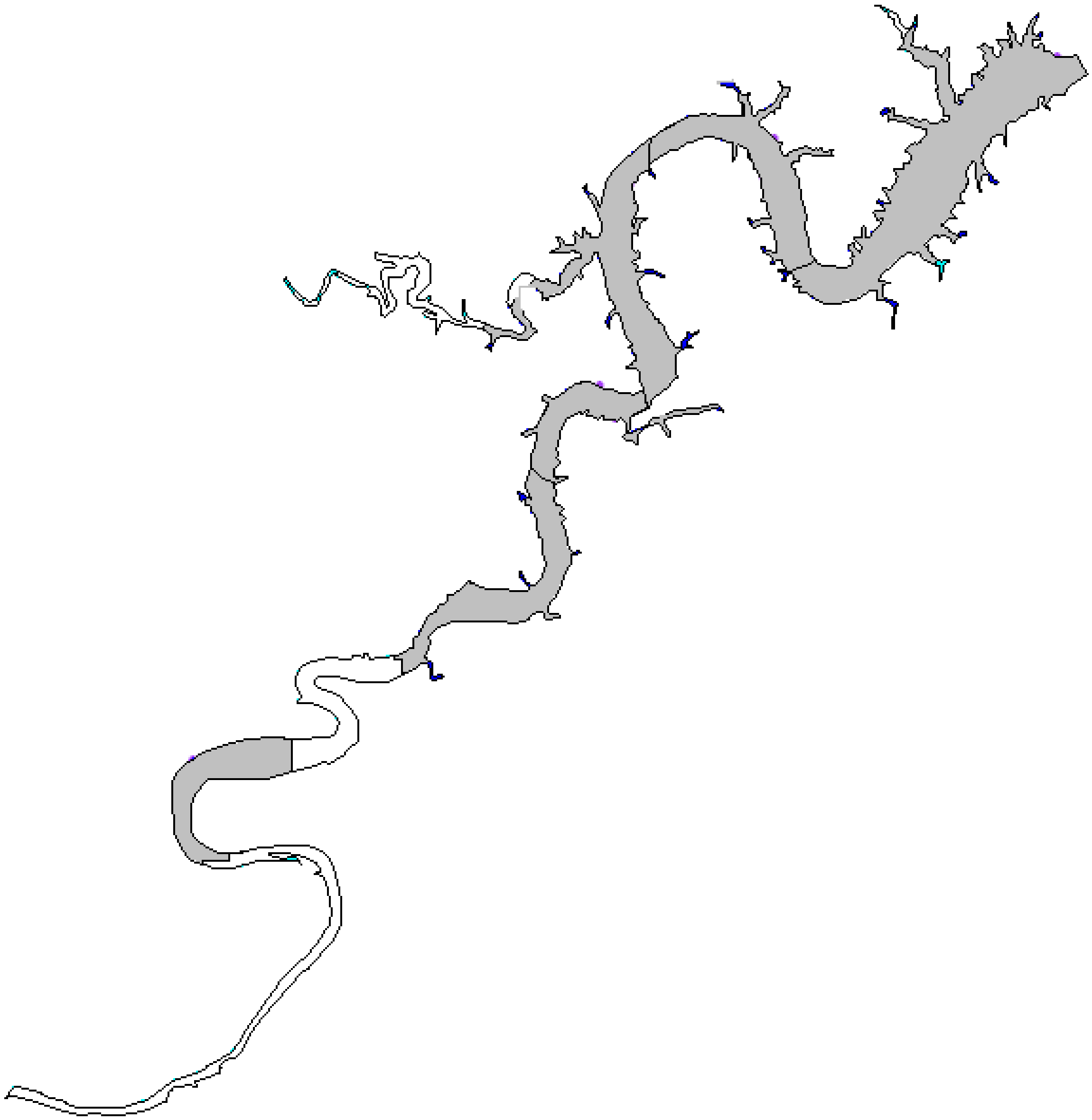
Utilization distribution for HSB # 48.659. Fish was located 16 times over the following seasons. Shaded areas represent 95% kernel estimated confidence bounds.

	2001			2002			
	Spring	Summer	Fall	Winter	Spring	Summer	Fall
Seasons					**X**	**X**	**X**



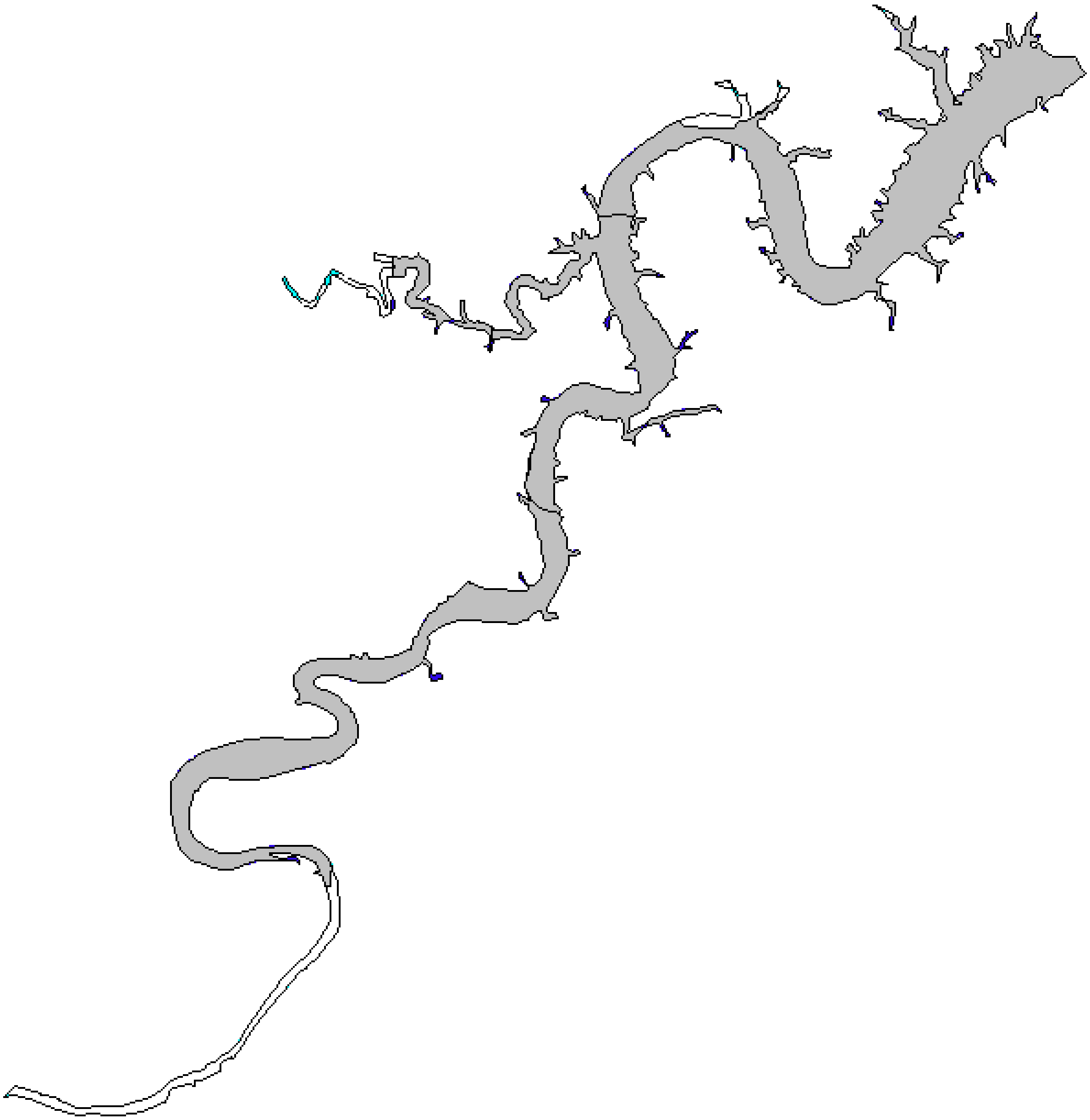
Utilization distribution for HSB # 48.681. Fish was located 12 times over the following seasons. Shaded areas represent 95% kernel estimated confidence bounds.

	2001			2002			
	Spring	Summer	Fall	Winter	Spring	Summer	Fall
Seasons					**X**	**X**	**X**



Utilization distribution for HSB # 48.791. Fish was located 21 times over the following seasons. Shaded areas represent 95% kernel estimated confidence bounds.

	2001			2002			
	Spring	Summer	Fall	Winter	Spring	Summer	Fall
Seasons			**X**	**X**	**X**	**X**	**X**



Utilization distribution for HSB # 48.841. Fish was located 9 times over the following seasons. Shaded areas represent 95% kernel estimated confidence bounds.

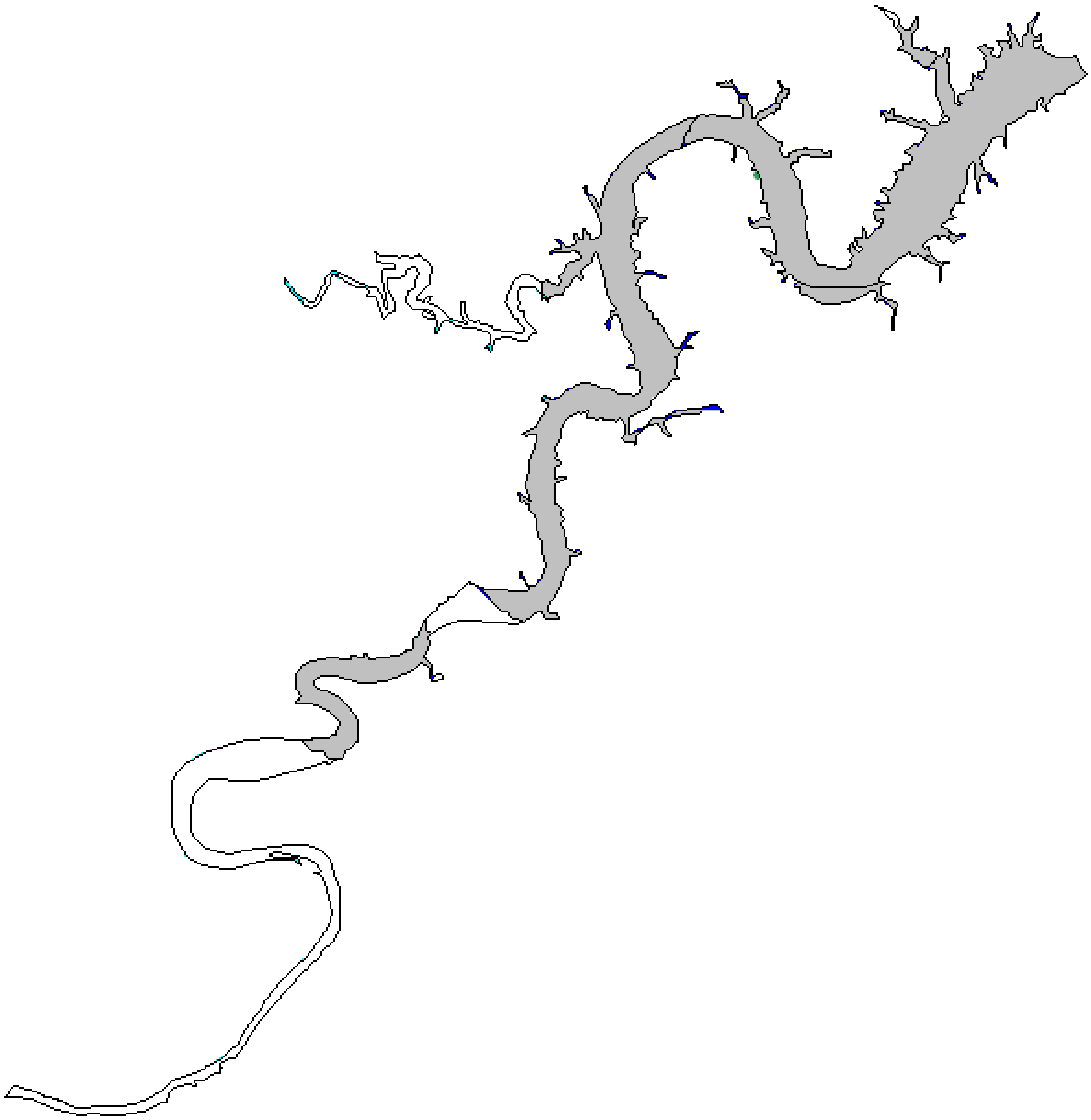
	2001			2002			
	Spring	Summer	Fall	Winter	Spring	Summer	Fall
Seasons			**X**	**X**	**X**		

Utilization distribution for HSB # 48.871. Fish was located 10 times over the following seasons. Shaded areas represent 95% kernel estimated confidence bounds.

	2001			2002			
	Spring	Summer	Fall	Winter	Spring	Summer	Fall
Seasons	**X**	**X**					

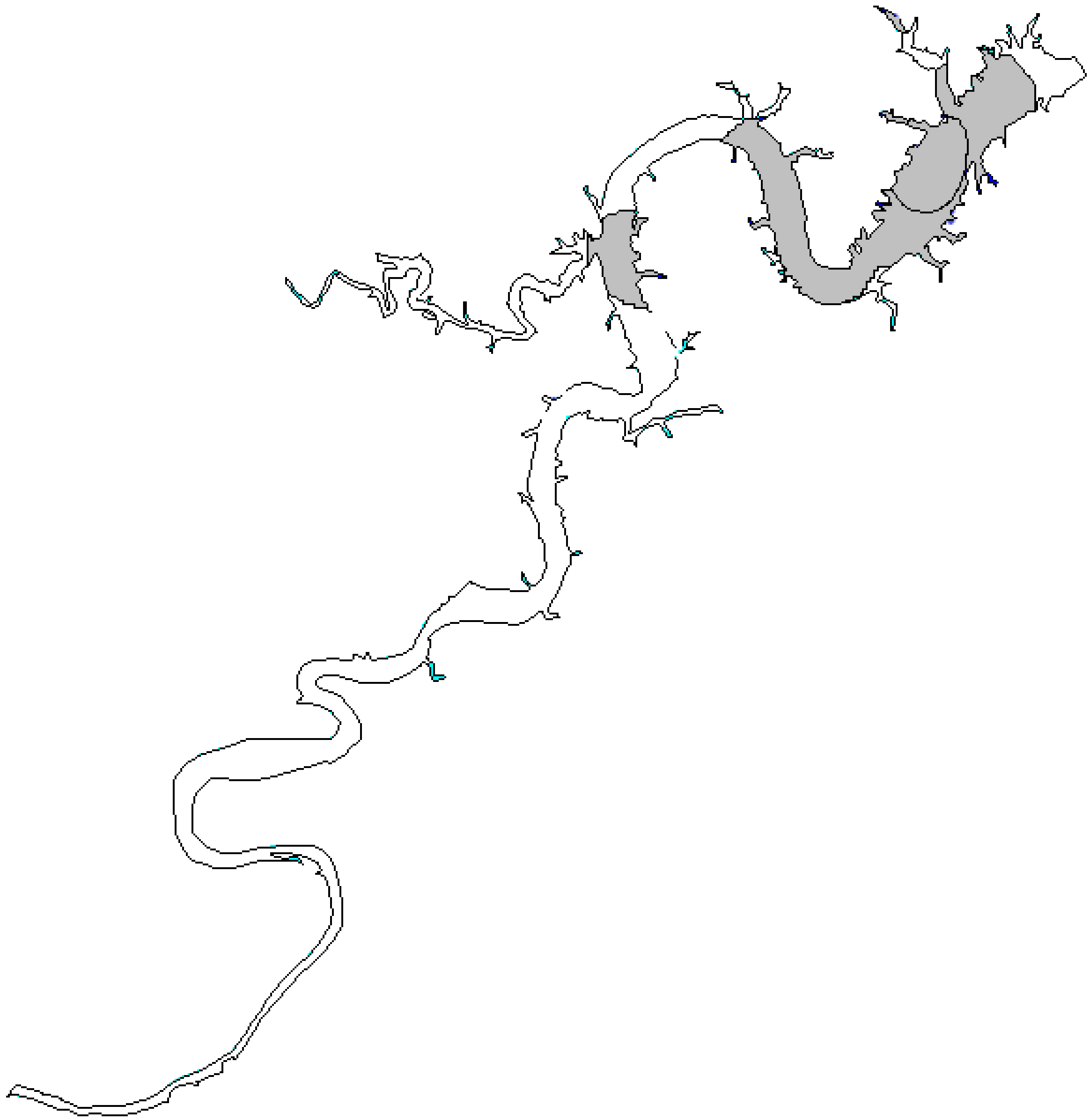
Utilization distribution for HSB # 48.902. Fish was located 24 times over the following seasons. Shaded areas represent 95% kernel estimated confidence bounds.

	2001			2002			
	Spring	Summer	Fall	Winter	Spring	Summer	Fall
Seasons			**X**	**X**	**X**	**X**	**X**



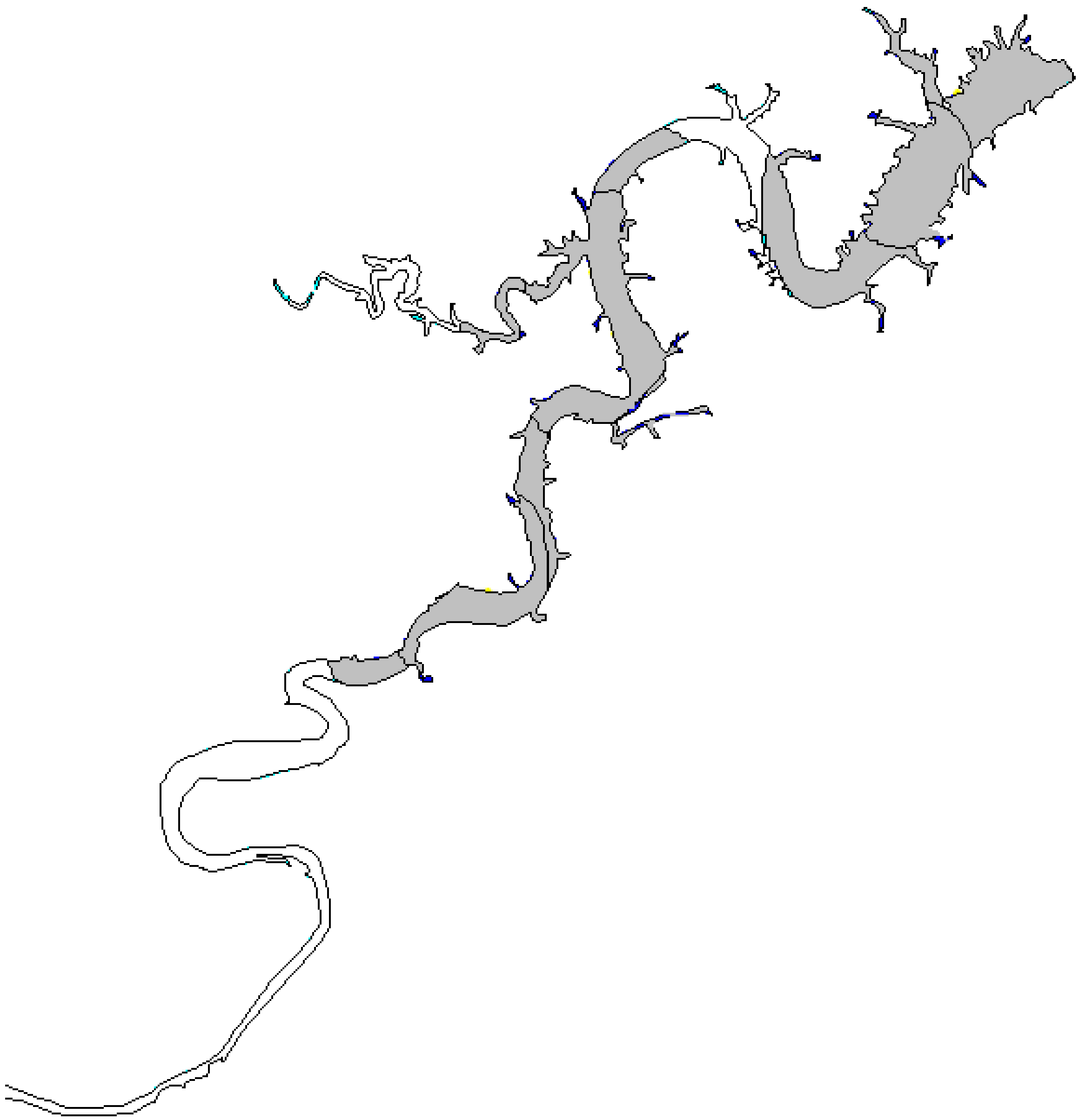
Utilization distribution for HSB # 48.931. Fish was located 26 times over the following seasons. Shaded areas represent 95% kernel estimated confidence bounds.

	2001			2002			
	Spring	Summer	Fall	Winter	Spring	Summer	Fall
Seasons	**X**	**X**	**X**	**X**	**X**		



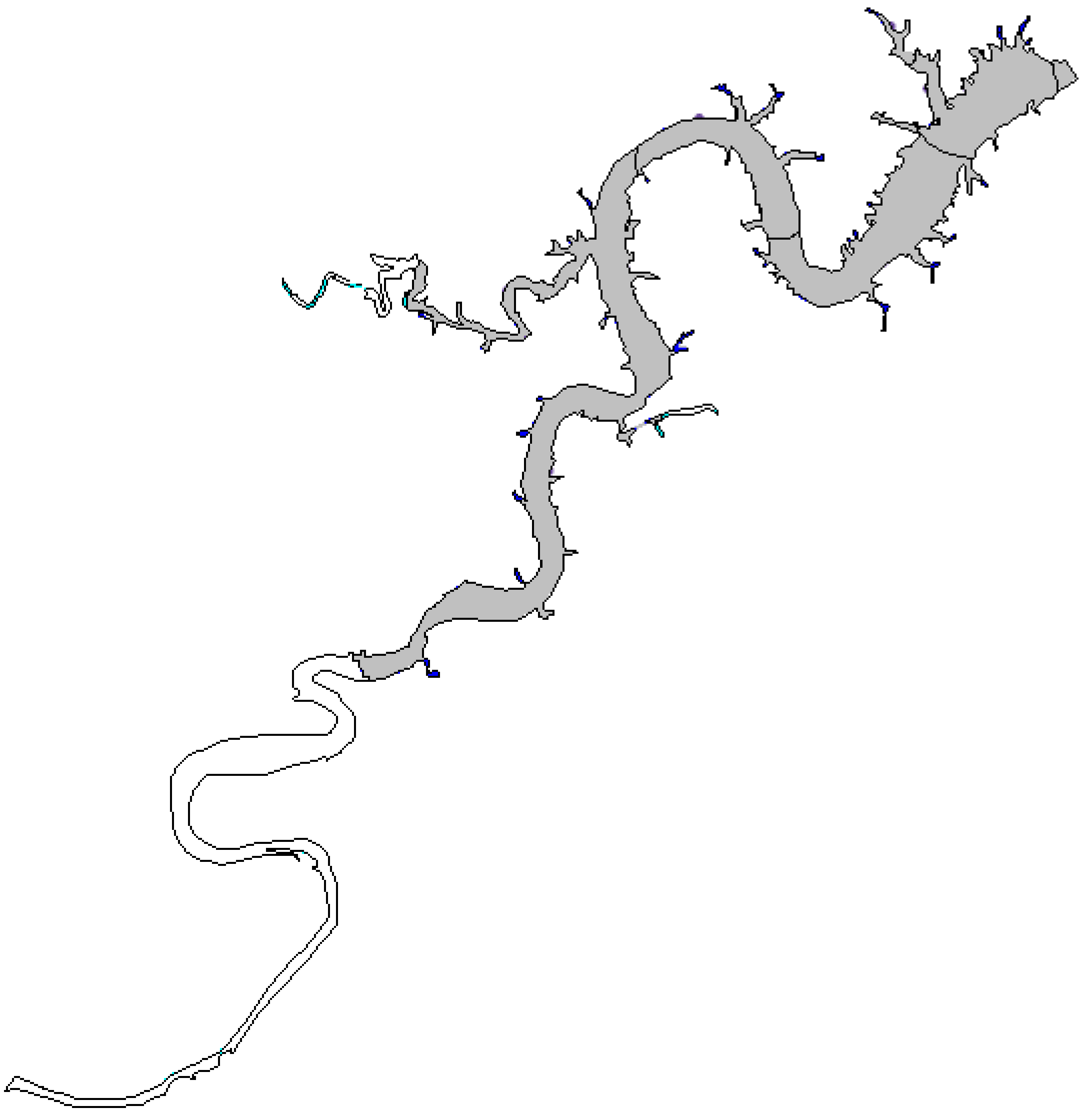
Utilization distribution for HSB # 48.972. Fish was located 38 times over the following seasons. Shaded areas represent 95% kernel estimated confidence bounds.

	2001			2002			
	Spring	Summer	Fall	Winter	Spring	Summer	Fall
Seasons	**X**	**X**	**X**		**X**	**X**	



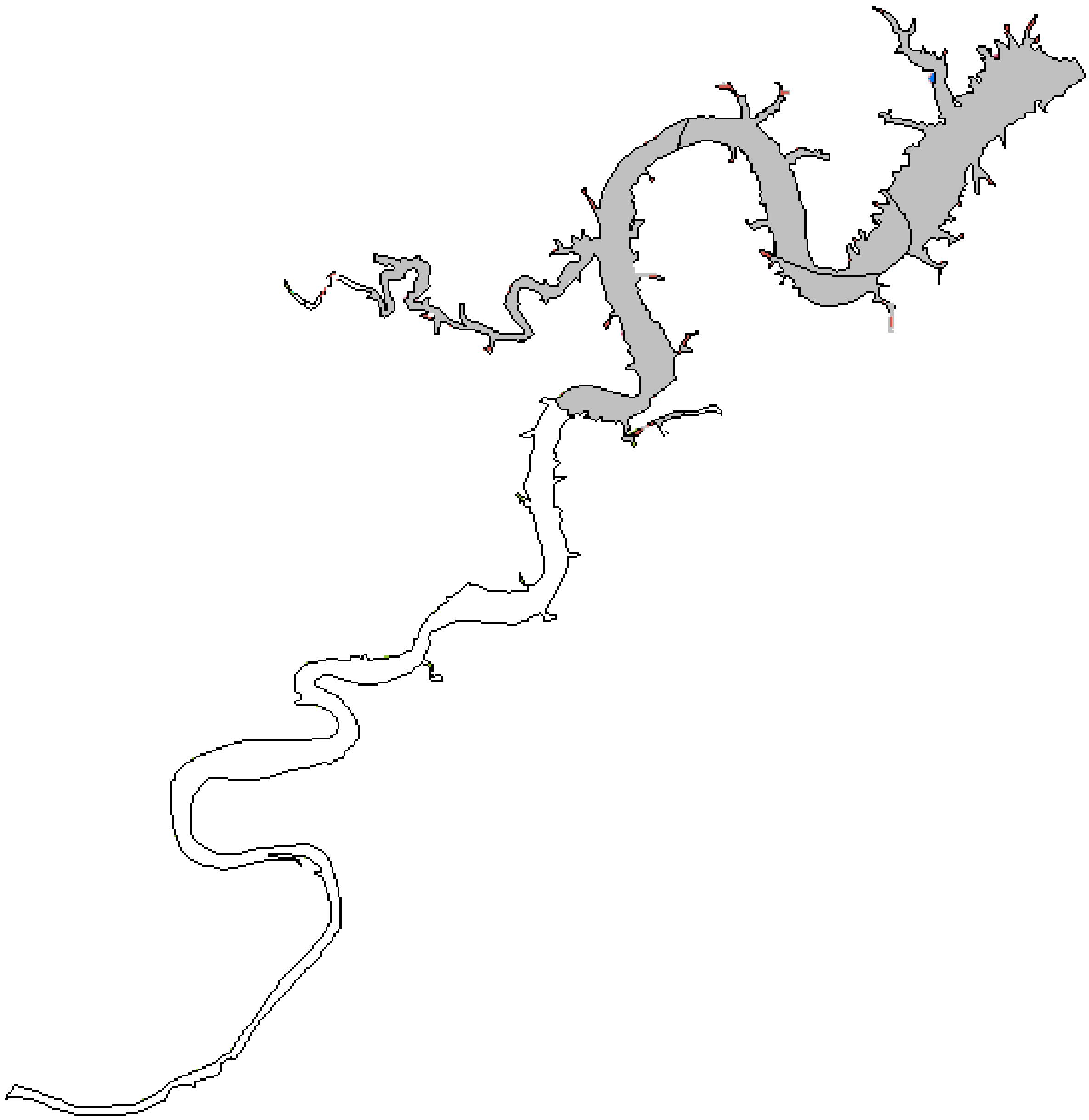
Utilization distribution for HSB # 49.015. Fish was located 13 times over the following seasons. Shaded areas represent 95% kernel estimated confidence bounds.

	2001			2002			
	Spring	Summer	Fall	Winter	Spring	Summer	Fall
Seasons					**X**	**X**	**X**



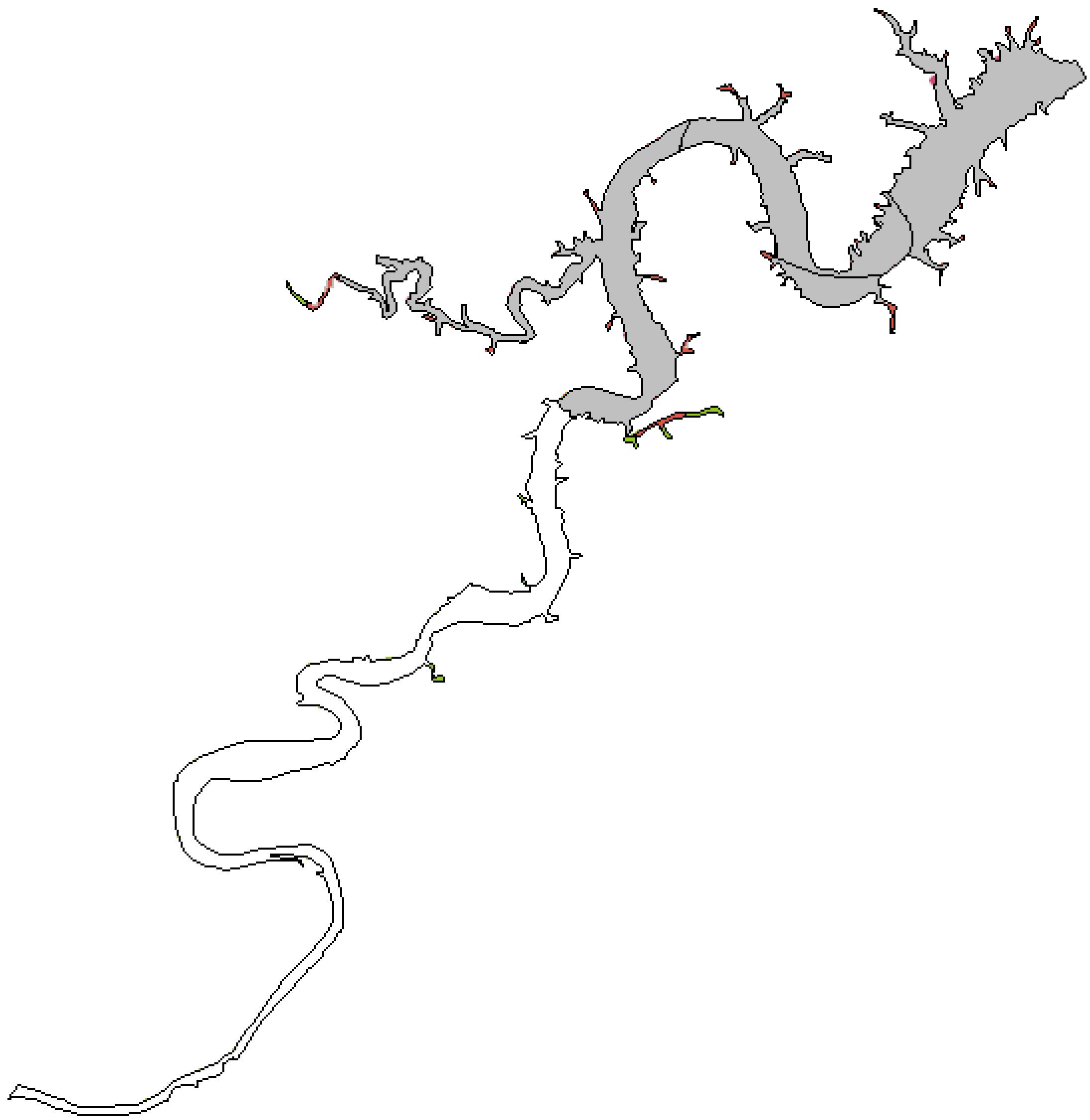
Utilization distribution for HSB # 49.024. Fish was located 24 times over the following seasons. Shaded areas represent 95% kernel estimated confidence bounds.

	2001			2002			
	Spring	Summer	Fall	Winter	Spring	Summer	Fall
Seasons			**X**	**X**	**X**	**X**	**X**



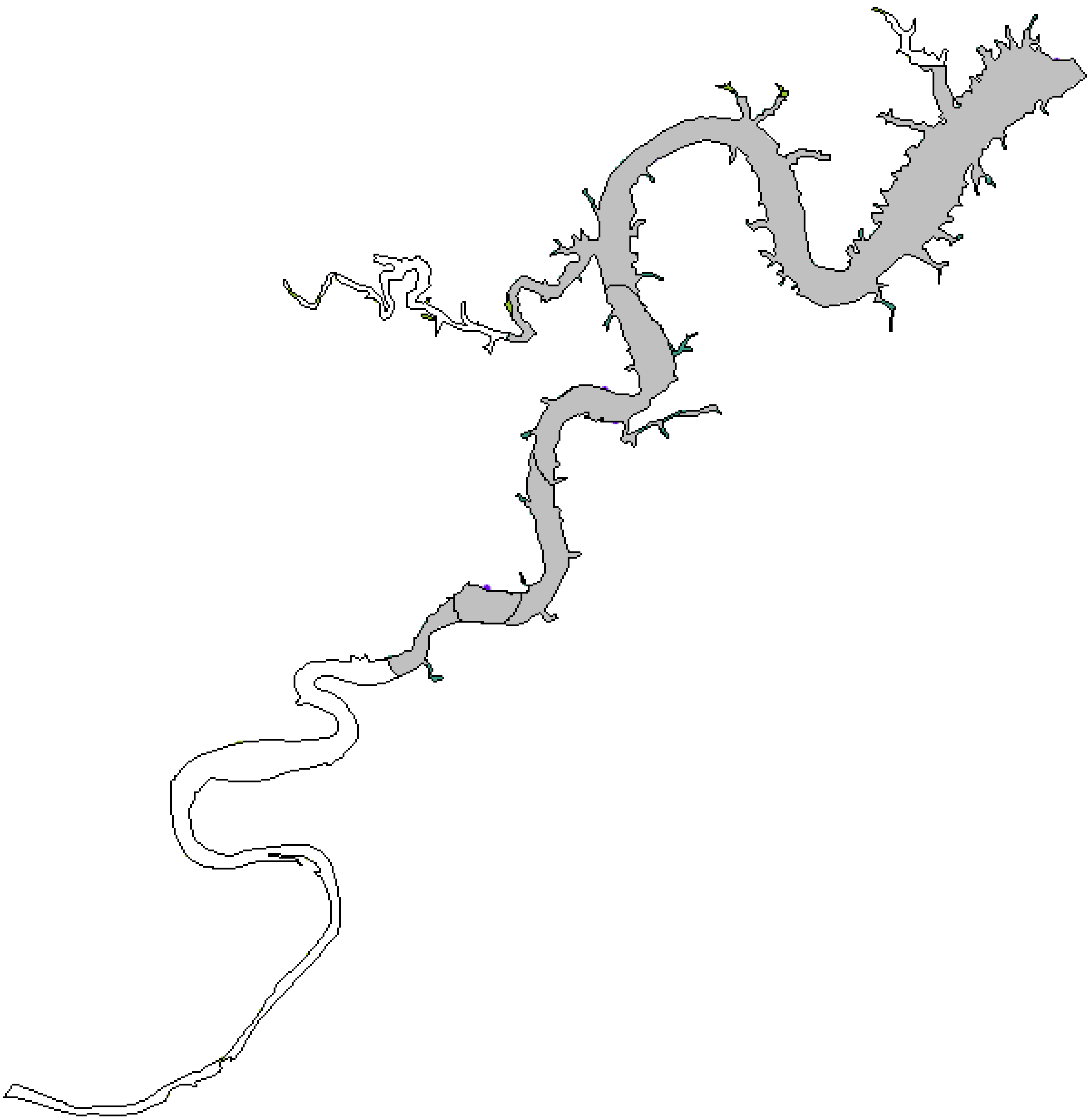
Utilization distribution for HSB # 49.034. Fish was located 17 times over the following seasons. Shaded areas represent 95% kernel estimated confidence bounds.

	2001			2002			
	Spring	Summer	Fall	Winter	Spring	Summer	Fall
Seasons			**X**	**X**	**X**	**X**	**X**



Utilization distribution for HSB # 49.045. Fish was located 16 times over the following seasons. Shaded areas represent 95% kernel estimated confidence bounds.

	2001			2002			
	Spring	Summer	Fall	Winter	Spring	Summer	Fall
Seasons					**X**	**X**	**X**



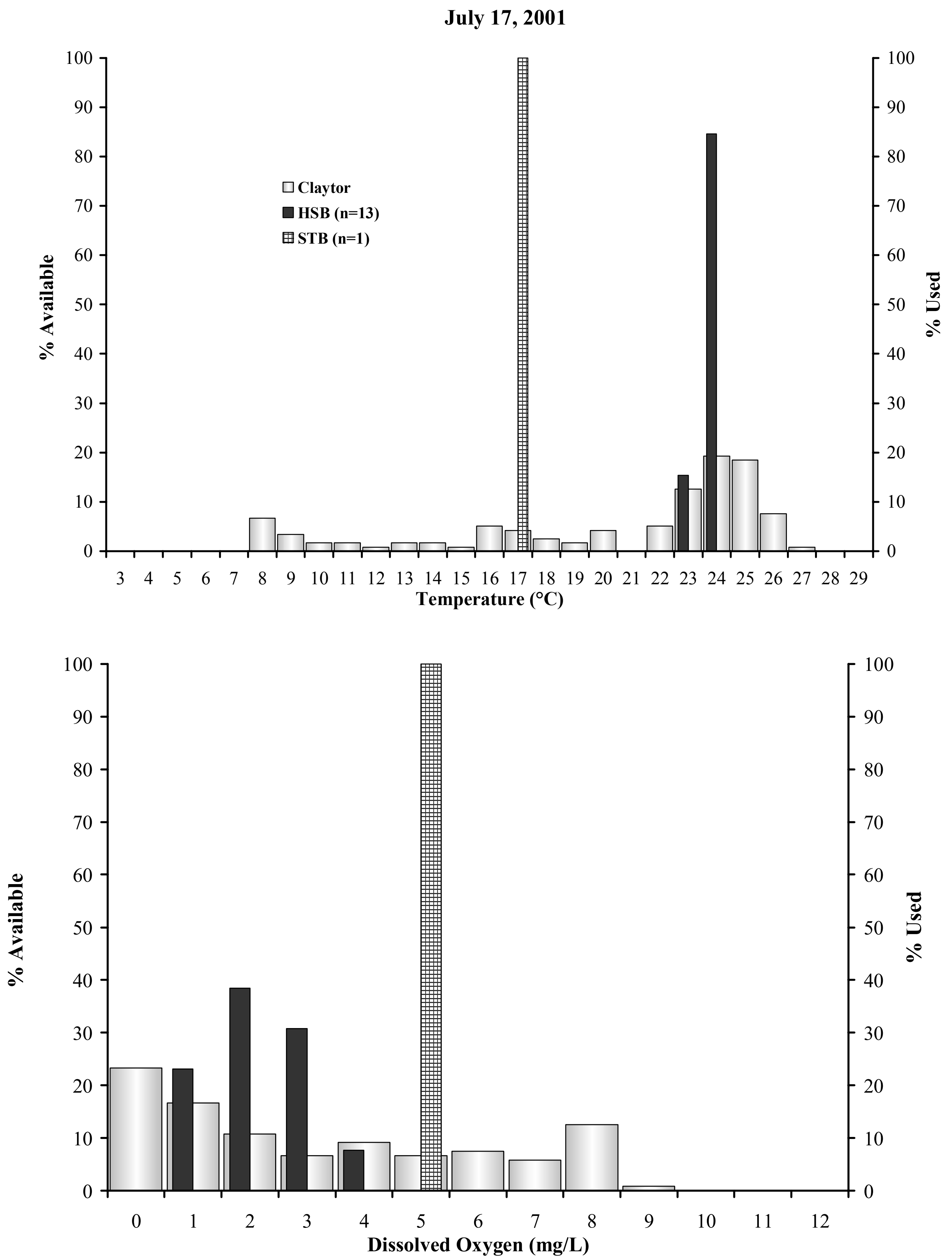
Utilization distribution for HSB # 49.054. Fish was located 22 times over the following seasons. Shaded areas represent 95% kernel estimated confidence bounds.

	2001			2002			
	Spring	Summer	Fall	Winter	Spring	Summer	Fall
Seasons			**X**	**X**	**X**	**X**	**X**

Utilization distribution for HSB # 49.095. Fish was located 4 times over the following seasons. Shaded areas represent 95% kernel estimated confidence bounds.

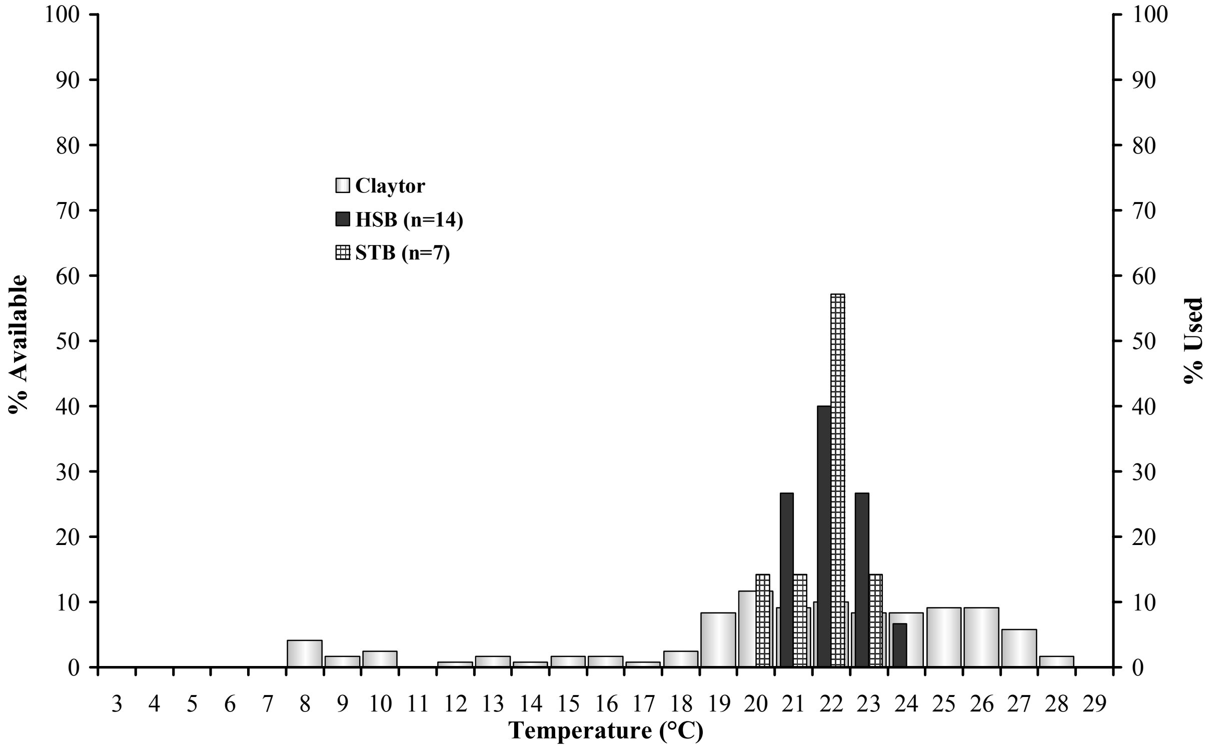
	2001			2002			
	Spring	Summer	Fall	Winter	Spring	Summer	Fall
Seasons				**X**	**X**		

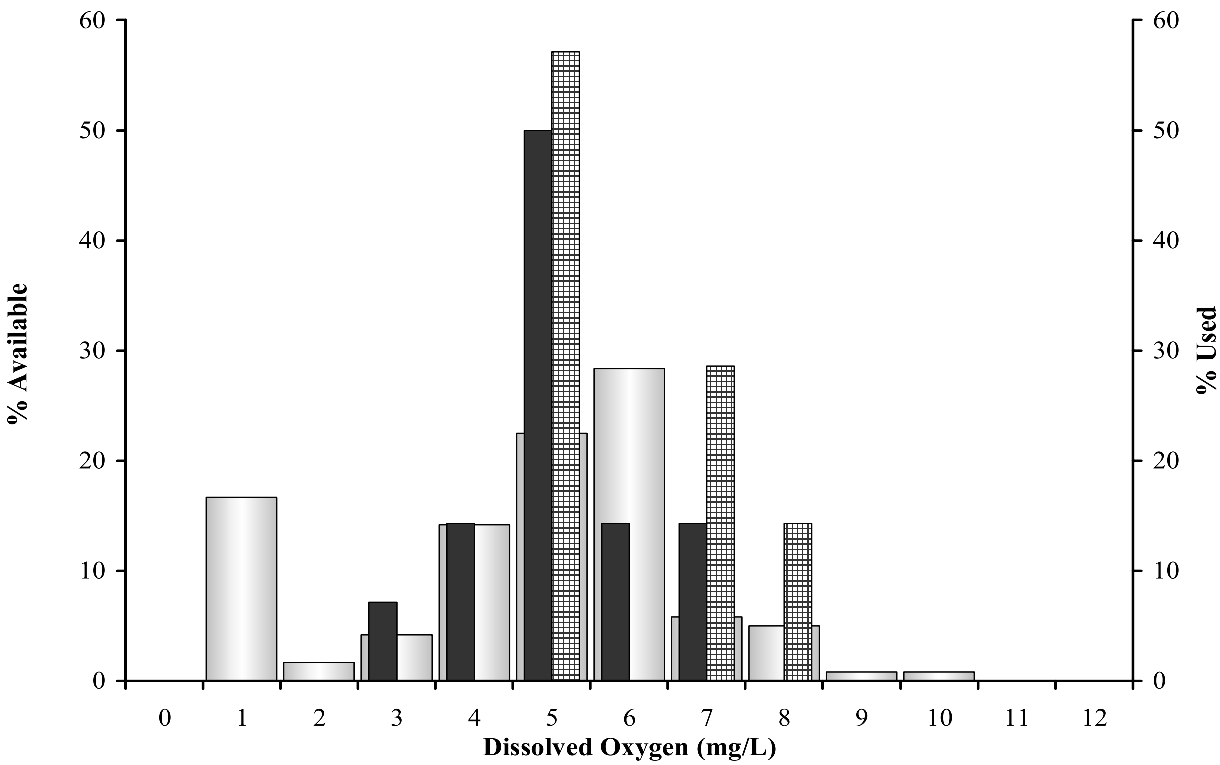
Appendix 3. Temperature and dissolved oxygen use for STB and HSB versus available habitat in Claytor Lake, July 2001 through December 2002.



Percentage of available habitat, based on temperature and DO profiles taken from Claytor Lake, compared to habitat use, as measured from telemetered STB and HSB, July 17, 2001.

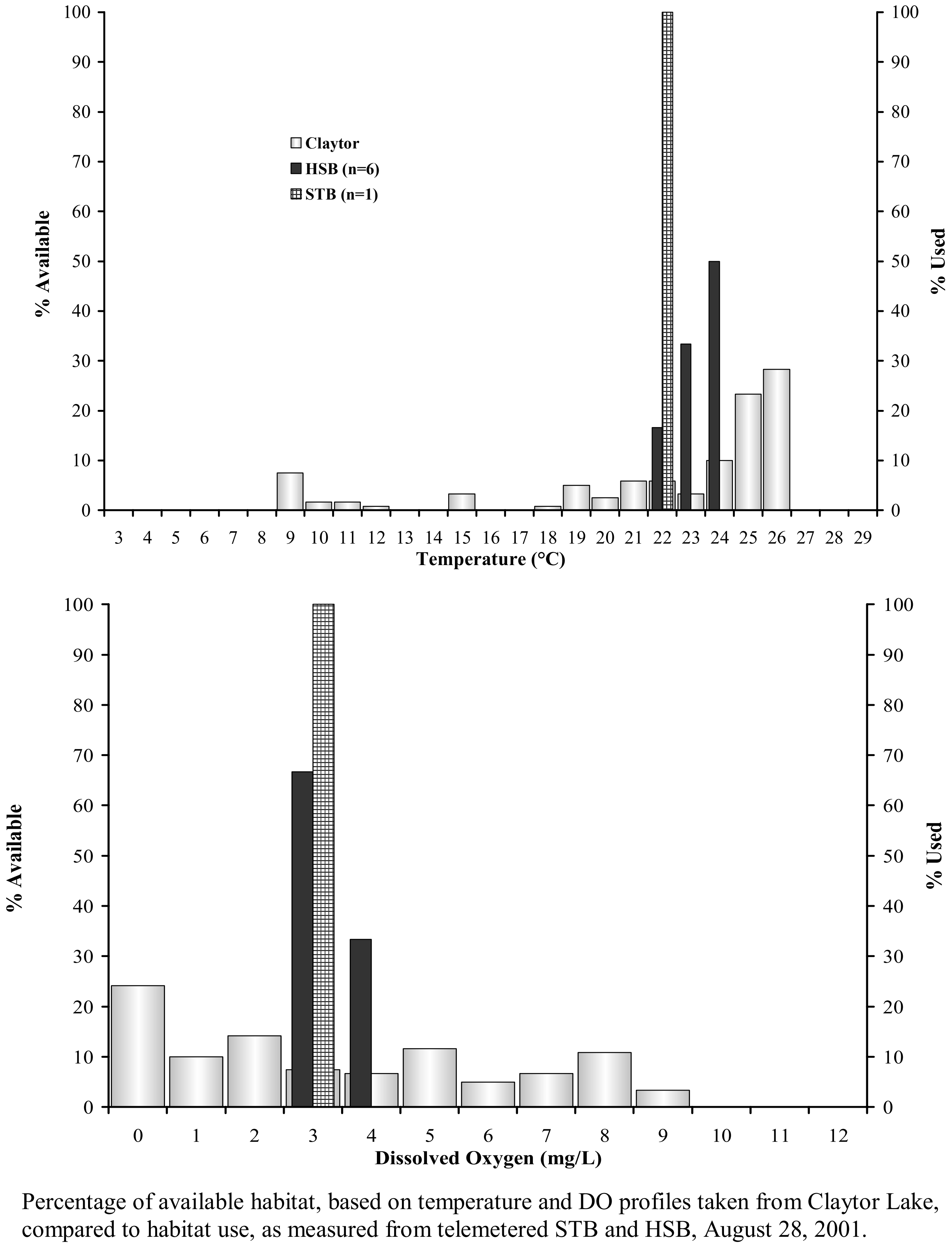
August 2, 2001



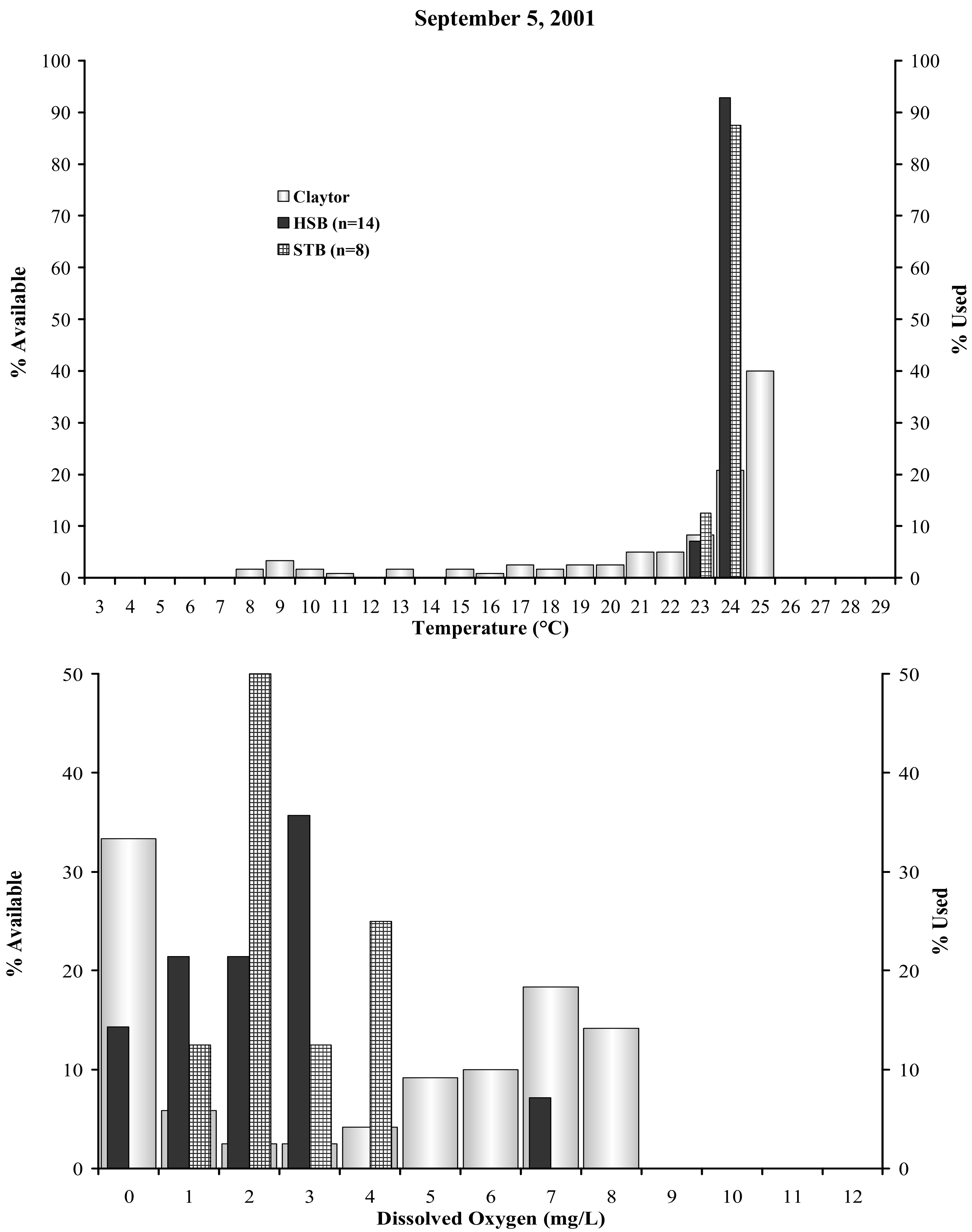


Percentage of available habitat, based on temperature and DO profiles taken from Claytor Lake, compared to habitat use, as measured from telemetered STB and HSB, August 2, 2001.

August 28, 2001

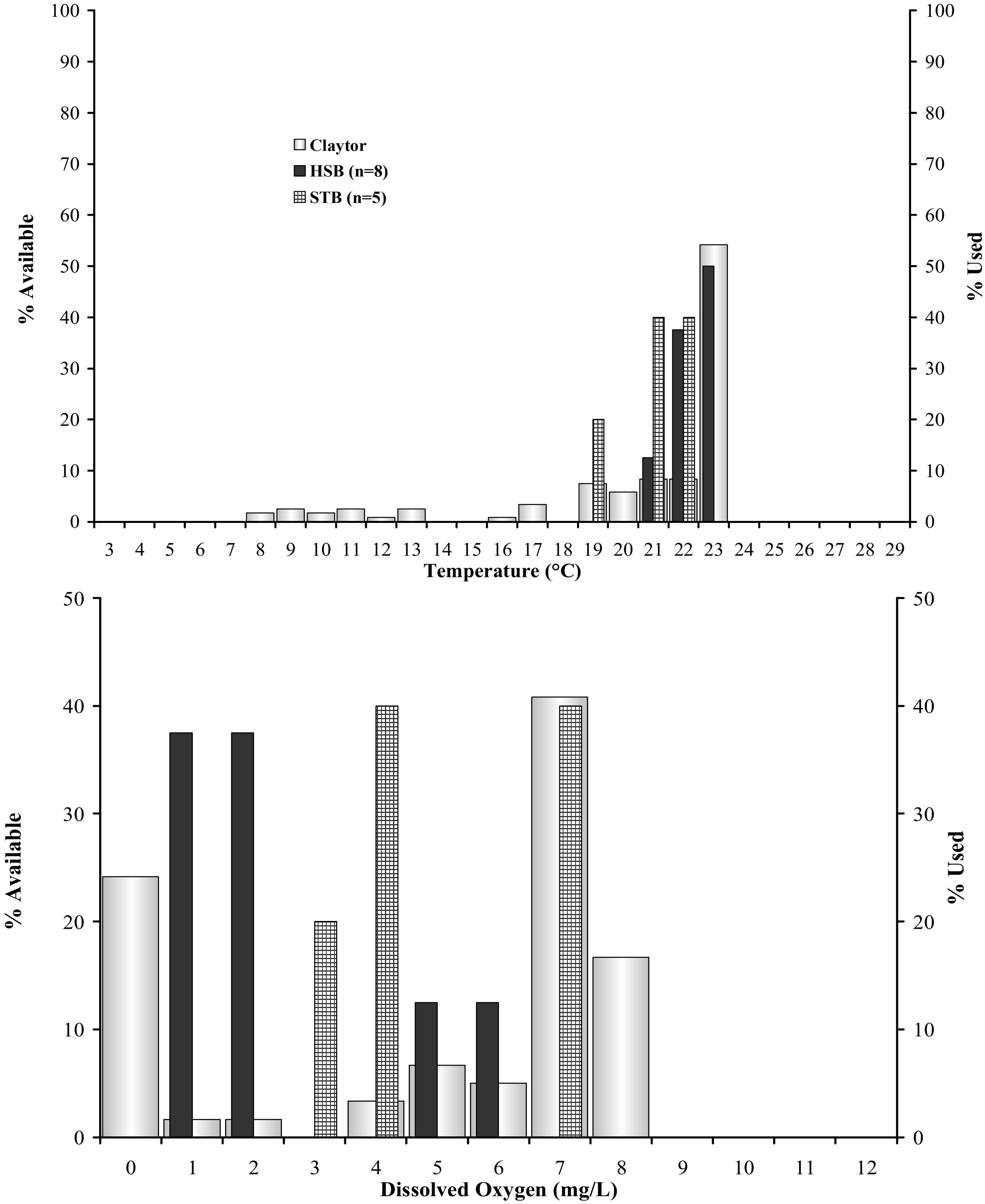


Percentage of available habitat, based on temperature and DO profiles taken from Claytor Lake, compared to habitat use, as measured from telemetered STB and HSB, August 28, 2001.

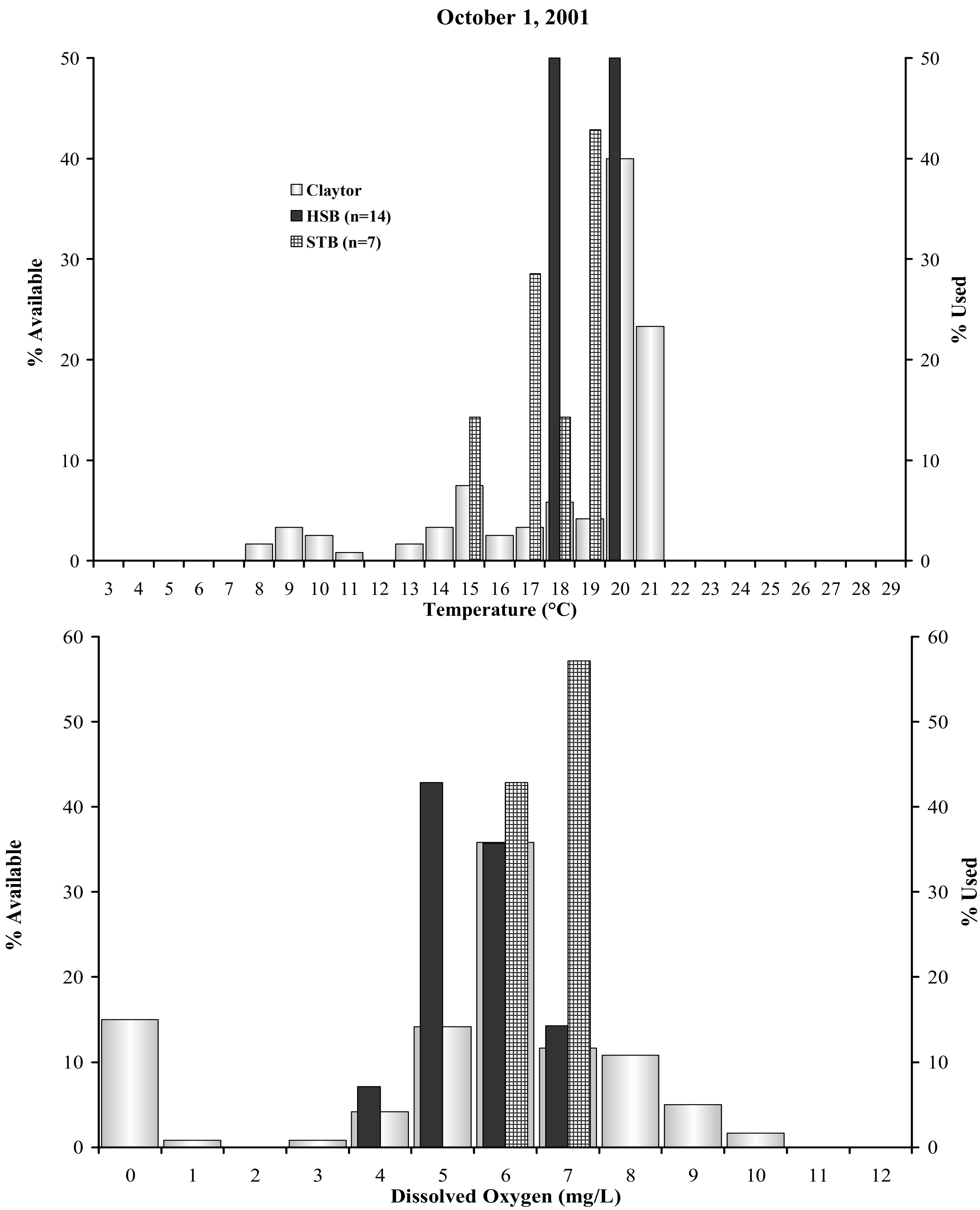


Percentage of available habitat, based on temperature and DO profiles taken from Claytor Lake, compared to habitat use, as measured from telemetered STB and HSB, September 5, 2001.

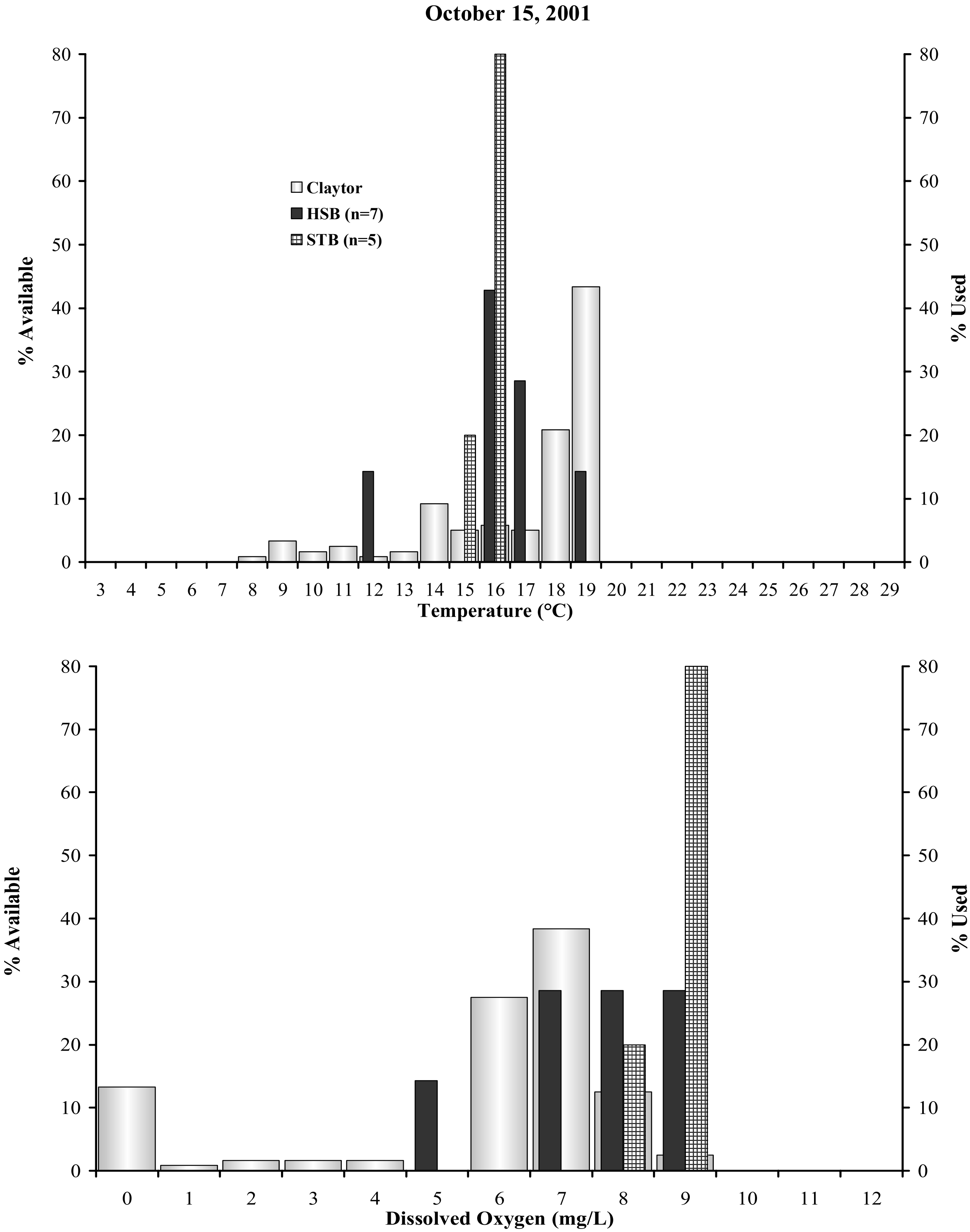
September 18, 2001



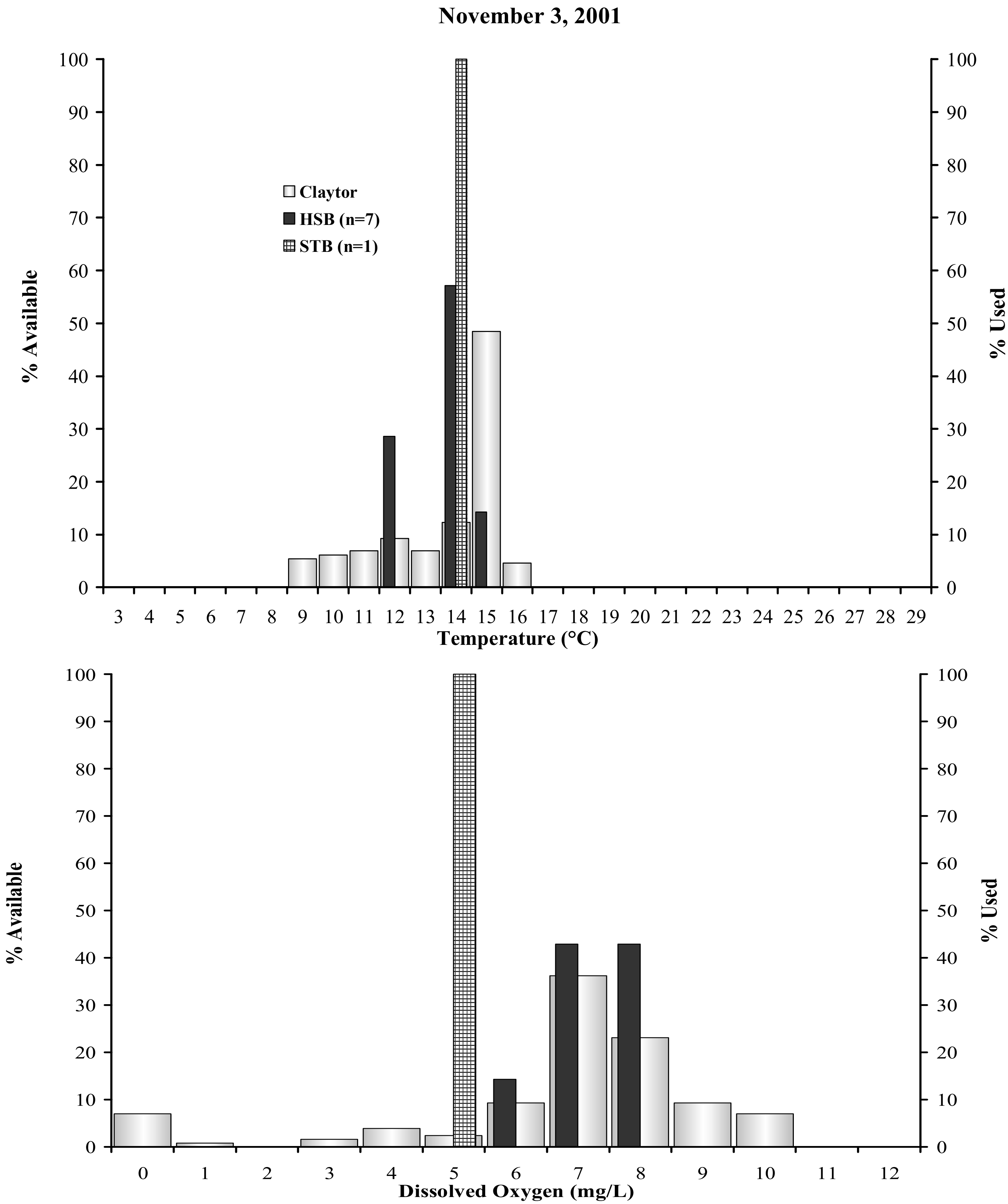
Percentage of available habitat, based on temperature and DO profiles taken from Claytor Lake, compared to habitat use, as measured from telemetered STB and HSB, September 18, 2001.



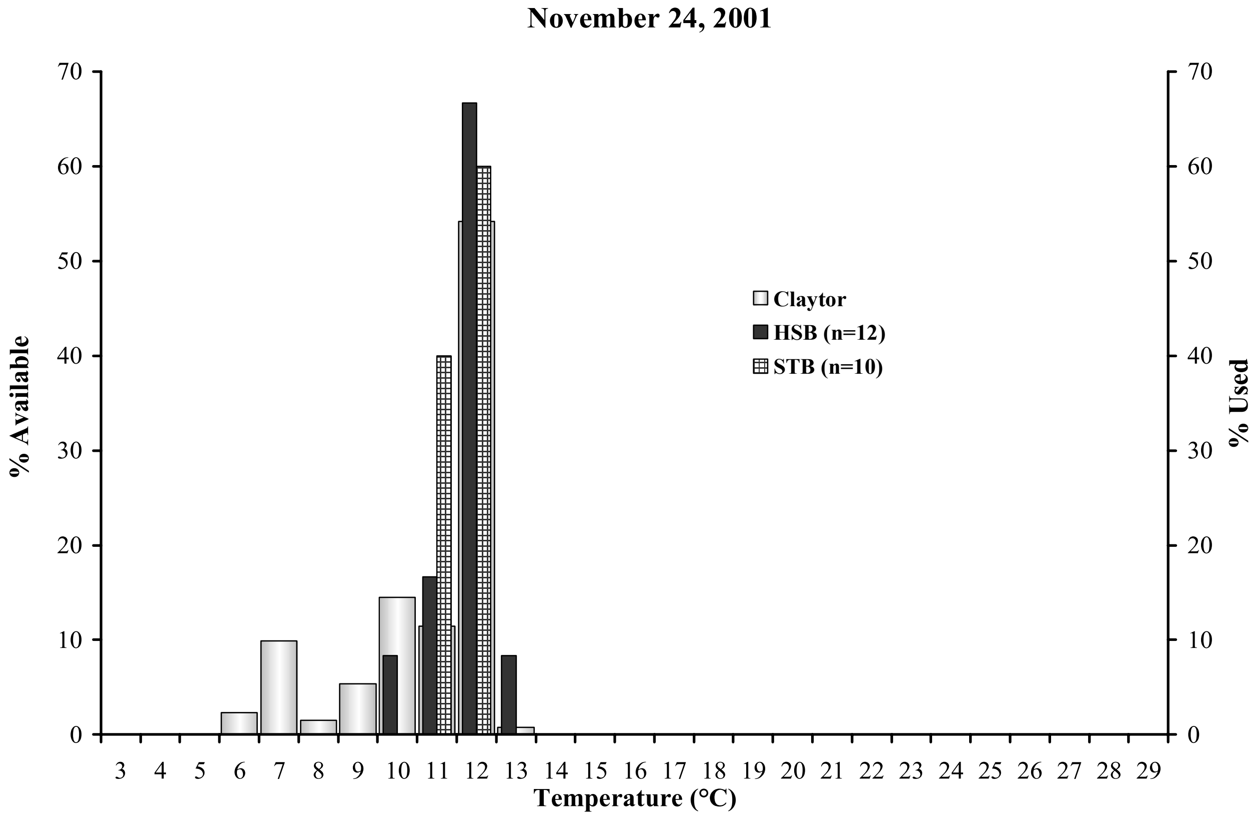
Percentage of available habitat, based on temperature and DO profiles taken from Claytor Lake, compared to habitat use, as measured from telemetered STB and HSB, October 1, 2001.

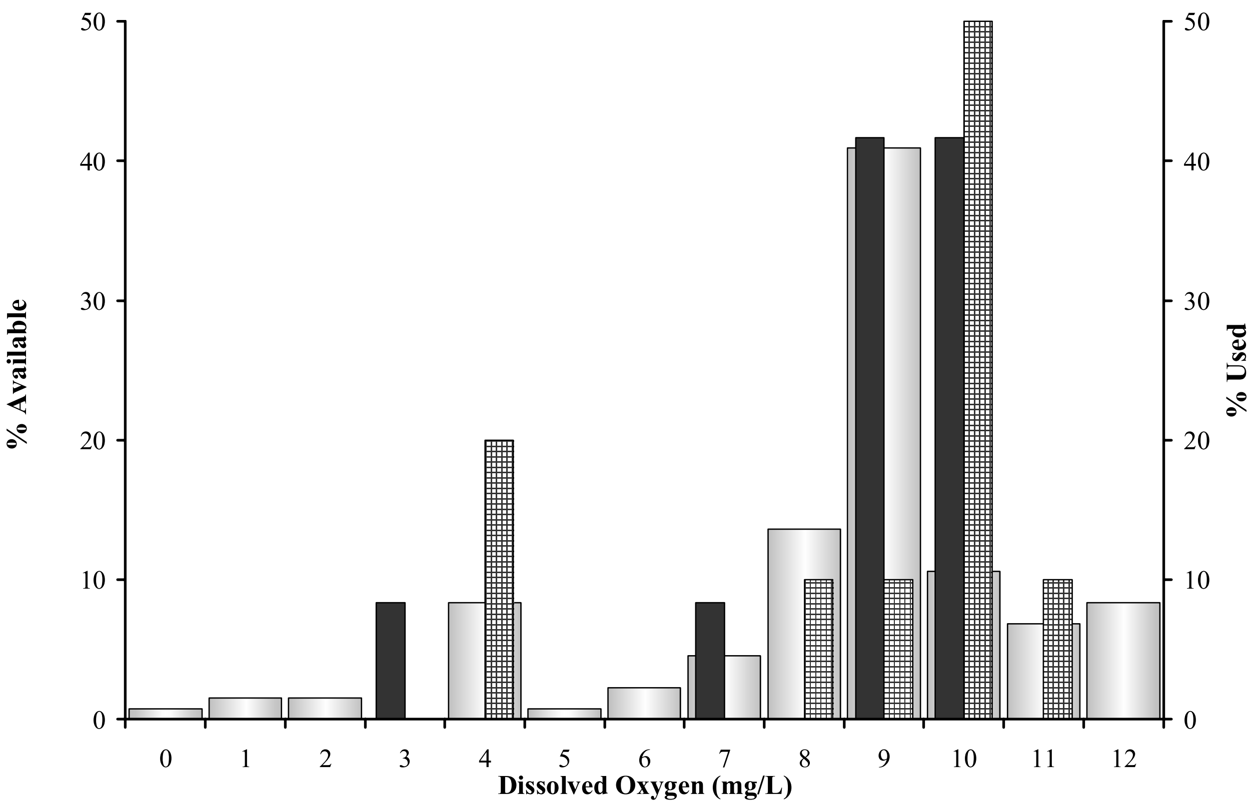


Percentage of available habitat, based on temperature and DO profiles taken from Claytor Lake, compared to habitat use, as measured from telemetered STB and HSB, October 15, 2001.



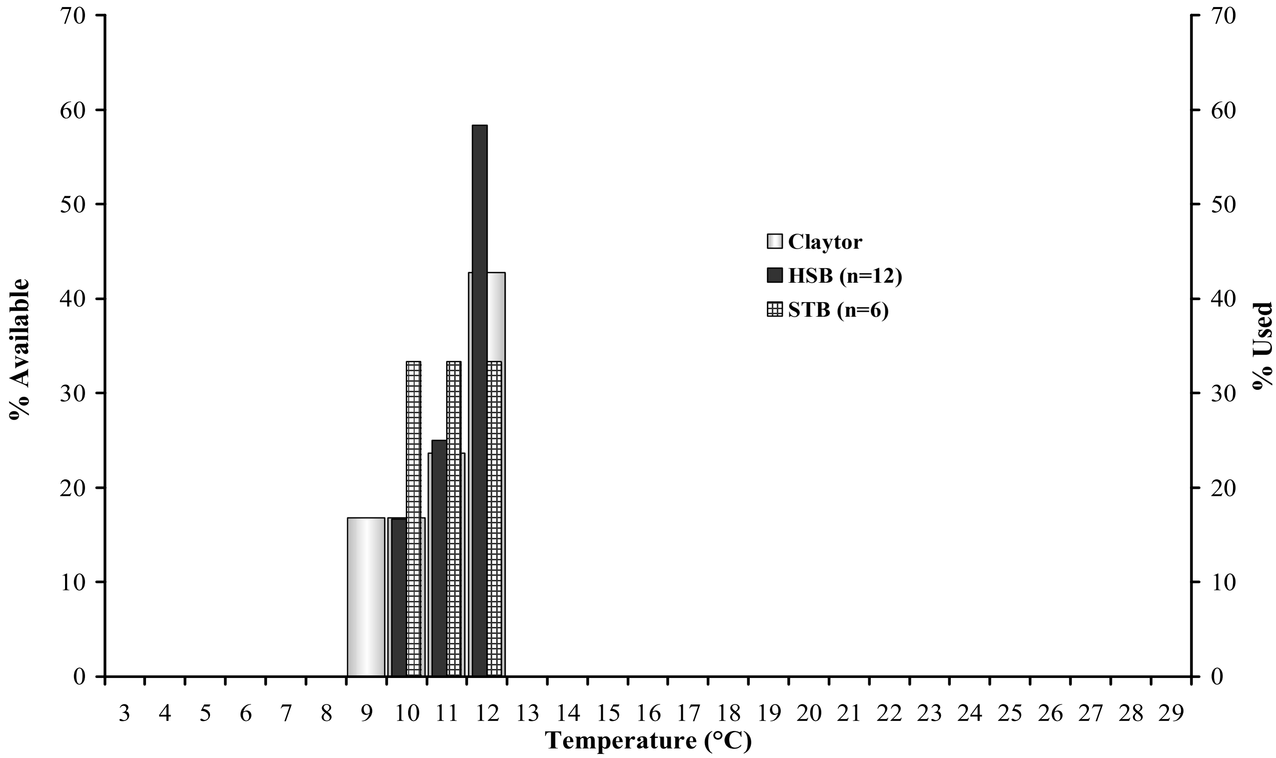
Percentage of available habitat, based on temperature and DO profiles taken from Claytor Lake, compared to habitat use, as measured from telemetered STB and HSB, November 3, 2001.

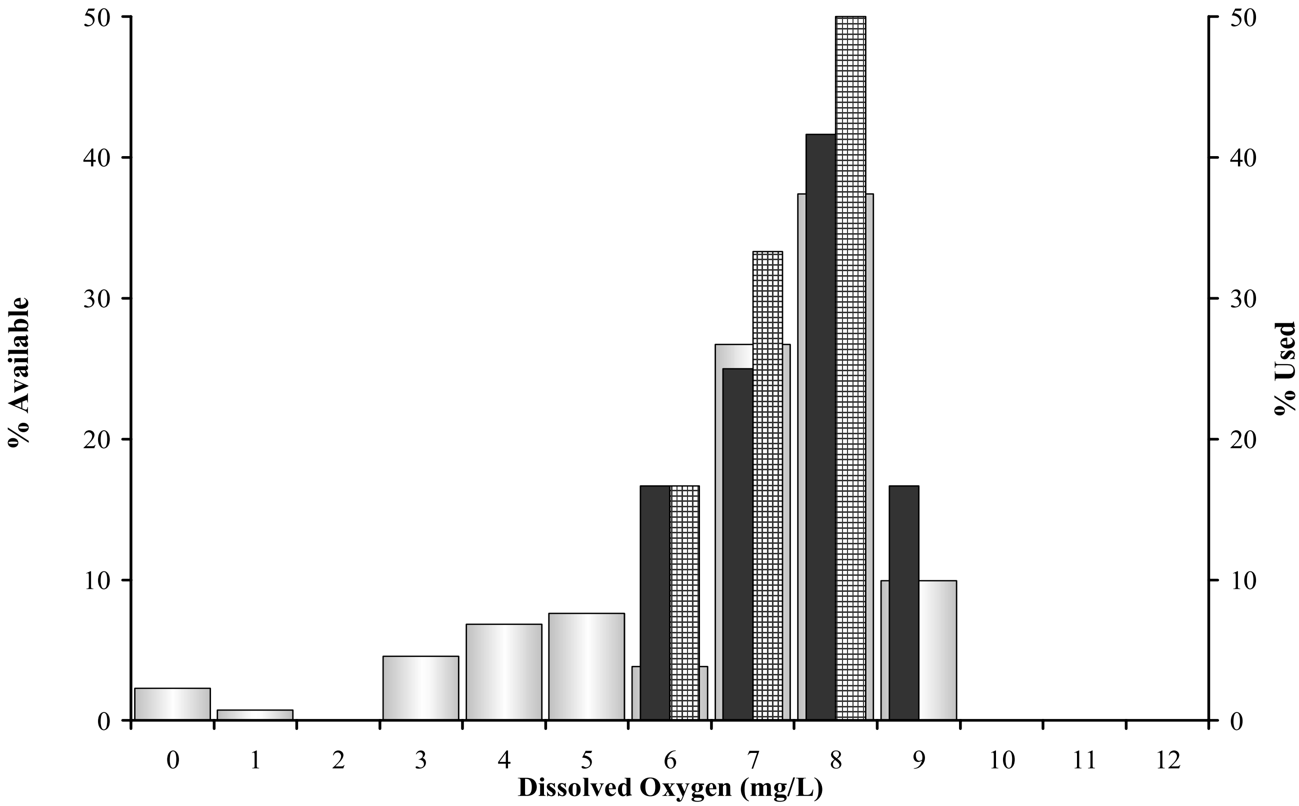




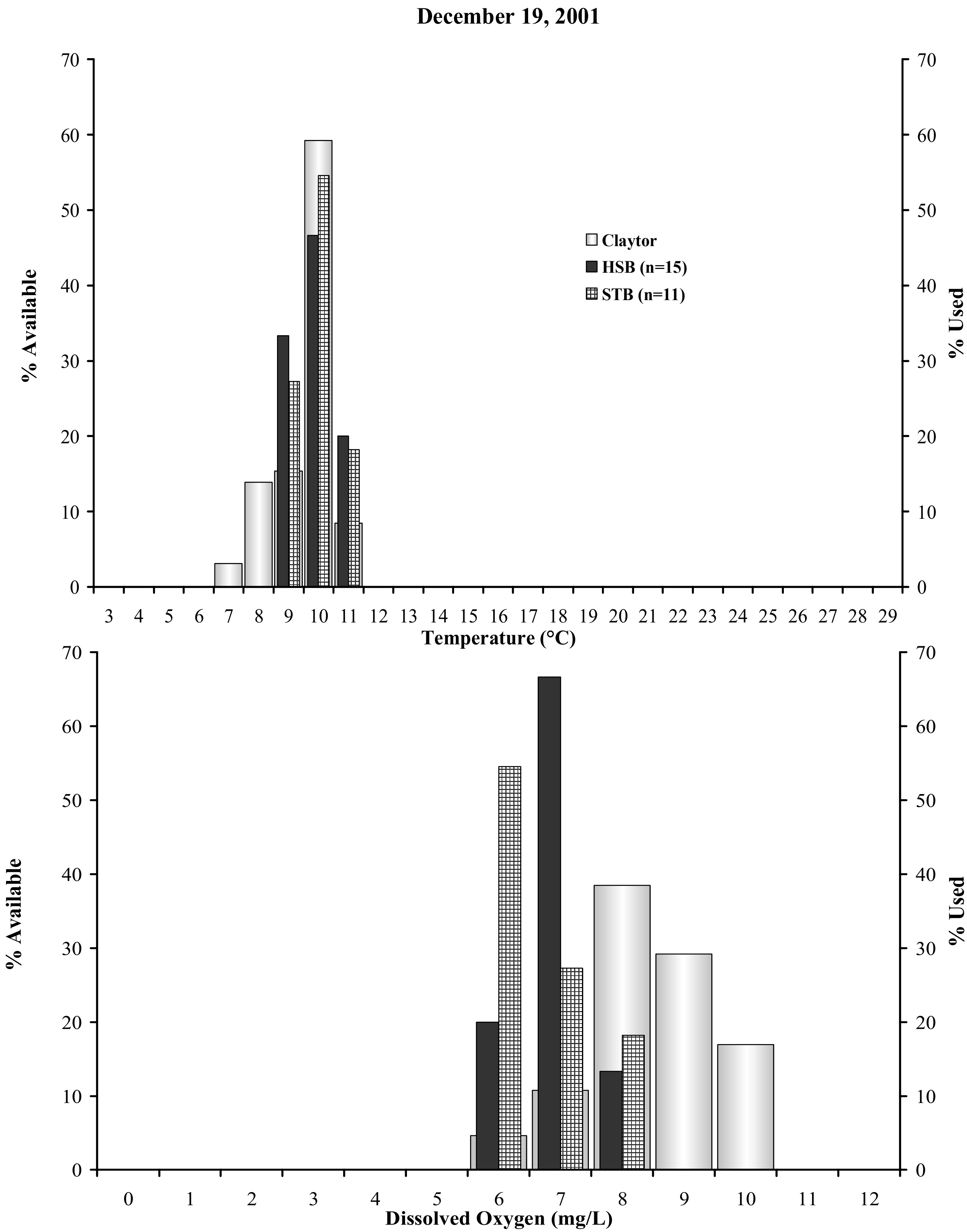
Percentage of available habitat, based on temperature and DO profiles taken from Claytor Lake, compared to habitat use, as measured from telemetered STB and HSB, November 24, 2001.

December 7, 2001

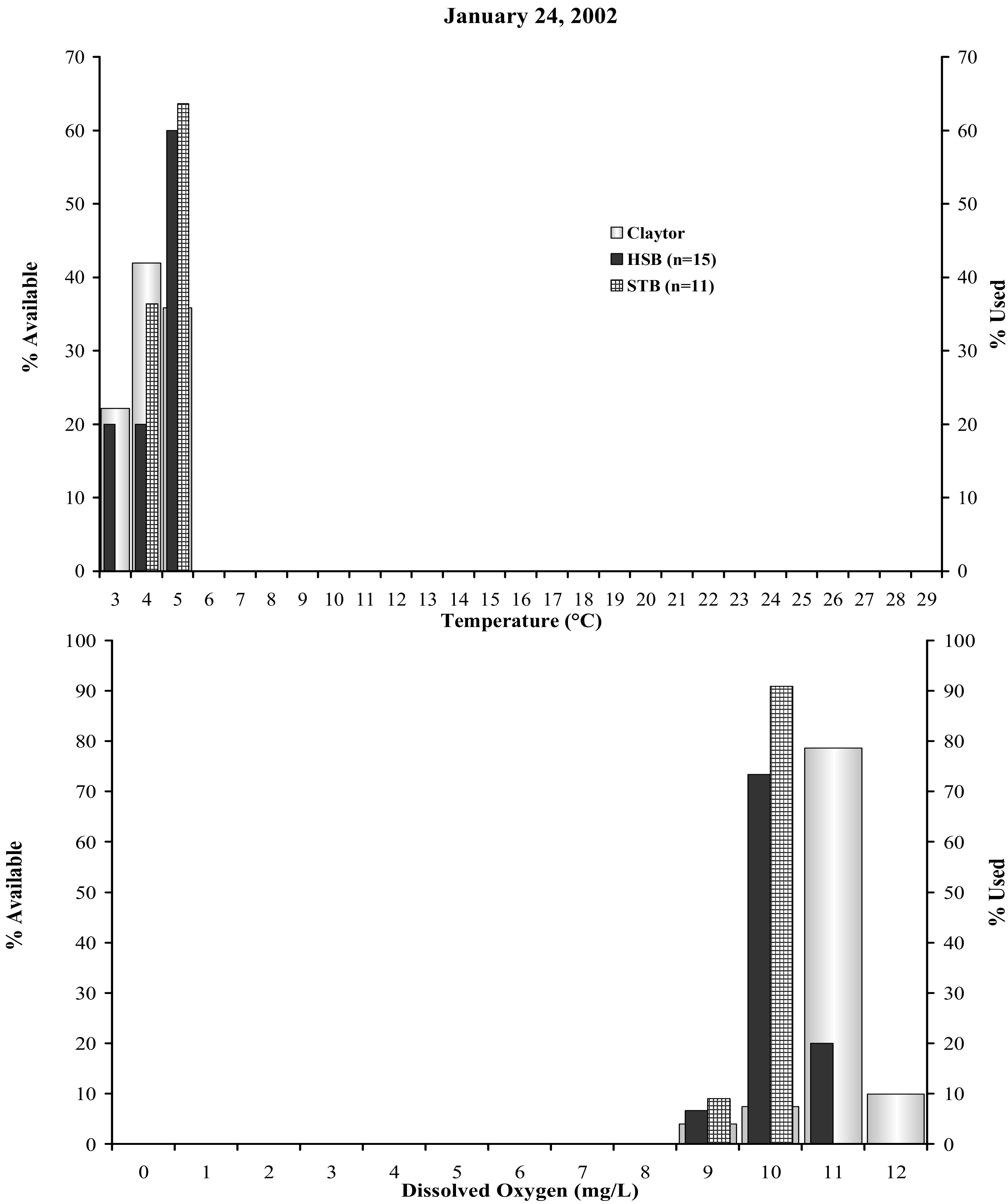




Percentage of available habitat, based on temperature and DO profiles taken from Claytor Lake, compared to habitat use, as measured from telemetered STB and HSB, December 7, 2001.

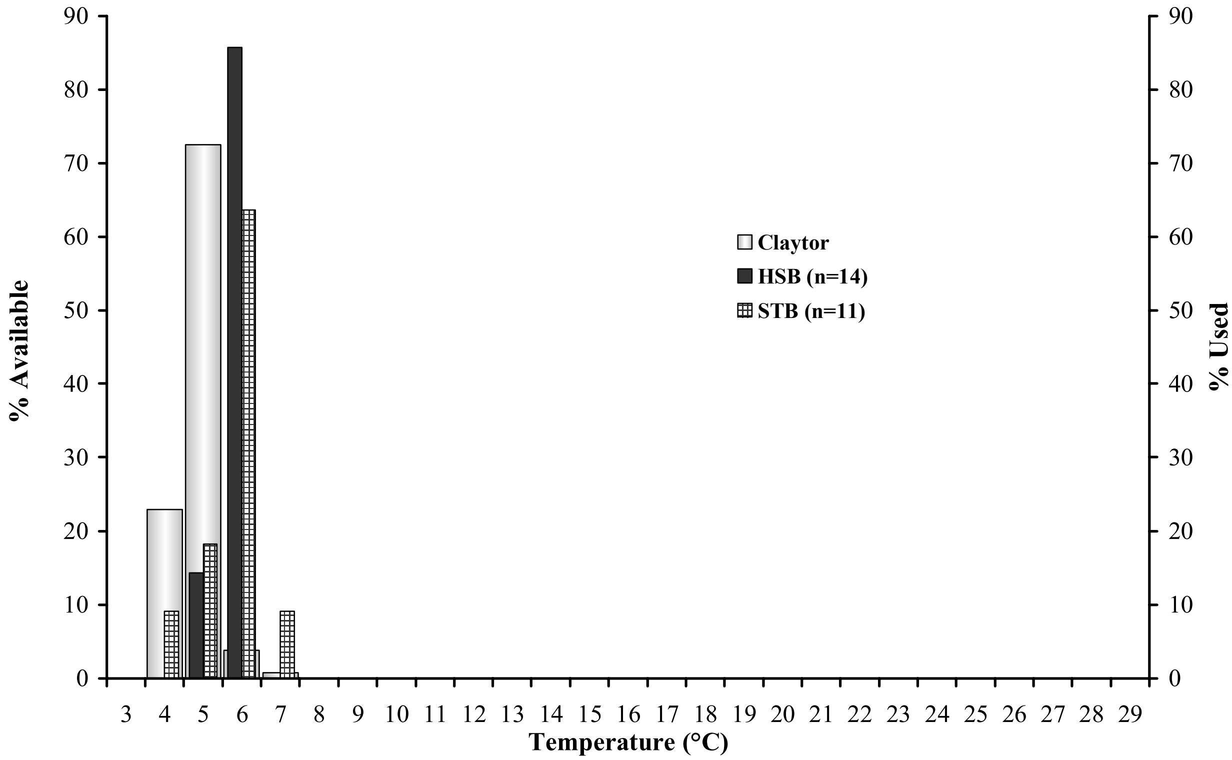


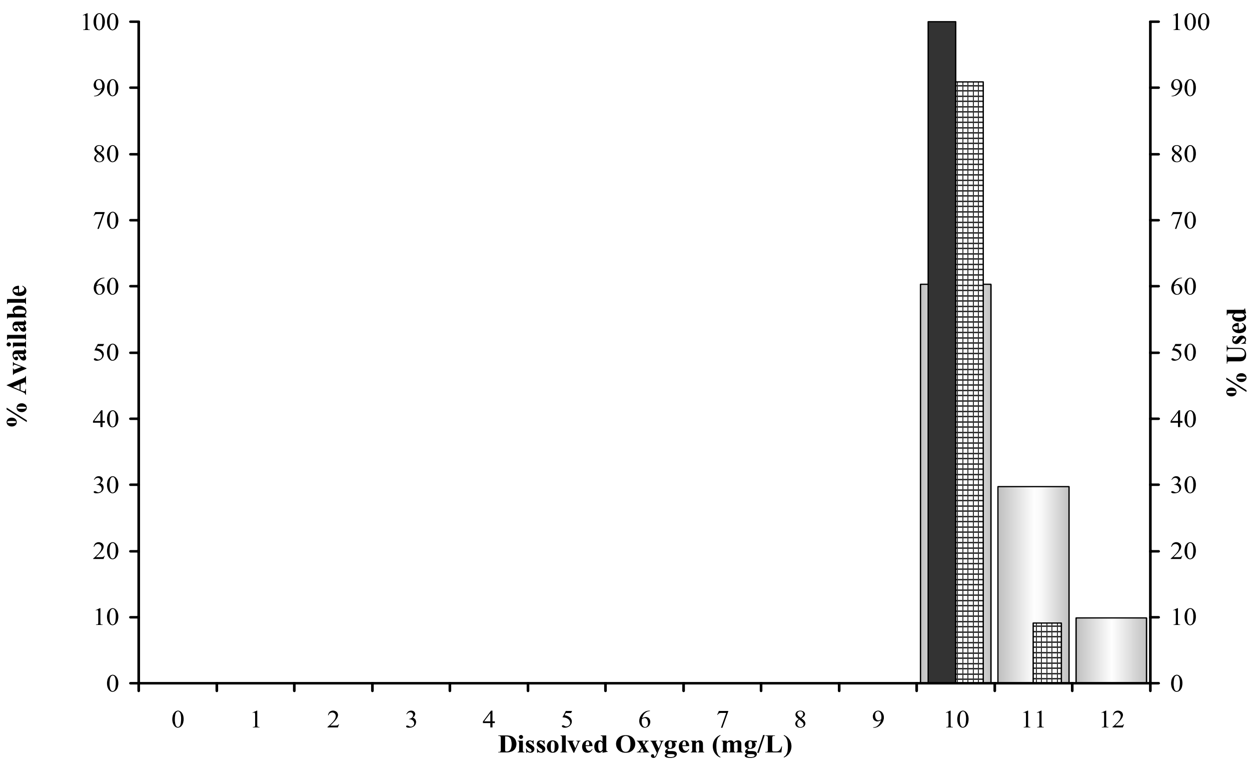
Percentage of available habitat, based on temperature and DO profiles taken from Claytor Lake, compared to habitat use, as measured from telemetered STB and HSB, December 19, 2001.



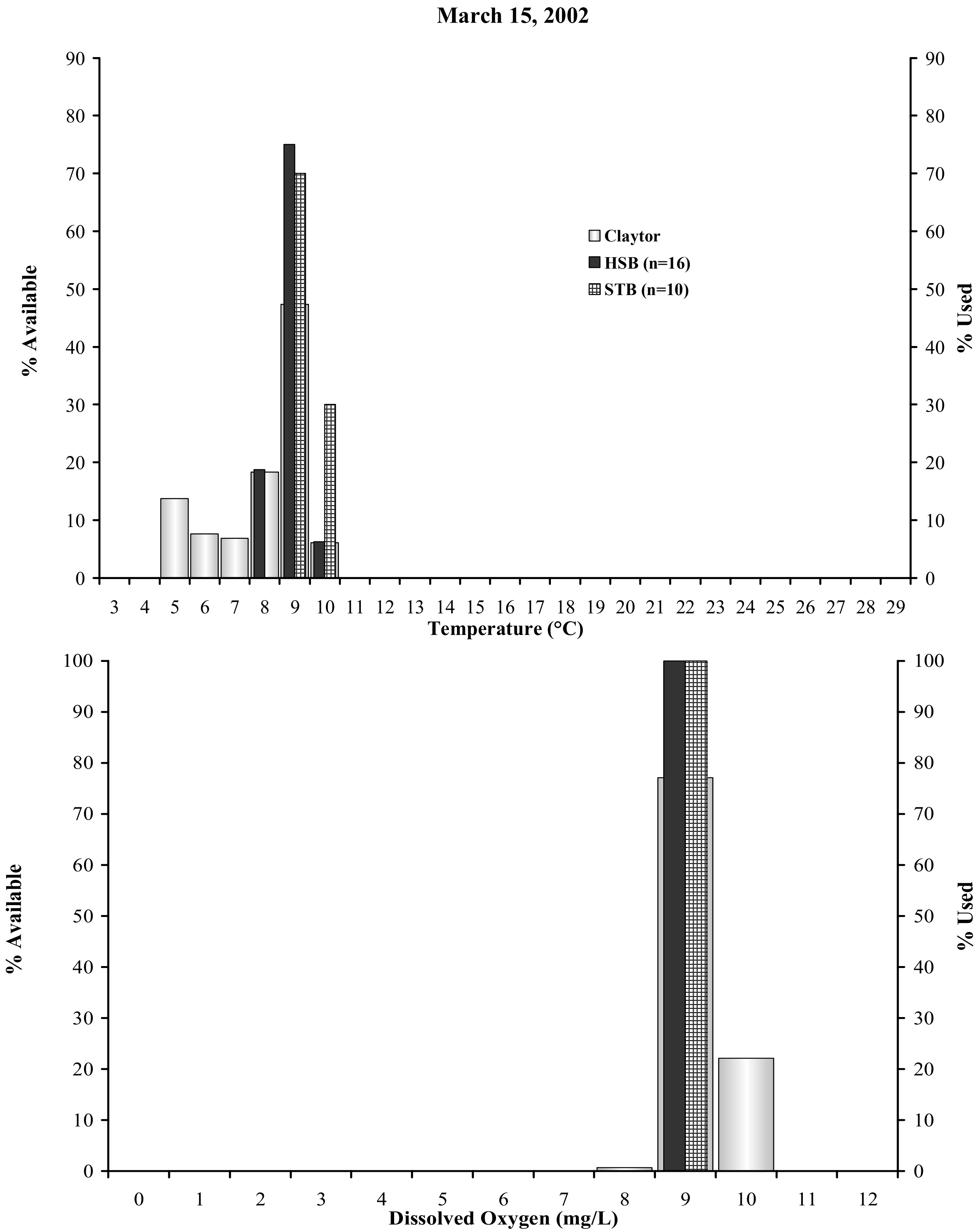
Percentage of available habitat, based on temperature and DO profiles taken from Claytor Lake, compared to habitat use, as measured from telemetered STB and HSB, January 24, 2002.

February 19, 2002



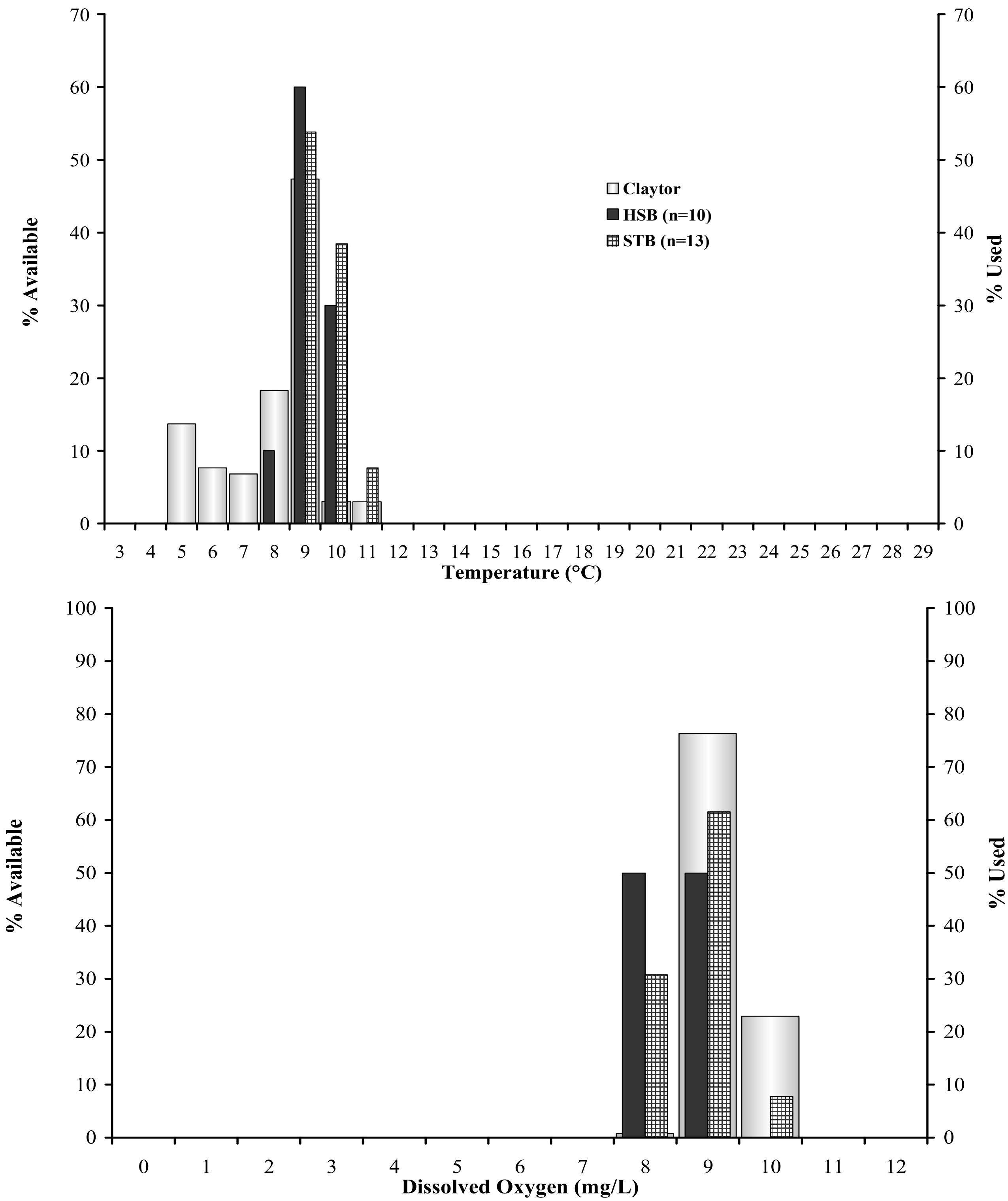


Percentage of available habitat, based on temperature and DO profiles taken from Claytor Lake, compared to habitat use, as measured from telemetered STB and HSB, February 19, 2002.



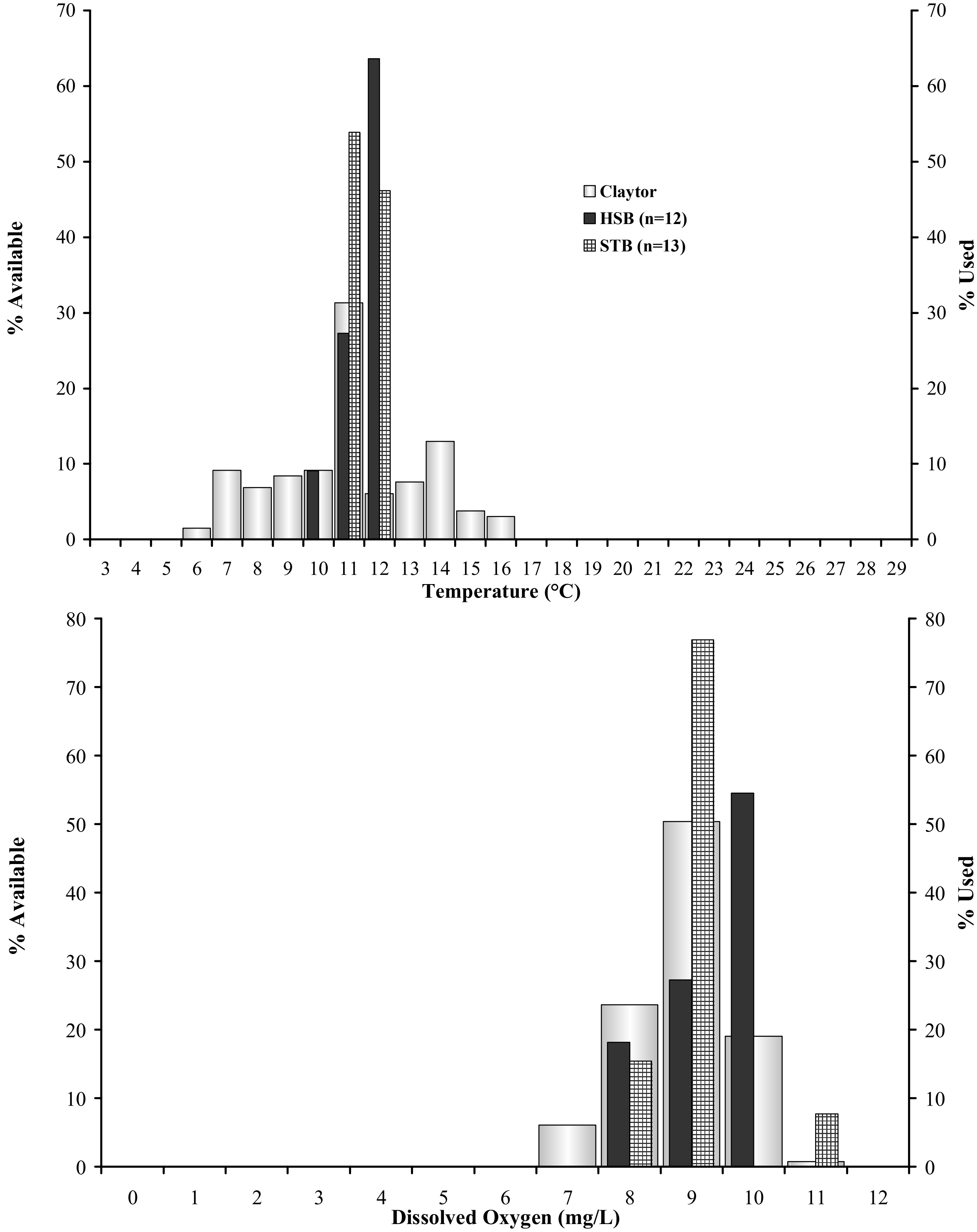
Percentage of available habitat, based on temperature and DO profiles taken from Claytor Lake, compared to habitat use, as measured from telemetered STB and HSB, March 15, 2002.

March 21, 2002

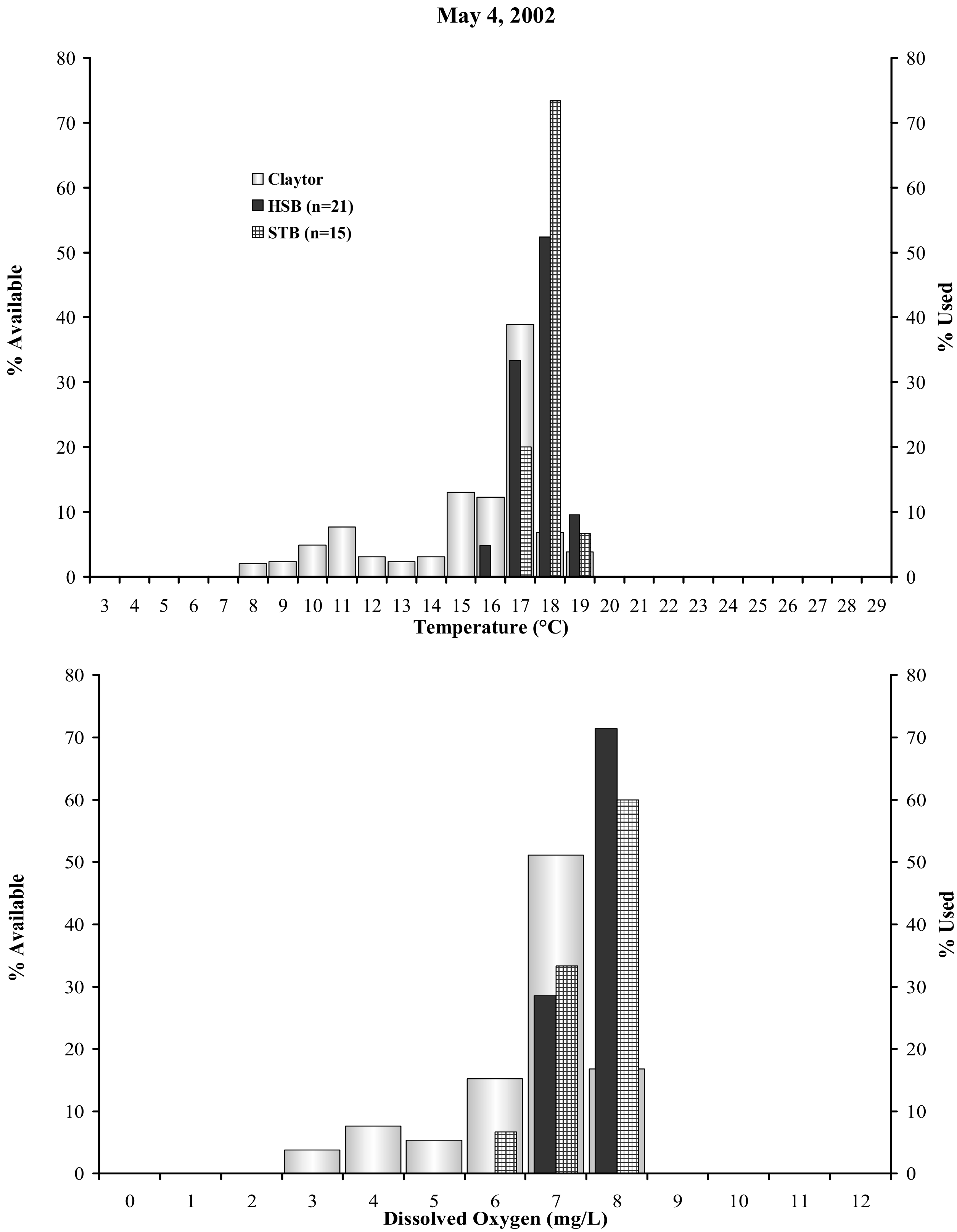


Percentage of available habitat, based on temperature and DO profiles taken from Claytor Lake, compared to habitat use, as measured from telemetered STB and HSB, March 21, 2002.

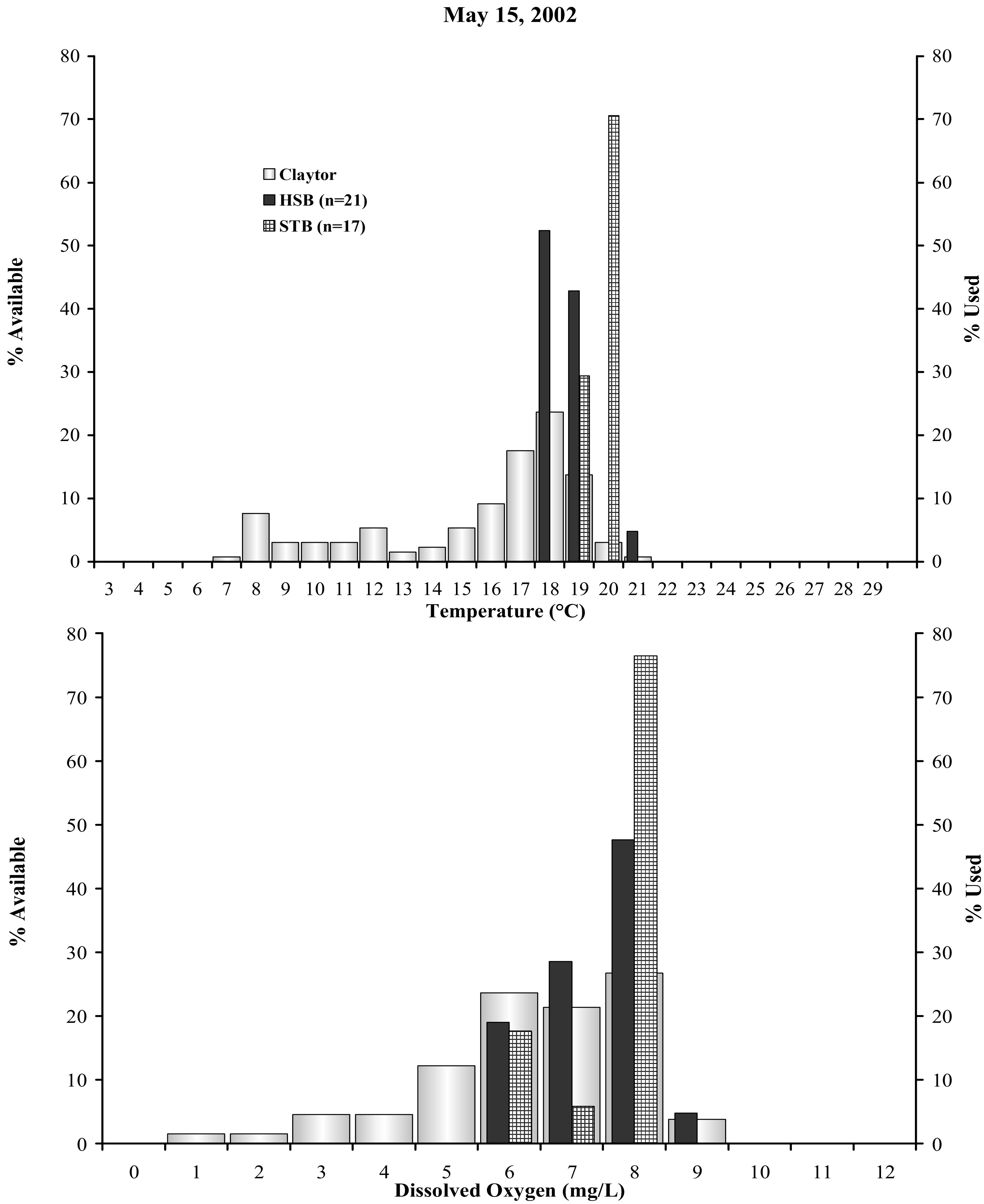
April 11, 2002



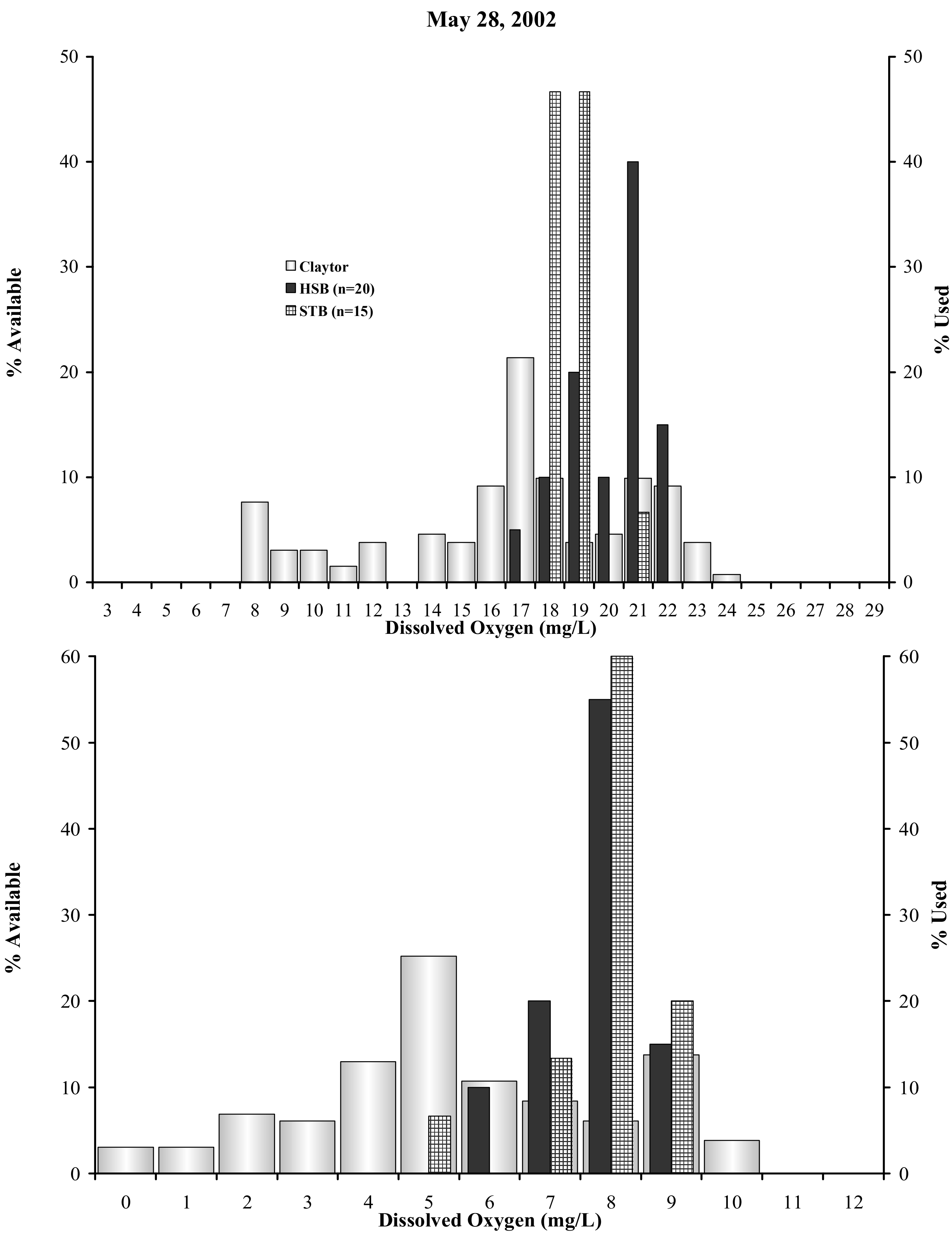
Percentage of available habitat, based on temperature and DO profiles taken from Claytor Lake, compared to habitat use, as measured from telemetered STB and HSB, April 11, 2002.



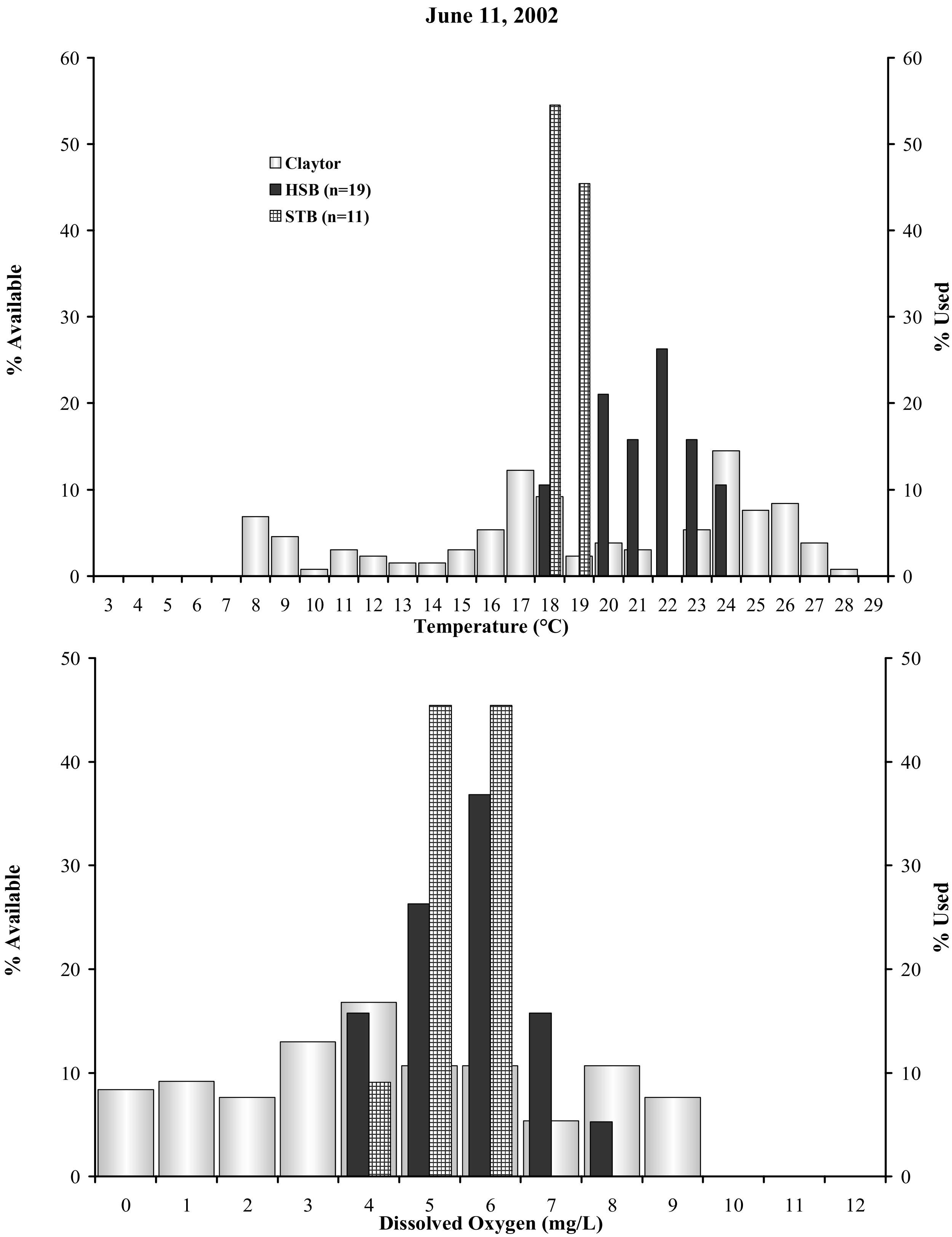
Percentage of available habitat, based on temperature and DO profiles taken from Claytor Lake, compared to habitat use, as measured from telemetered STB and HSB, May 4, 2002.



Percentage of available habitat, based on temperature and DO profiles taken from Claytor Lake, compared to habitat use, as measured from telemetered STB and HSB, May 15, 2002.

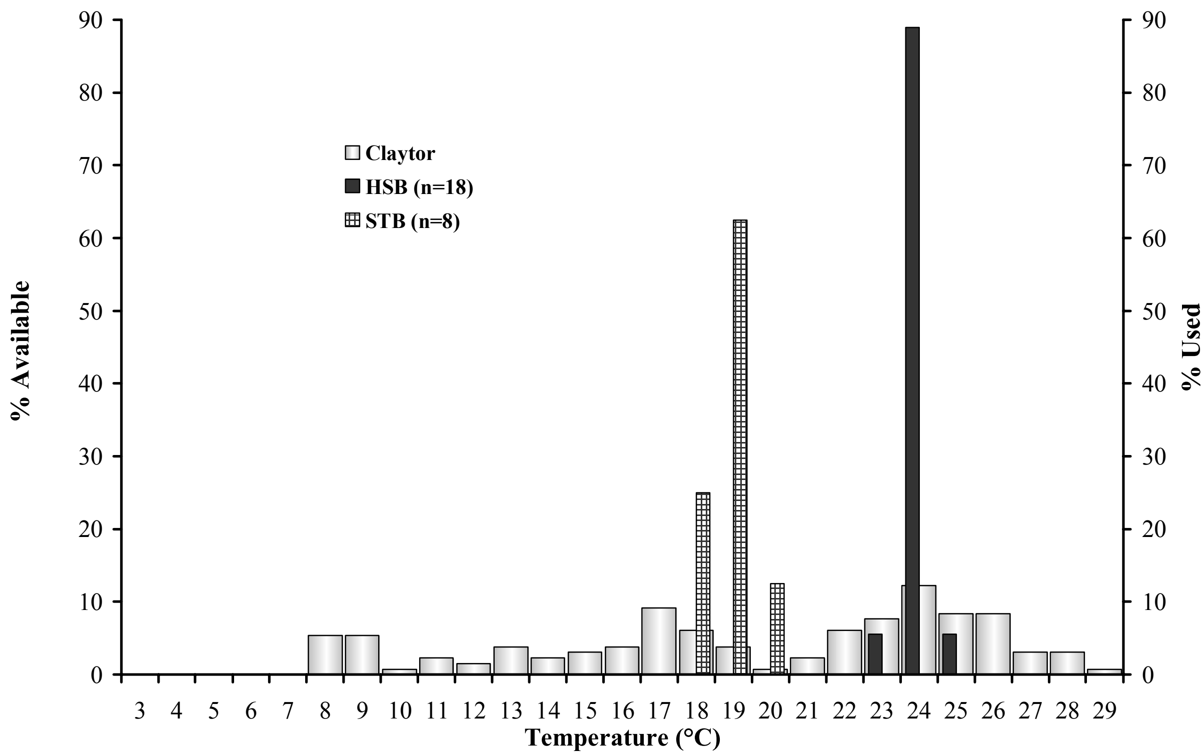


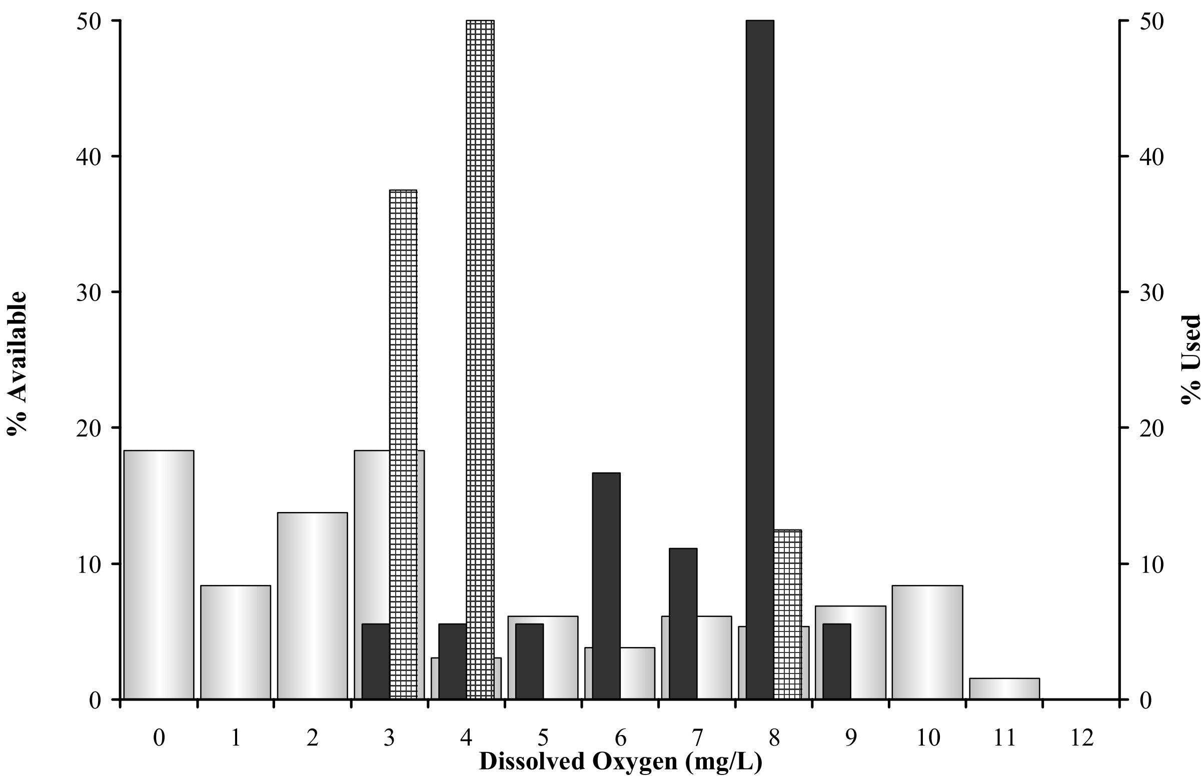
Percentage of available habitat, based on temperature and DO profiles taken from Claytor Lake, compared to habitat use, as measured from telemetered STB and HSB, May 28, 2002.



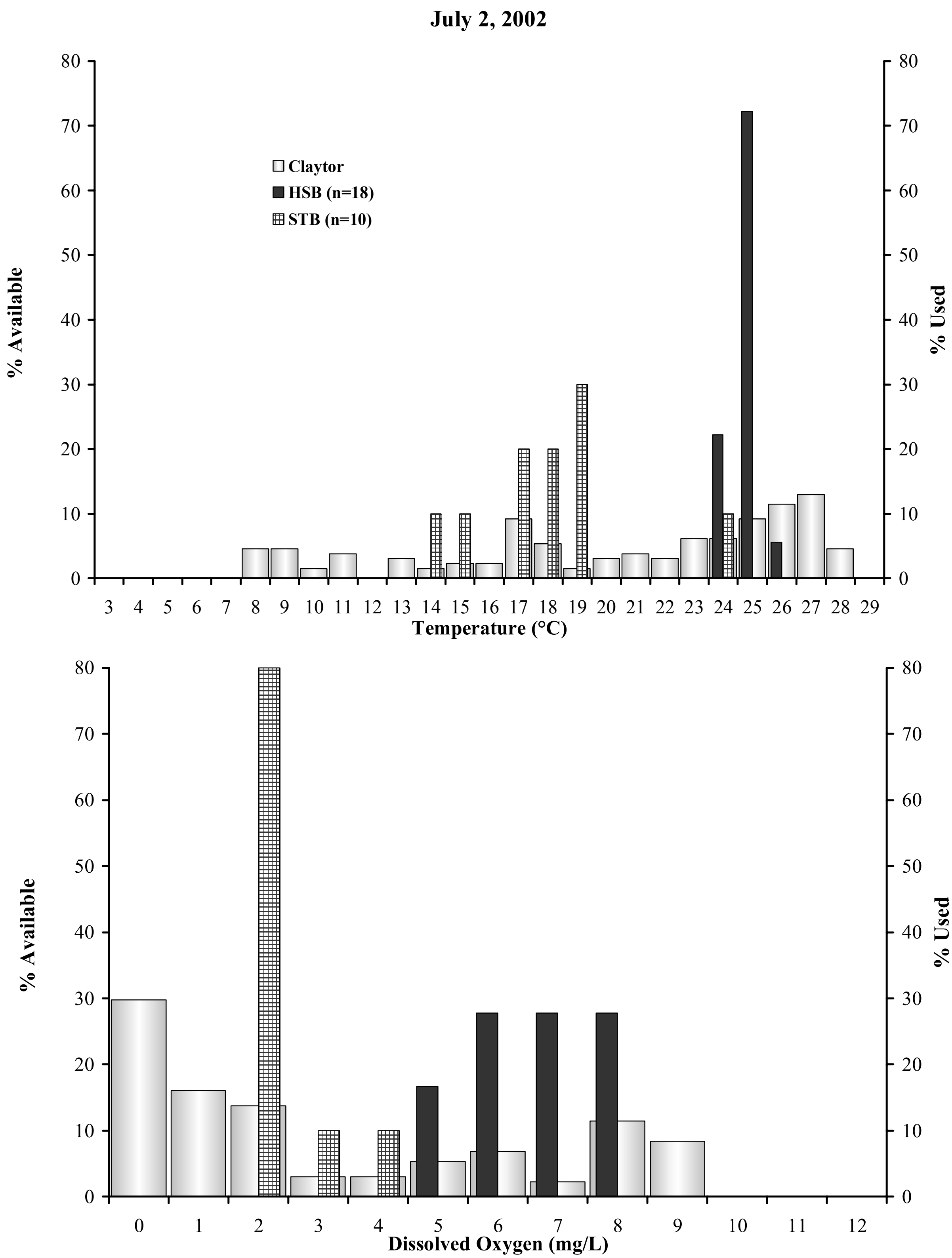
Percentage of available habitat, based on temperature and DO profiles taken from Claytor Lake, compared to habitat use, as measured from telemetered STB and HSB, June 11, 2002.

June 25, 2002



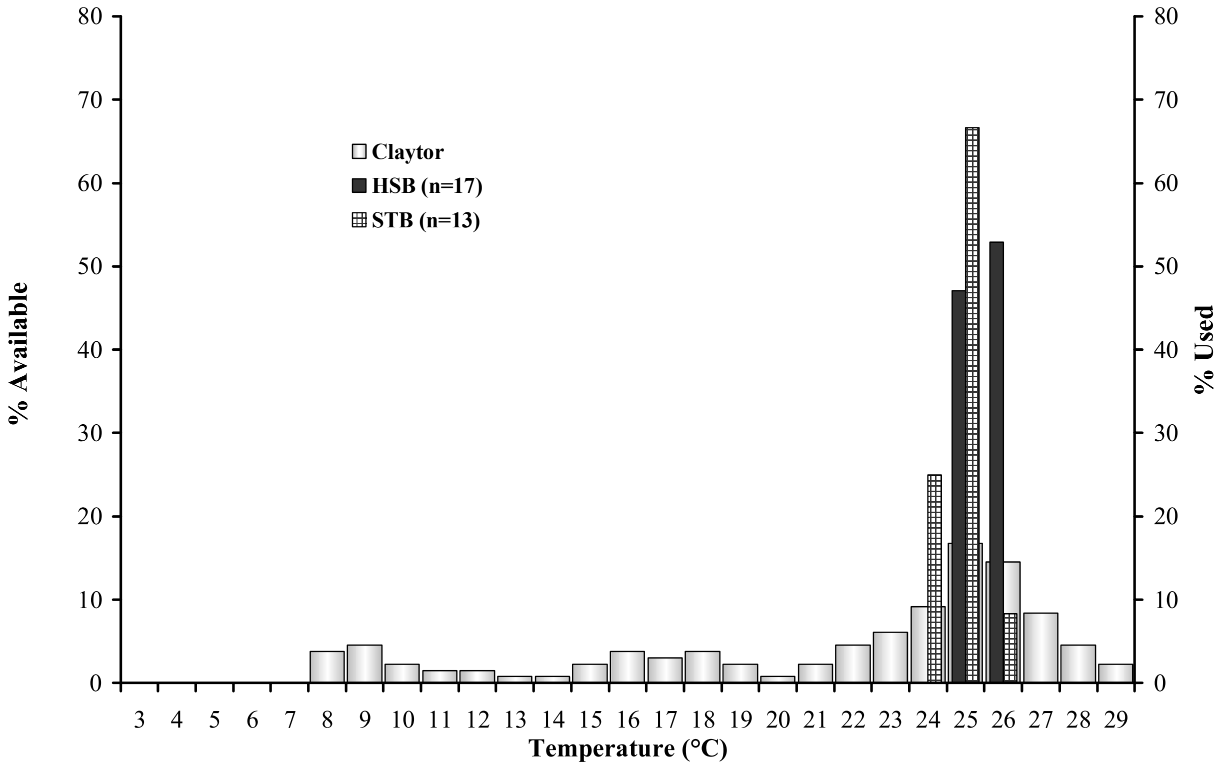


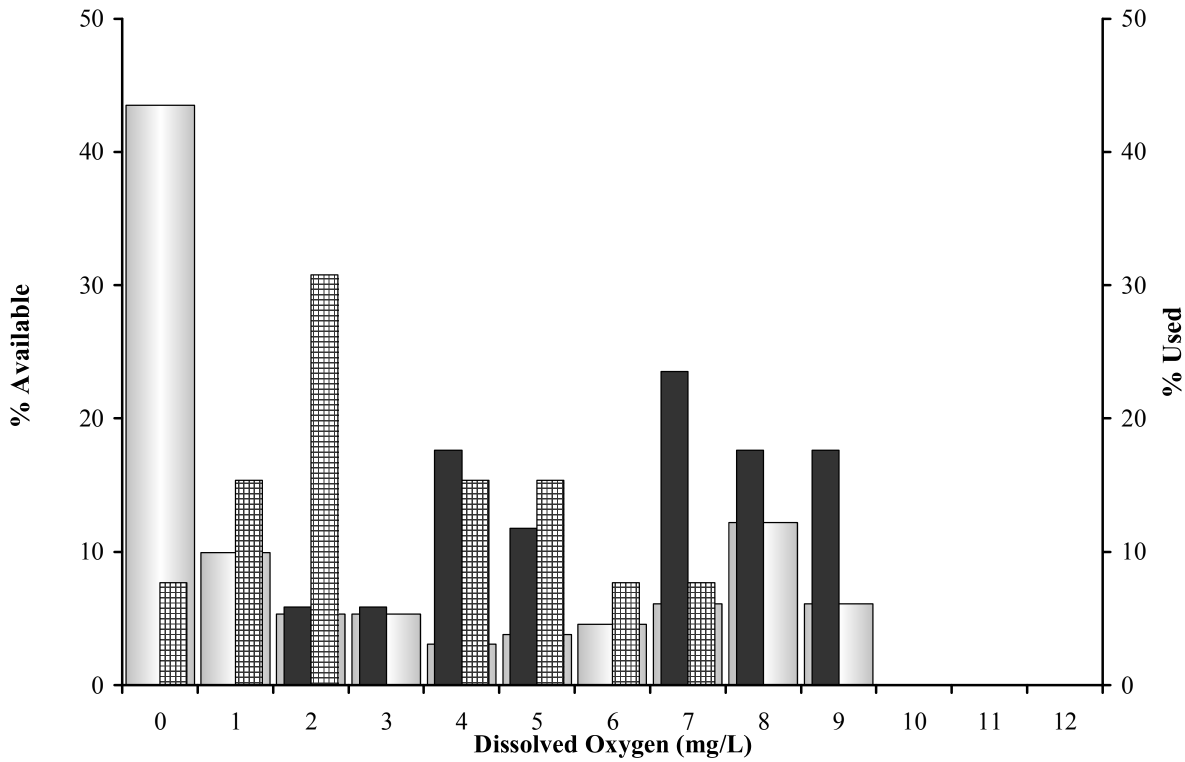
Percentage of available habitat, based on temperature and DO profiles taken from Claytor Lake, compared to habitat use, as measured from telemetered STB and HSB, June 25, 2002.



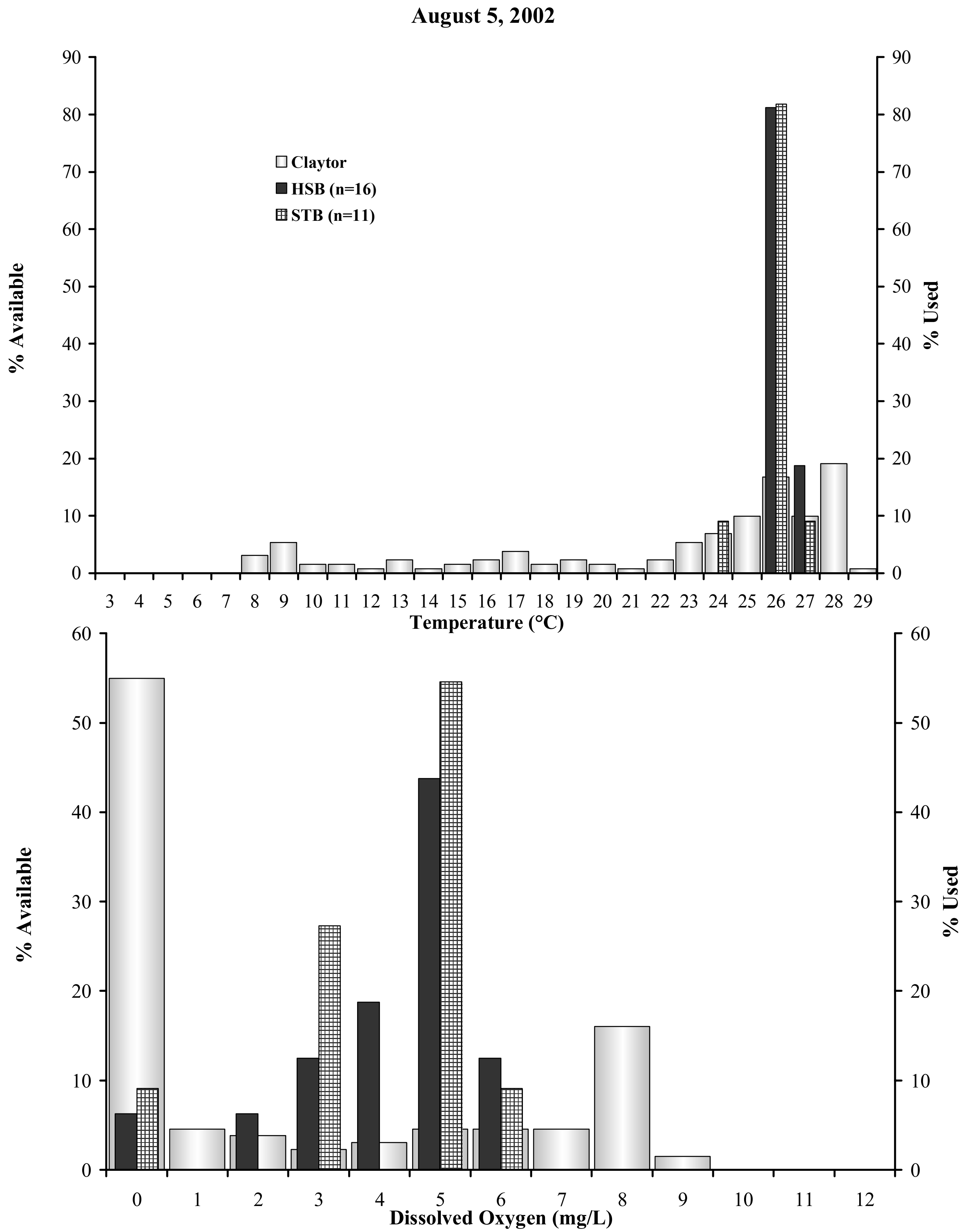
Percentage of available habitat, based on temperature and DO profiles taken from Claytor Lake, compared to habitat use, as measured from telemetered STB and HSB, July 2, 2002.

July 23, 2002

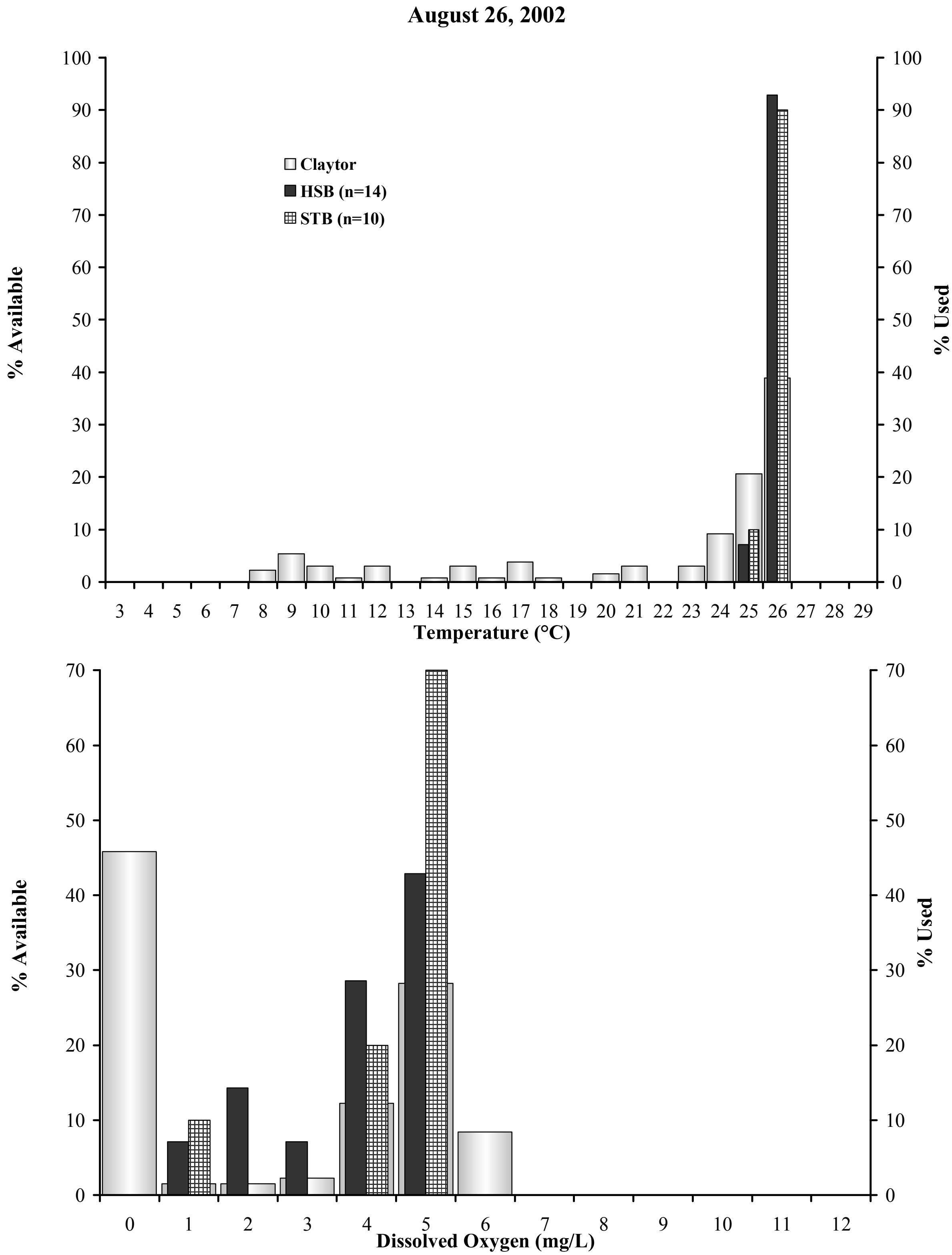




Percentage of available habitat, based on temperature and DO profiles taken from Claytor Lake, compared to habitat use, as measured from telemetered STB and HSB, July 23, 2002.

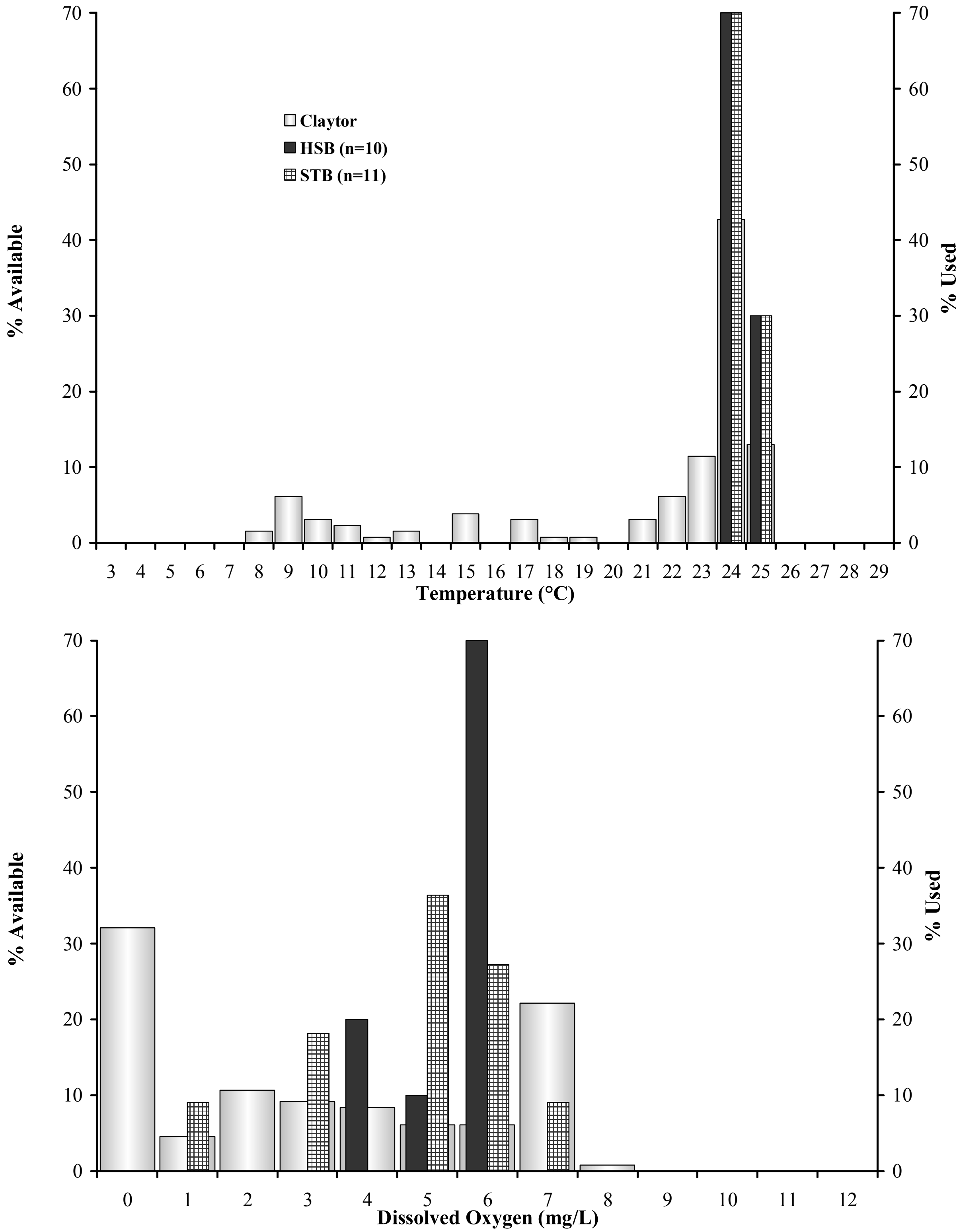


Percentage of available habitat, based on temperature and DO profiles taken from Claytor Lake, compared to habitat use, as measured from telemetered STB and HSB, August 5, 2002.



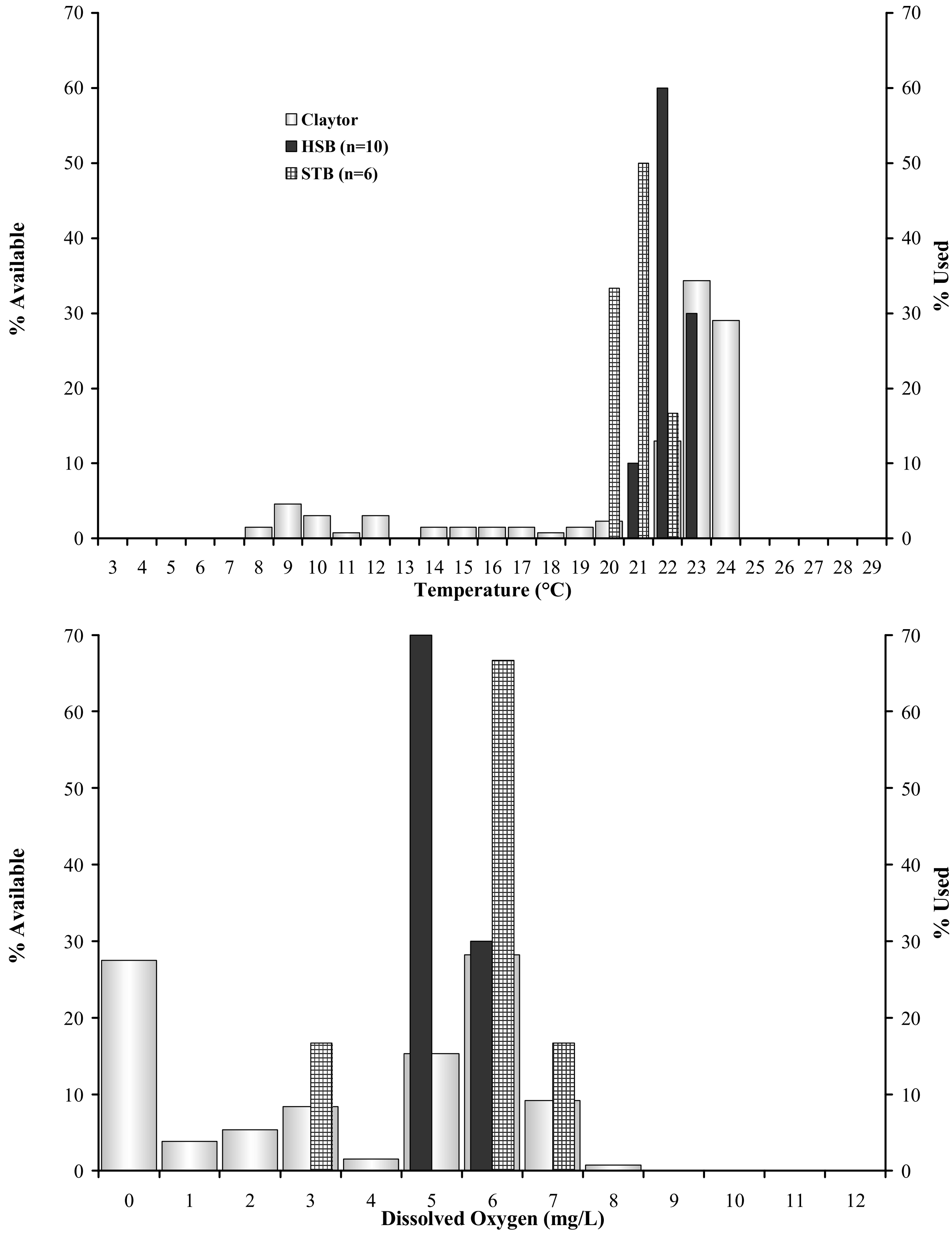
Percentage of available habitat, based on temperature and DO profiles taken from Claytor Lake, compared to habitat use, as measured from telemetered STB and HSB, August 26, 2002.

September 9, 2002



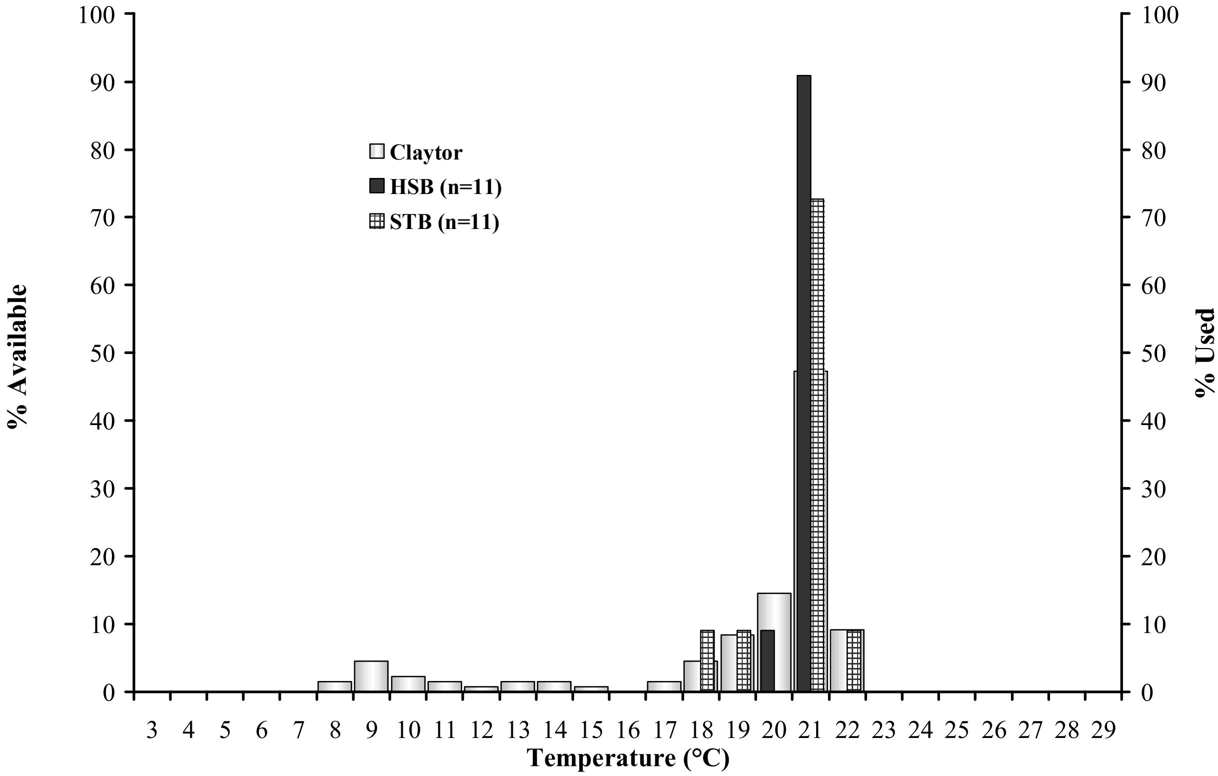
Percentage of available habitat, based on temperature and DO profiles taken from Claytor Lake, compared to habitat use, as measured from telemetered STB and HSB, September 9, 2002.

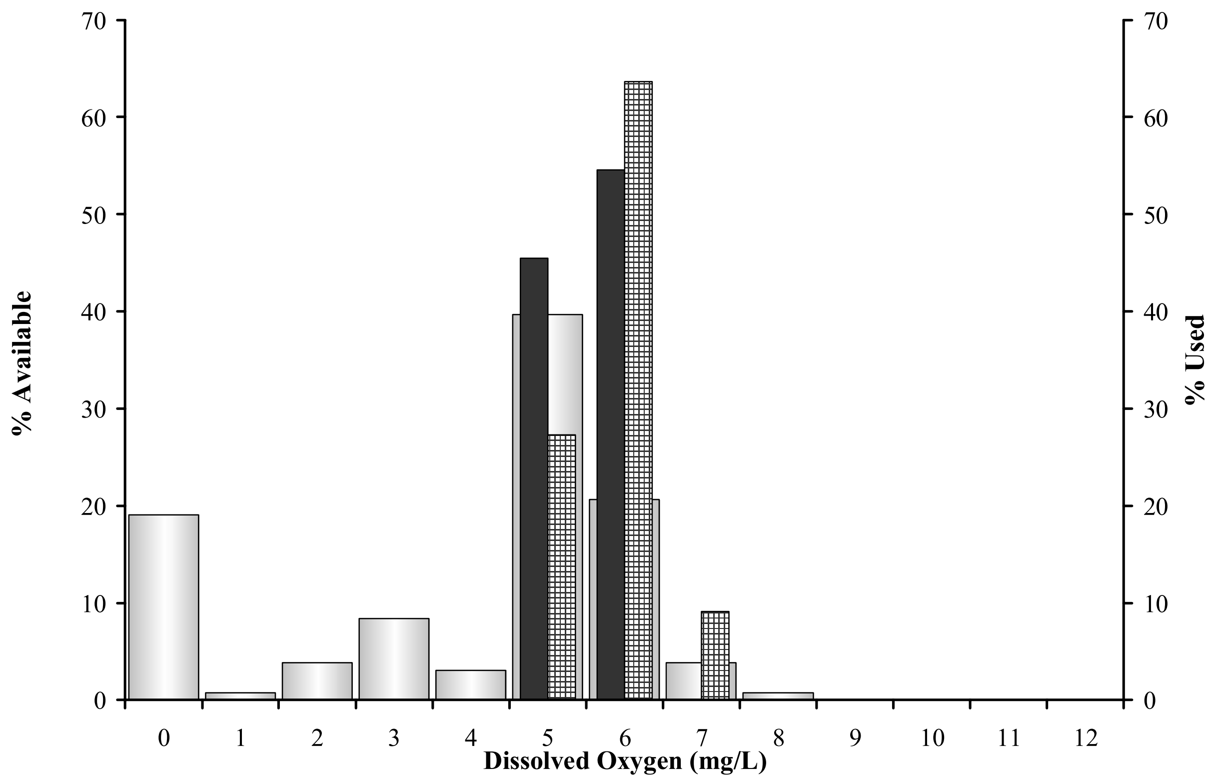
September 23, 2002



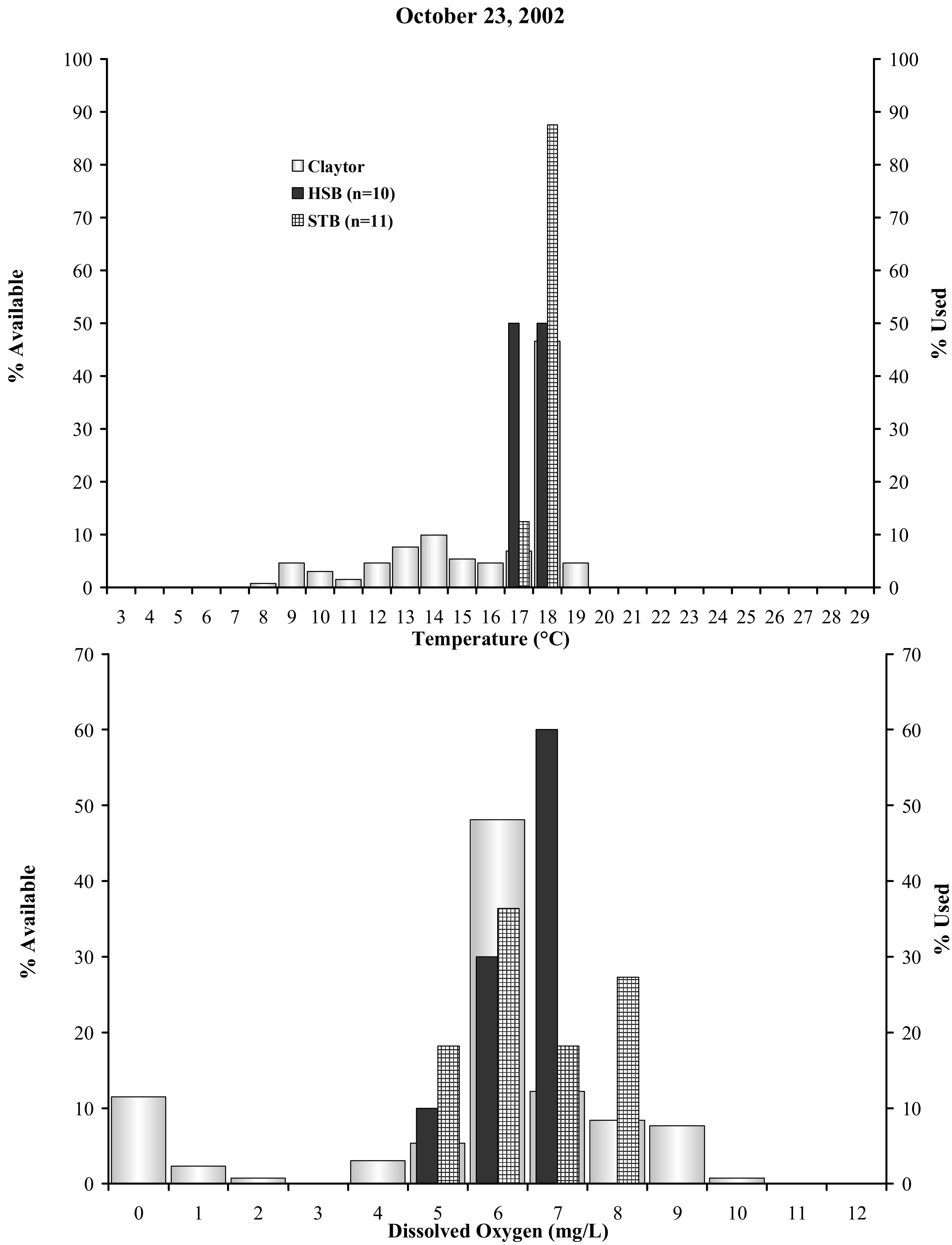
Percentage of available habitat, based on temperature and DO profiles taken from Claytor Lake, compared to habitat use, as measured from telemetered STB and HSB, September 23, 2002.

October 9, 2002

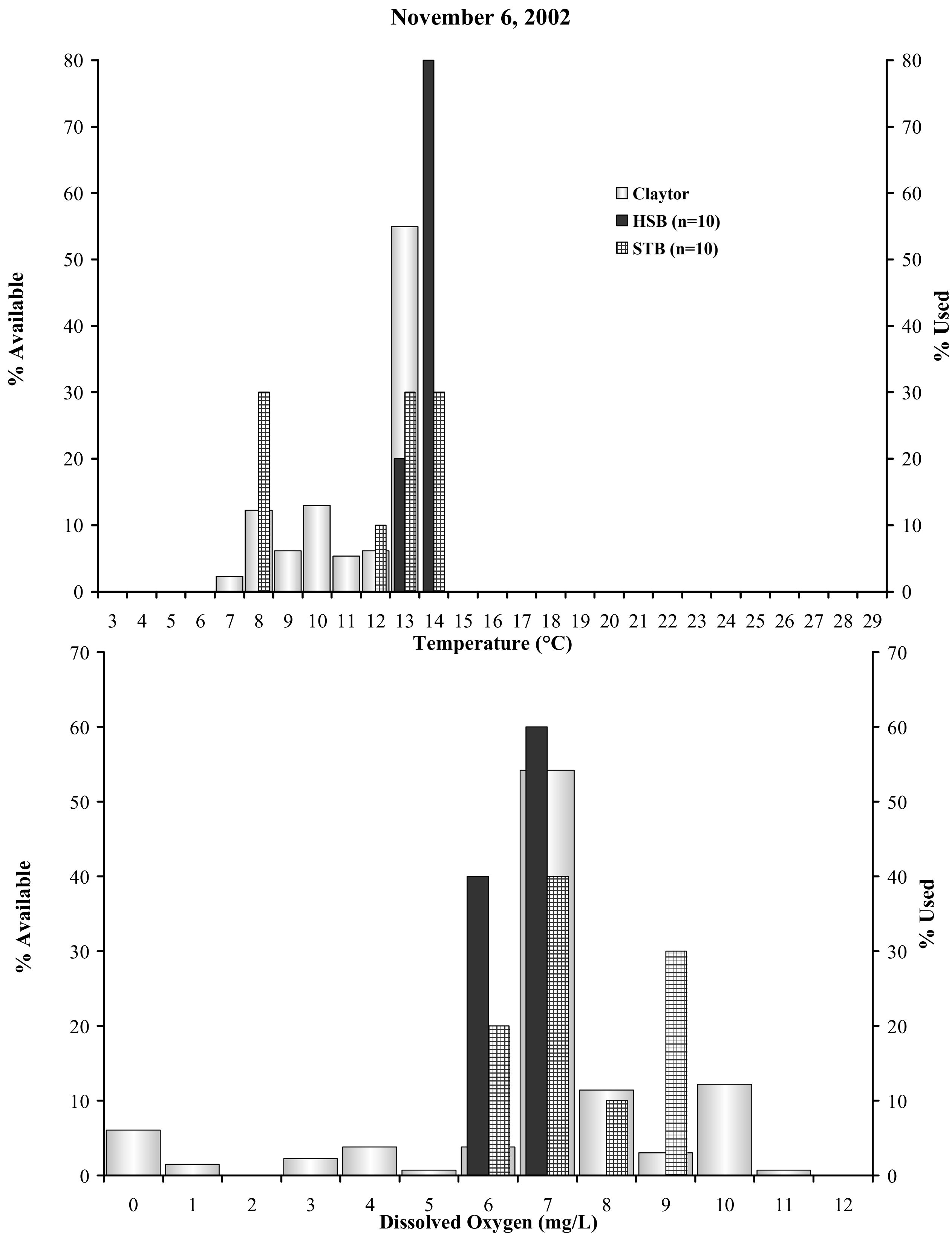




Percentage of available habitat, based on temperature and DO profiles taken from Claytor Lake, compared to habitat use, as measured from telemetered STB and HSB, October 9, 2002.

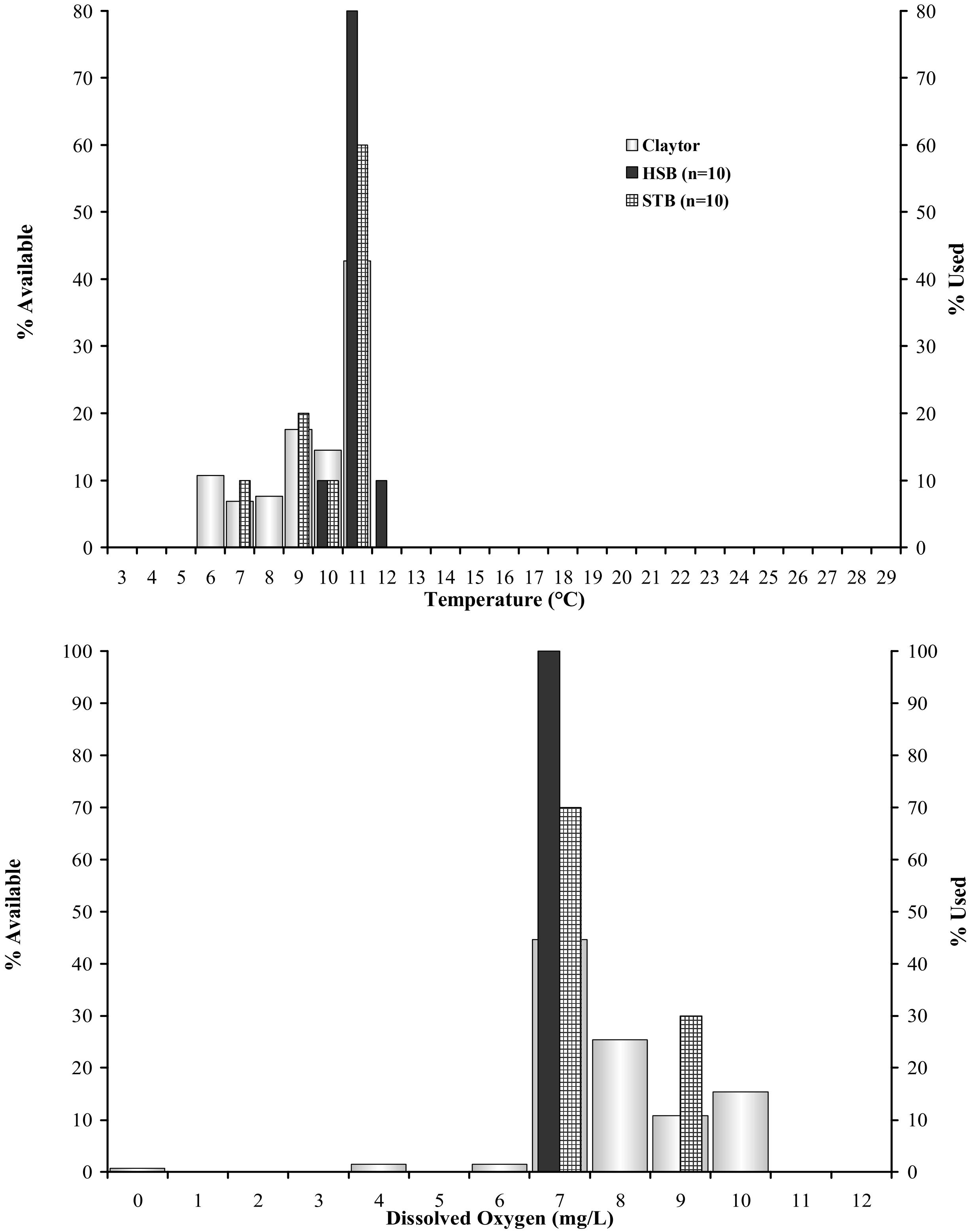


Percentage of available habitat, based on temperature and DO profiles taken from Claytor Lake, compared to habitat use, as measured from telemetered STB and HSB, October 23, 2002.



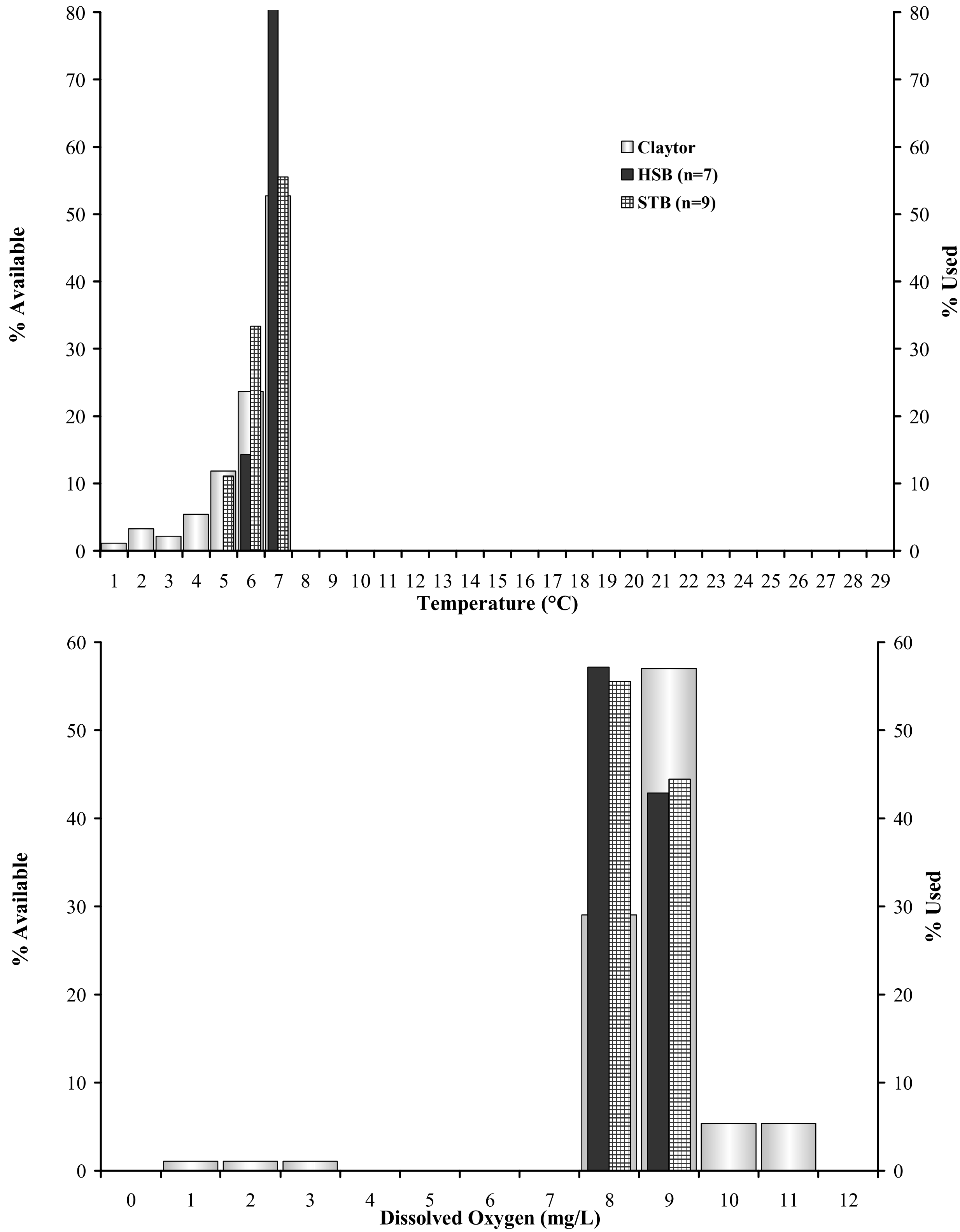
Percentage of available habitat, based on temperature and DO profiles taken from Claytor Lake, compared to habitat use, as measured from telemetered STB and HSB, November 6, 2002.

November 19, 2002



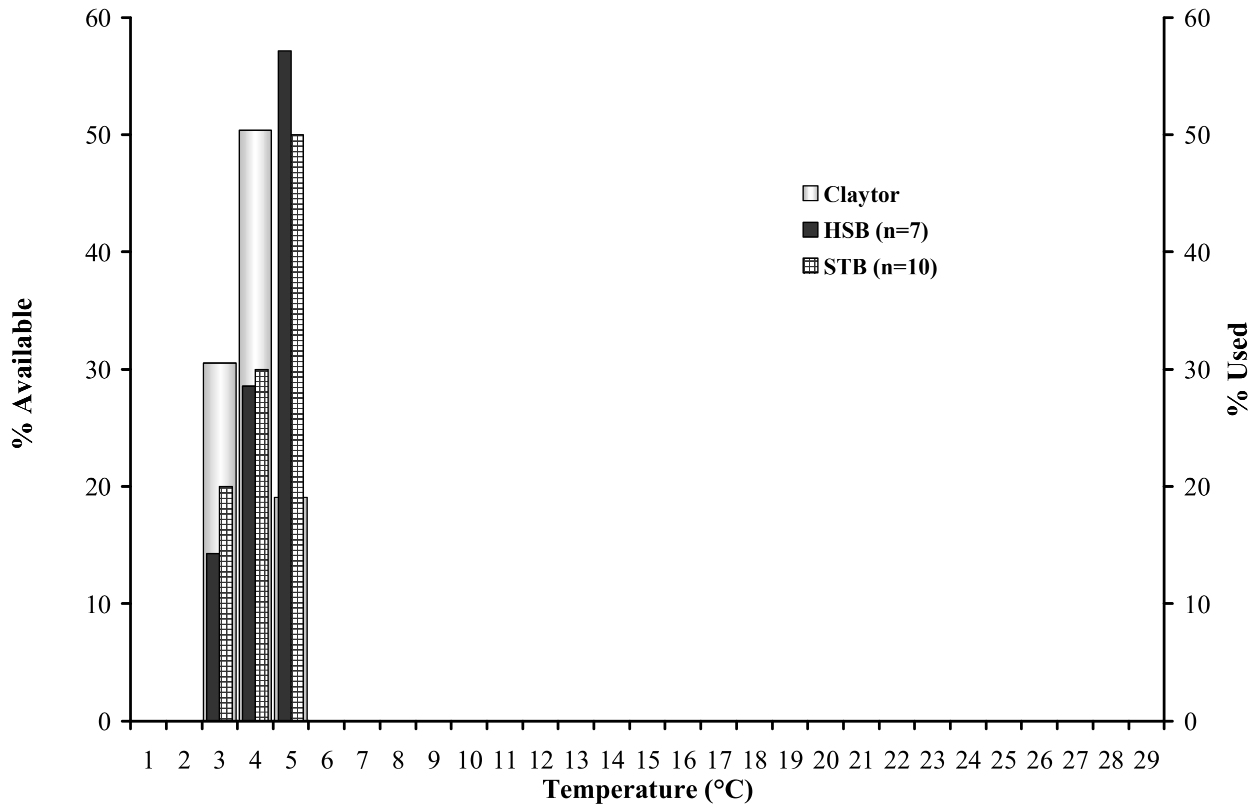
Percentage of available habitat, based on temperature and DO profiles taken from Claytor Lake, compared to habitat use, as measured from telemetered STB and HSB, November 19, 2002.

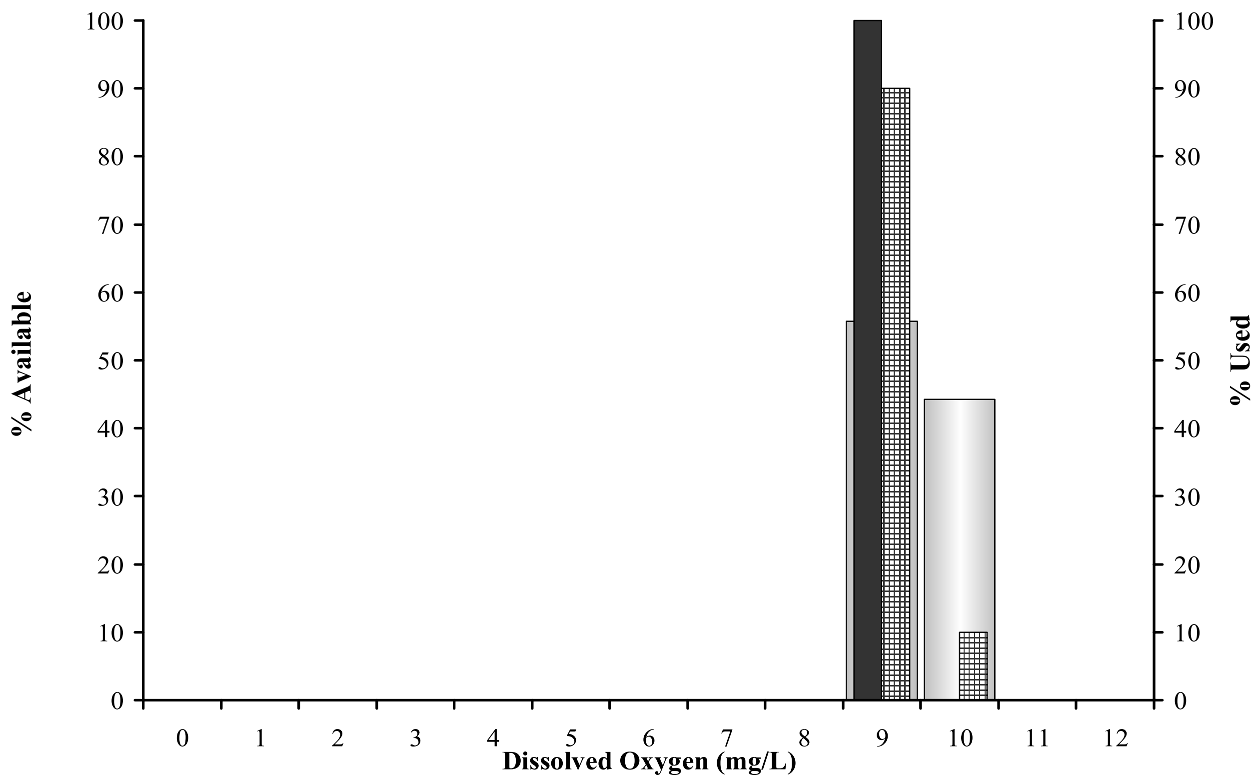
December 5, 2002



Percentage of available habitat, based on temperature and DO profiles taken from Claytor Lake, compared to habitat use, as measured from telemetered STB and HSB, December 5, 2002.

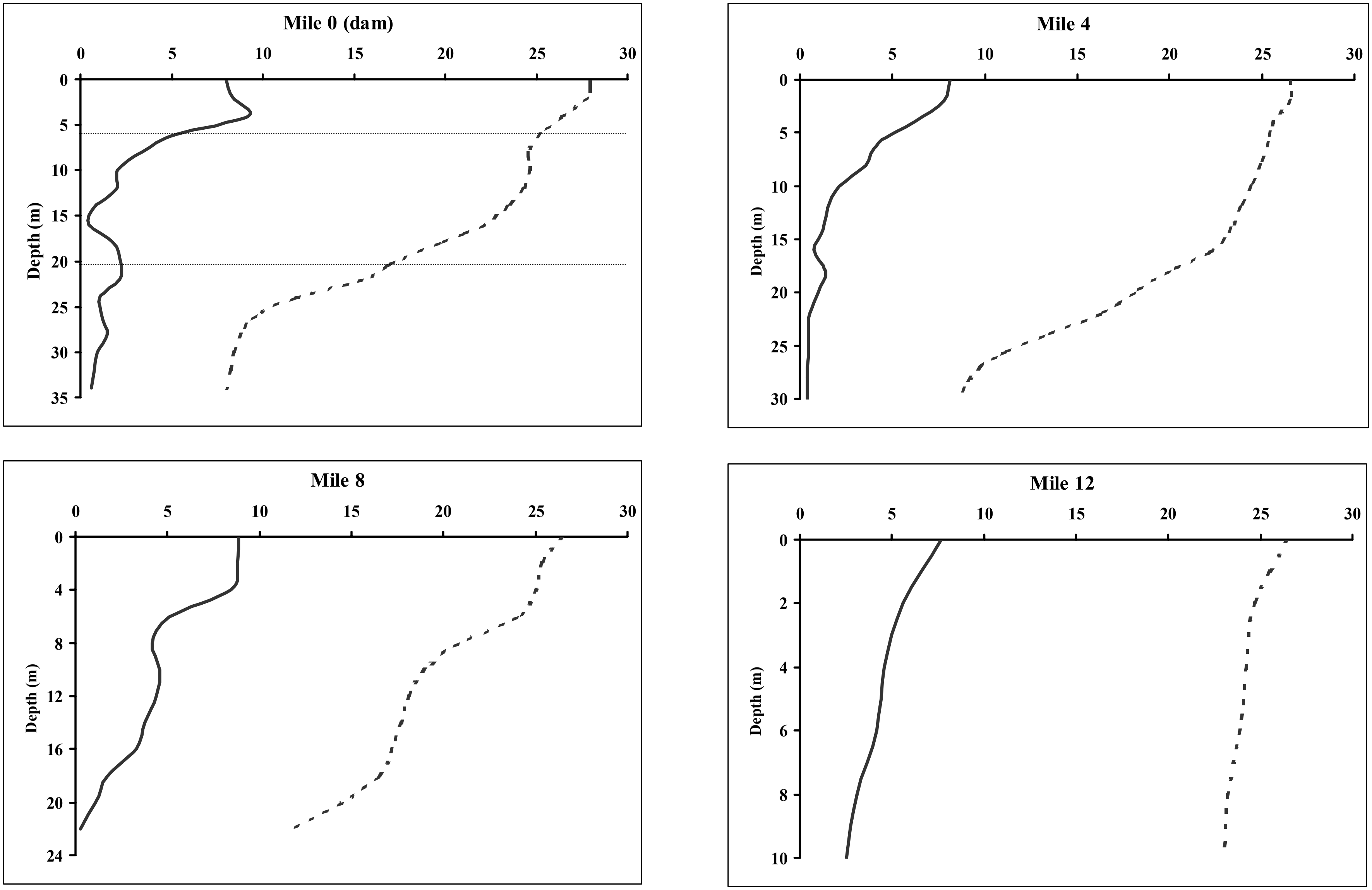
December 19, 2002



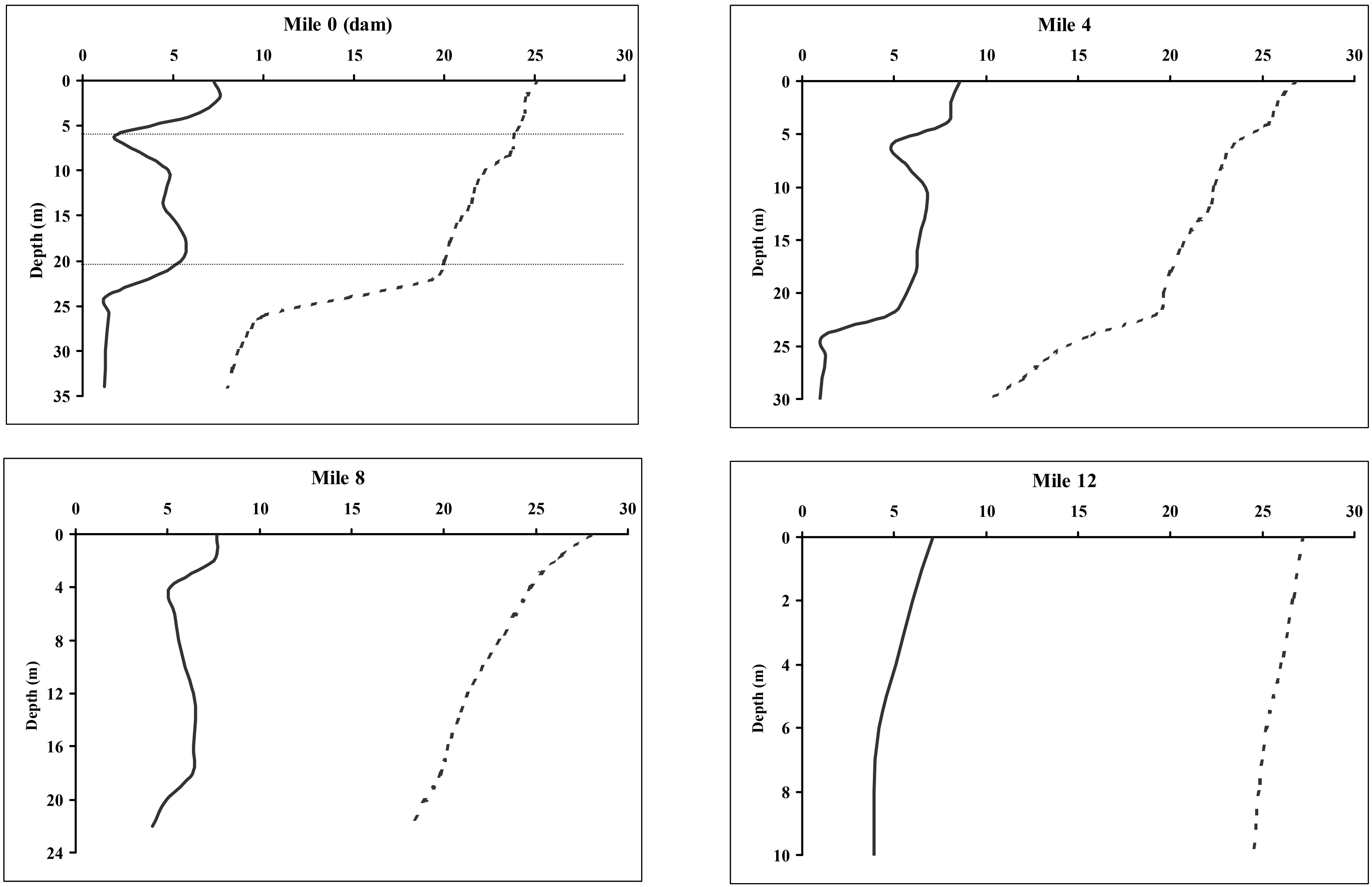


Percentage of available habitat, based on temperature and DO profiles taken from Claytor Lake, compared to habitat use, as measured from telemetered STB and HSB, December 19, 2002.

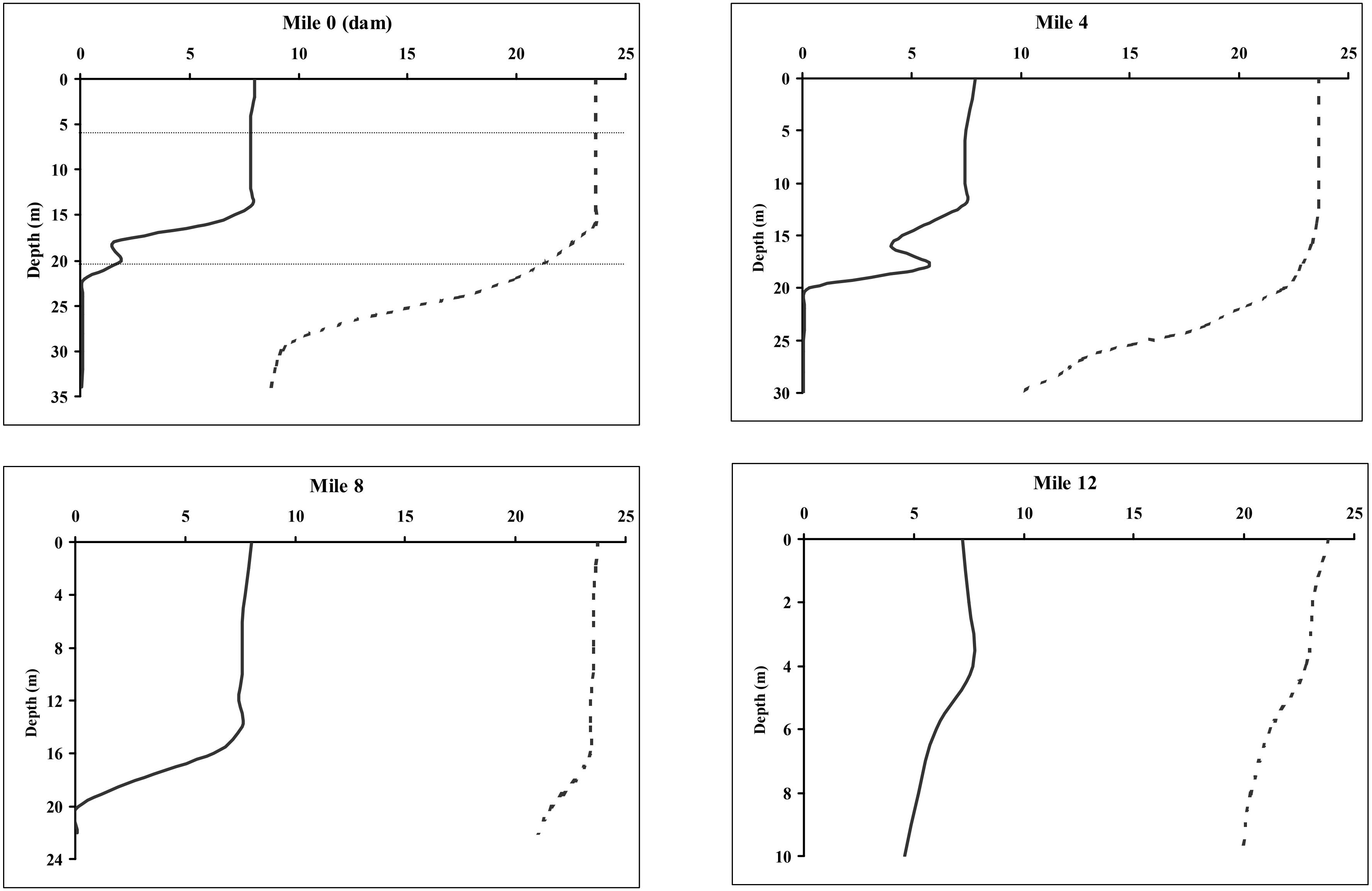
Appendix 4. Vertical profiles for Claytor Lake, July 2001-December 2002. Graphs represent habitat at mile 0 (directly in front of the dam), mile 4, mile 8, and mile 12 from the dam.



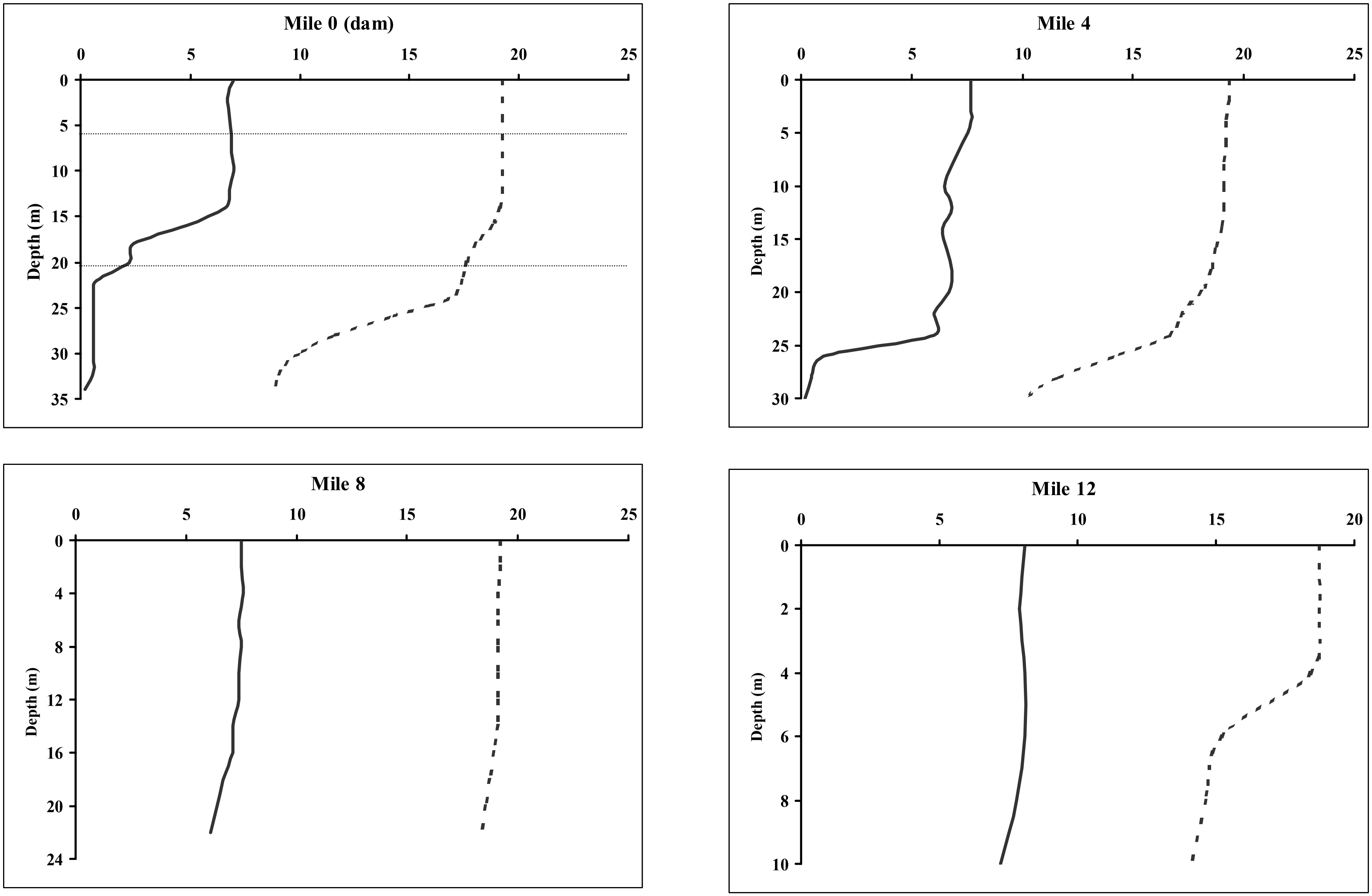
Claytor Lake Profiles, July 2001. Vertical dashed lines represent temperature (°C) and (for mile 0 profile) horizontal dashed lines represent upper and lower bounds of dam intakes. Solid lines represent dissolved oxygen (mg/L).



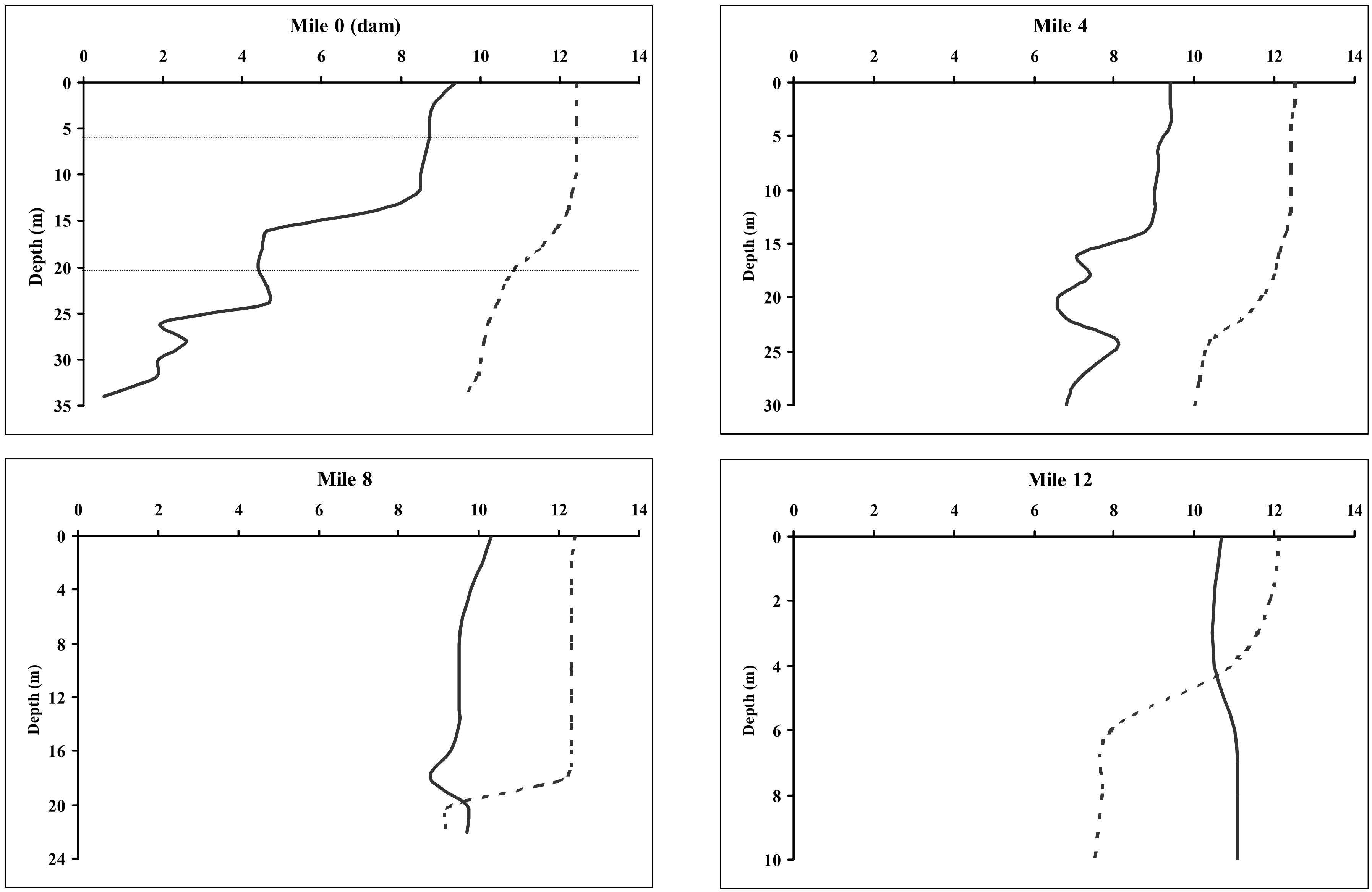
Claytor Lake Profiles, August 2001. Vertical dashed lines represent temperature (°C) and (for mile 0 profile) horizontal dashed lines represent upper and lower bounds of dam intakes. Solid lines represent dissolved oxygen (mg/L).



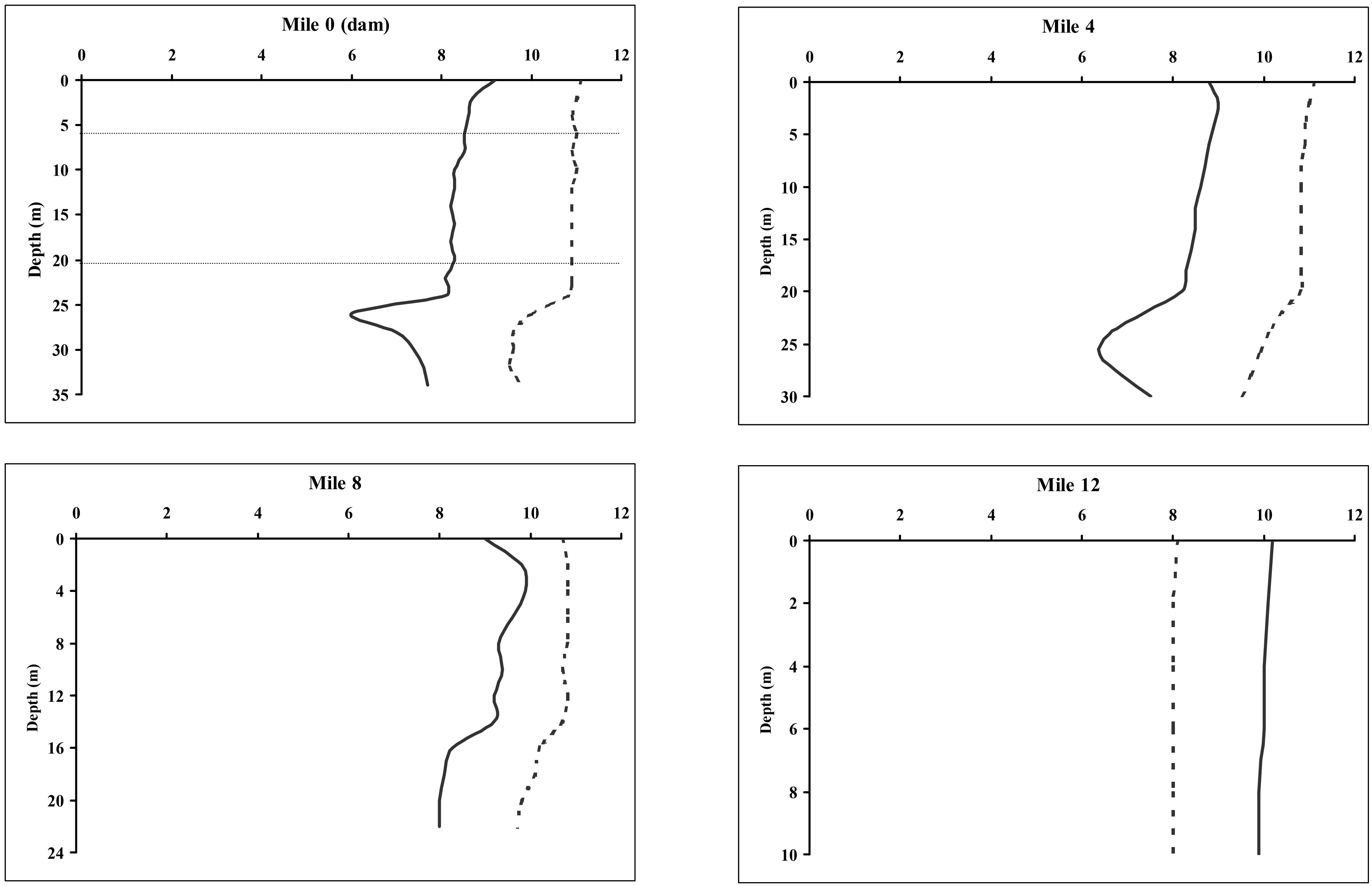
Claytor Lake Profiles, September 2001. Vertical dashed lines represent temperature (°C) and (for mile 0 profile) horizontal dashed lines represent upper and lower bounds of dam intakes. Solid lines represent dissolved oxygen (mg/L).



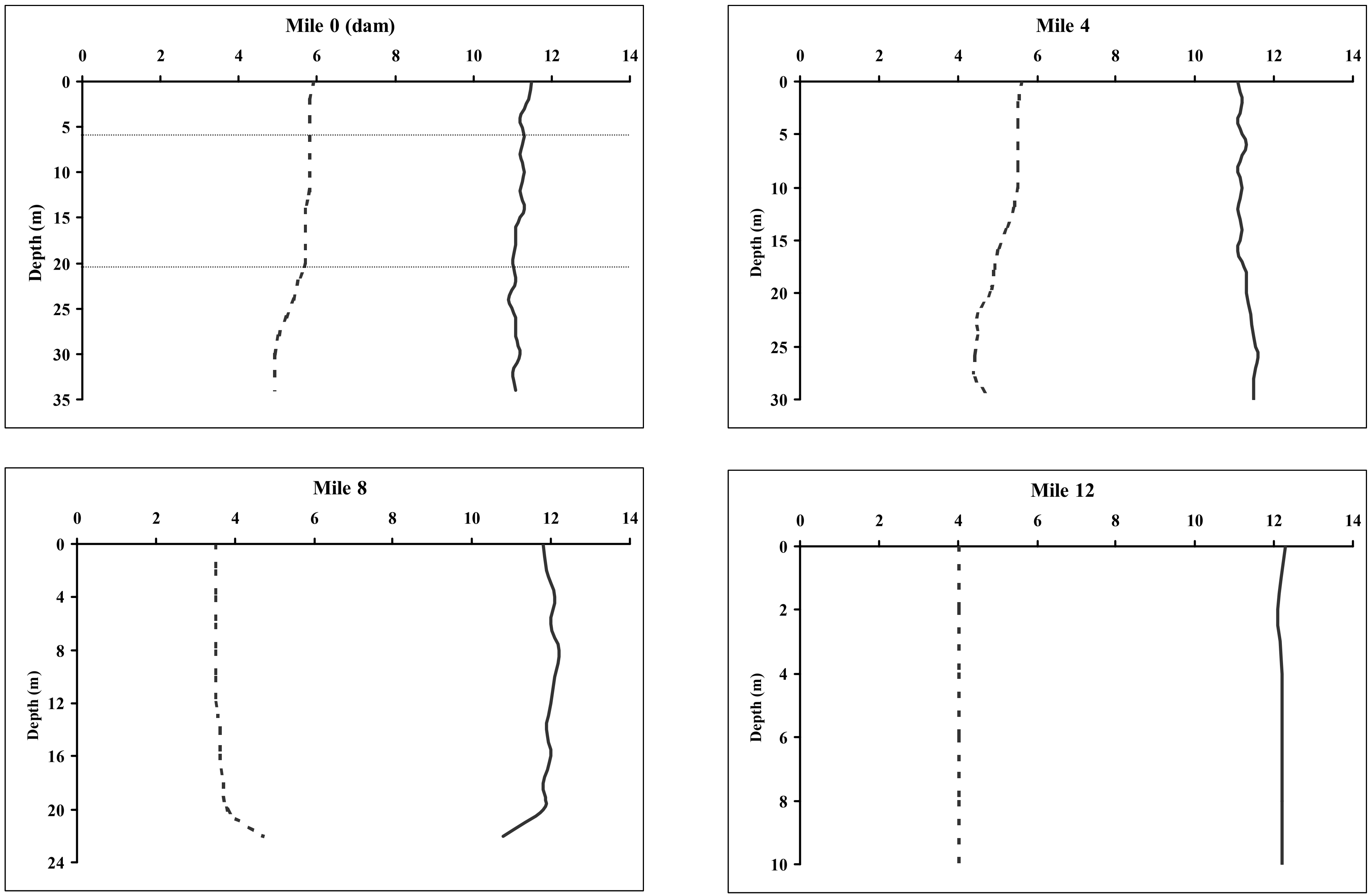
Claytor Lake Profiles, October 2001. Vertical dashed lines represent temperature (°C) and (for mile 0 profile) horizontal dashed lines represent upper and lower bounds of dam intakes. Solid lines represent dissolved oxygen (mg/L).



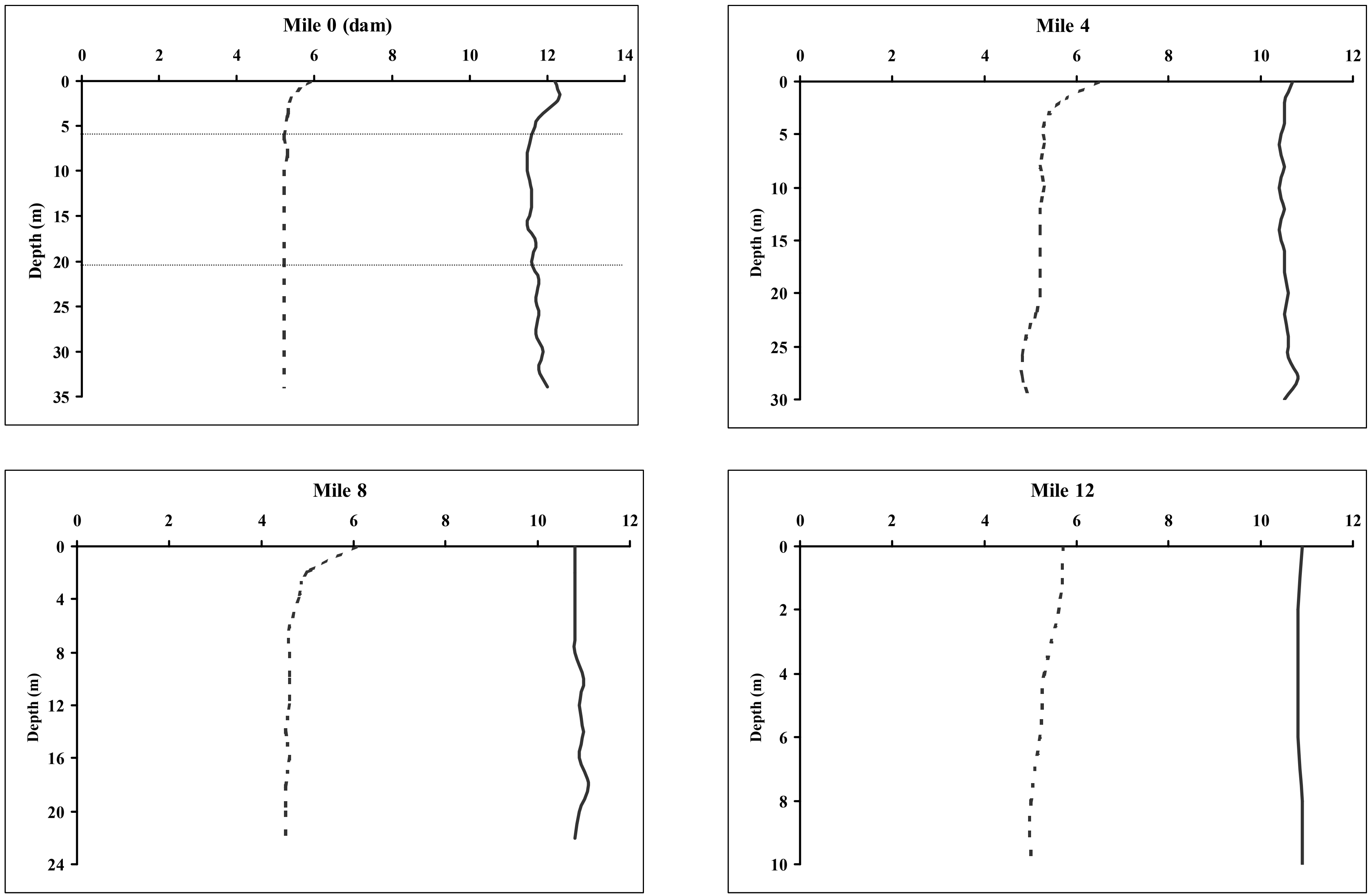
Claytor Lake Profiles, November 2001. Vertical dashed lines represent temperature (°C) and (for mile 0 profile) horizontal dashed lines represent upper and lower bounds of dam intakes. Solid lines represent dissolved oxygen (mg/L).



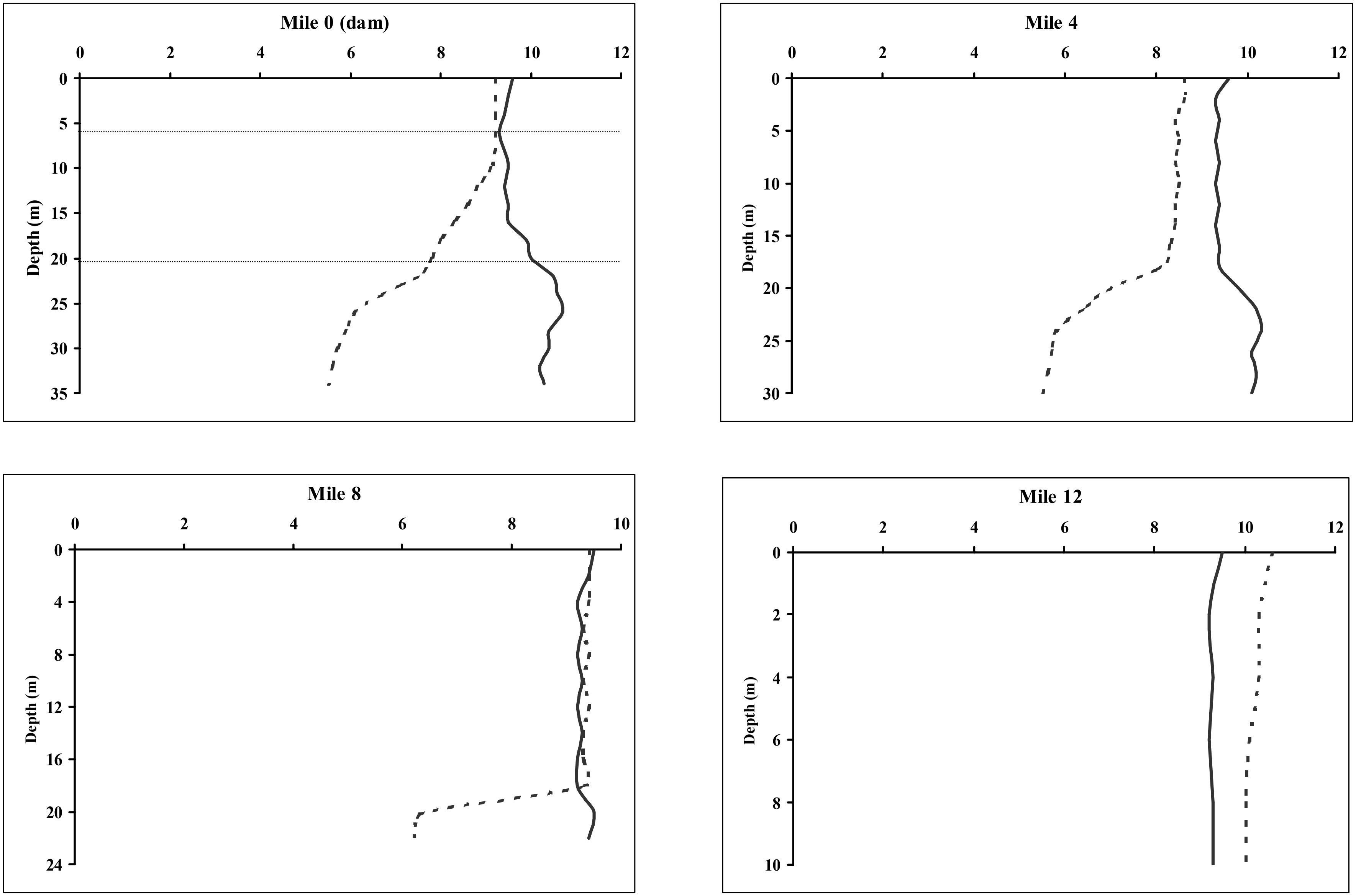
Claytor Lake Profiles, December 2001. Vertical dashed lines represent temperature (°C) and (for mile 0 profile) horizontal dashed lines represent upper and lower bounds of dam intakes. Solid lines represent dissolved oxygen (mg/L).



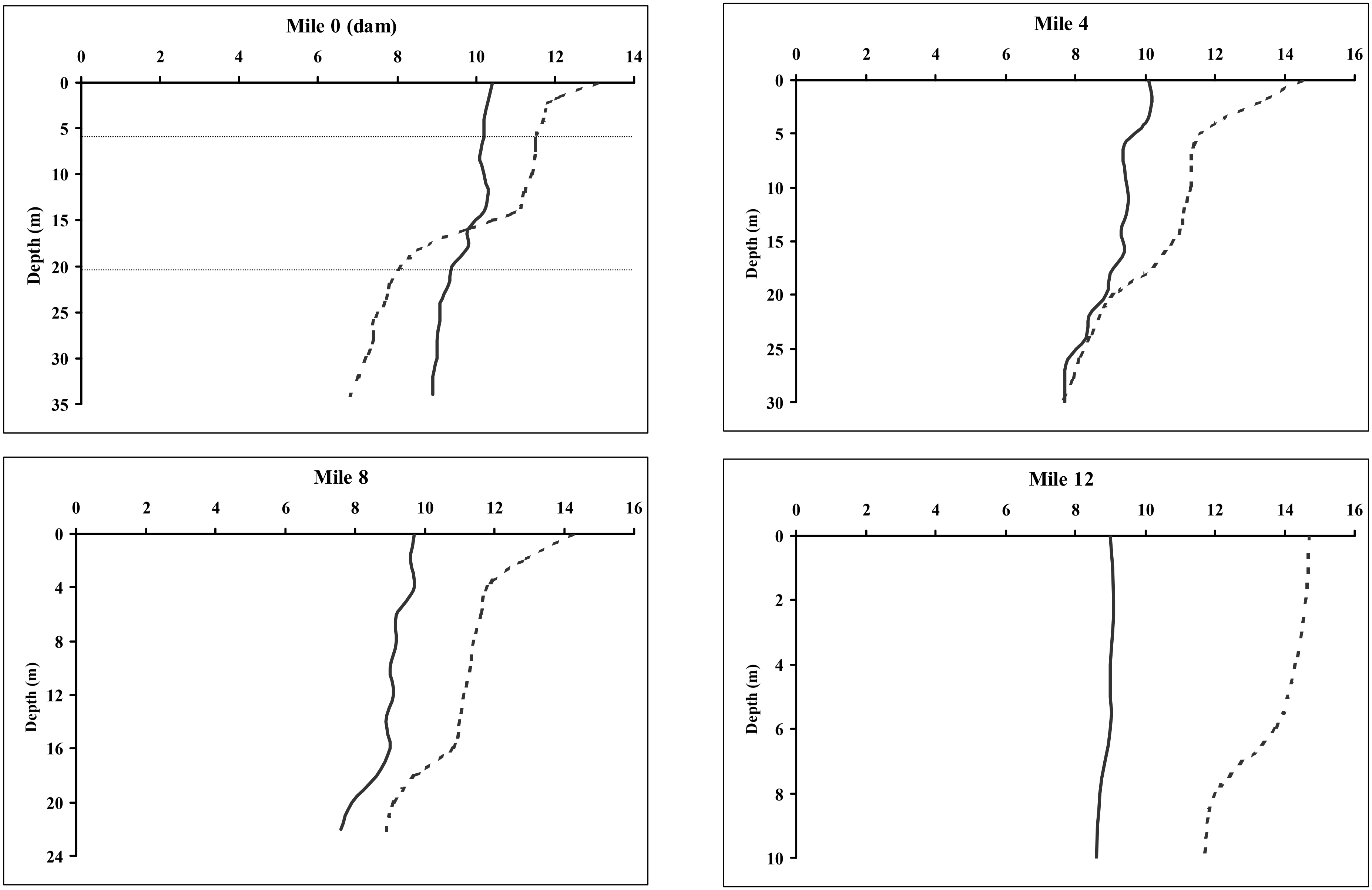
Claytor Lake Profiles, January 2002. Vertical dashed lines represent temperature (°C) and (for mile 0 profile) horizontal dashed lines represent upper and lower bounds of dam intakes. Solid lines represent dissolved oxygen (mg/L).



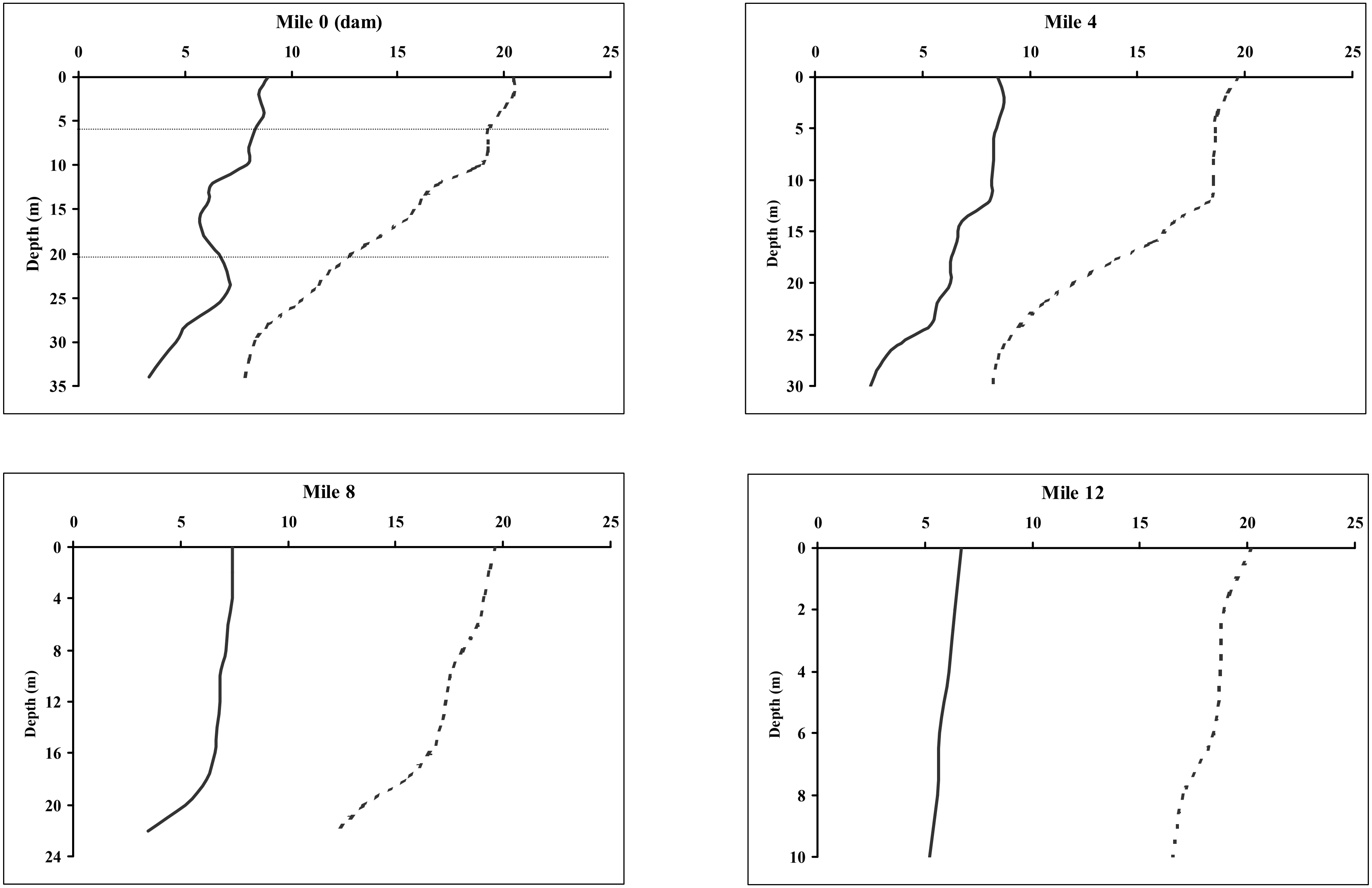
Claytor Lake Profiles, February 2002. Vertical dashed lines represent temperature (°C) and (for mile 0 profile) horizontal dashed lines represent upper and lower bounds of dam intakes. Solid lines represent dissolved oxygen (mg/L).



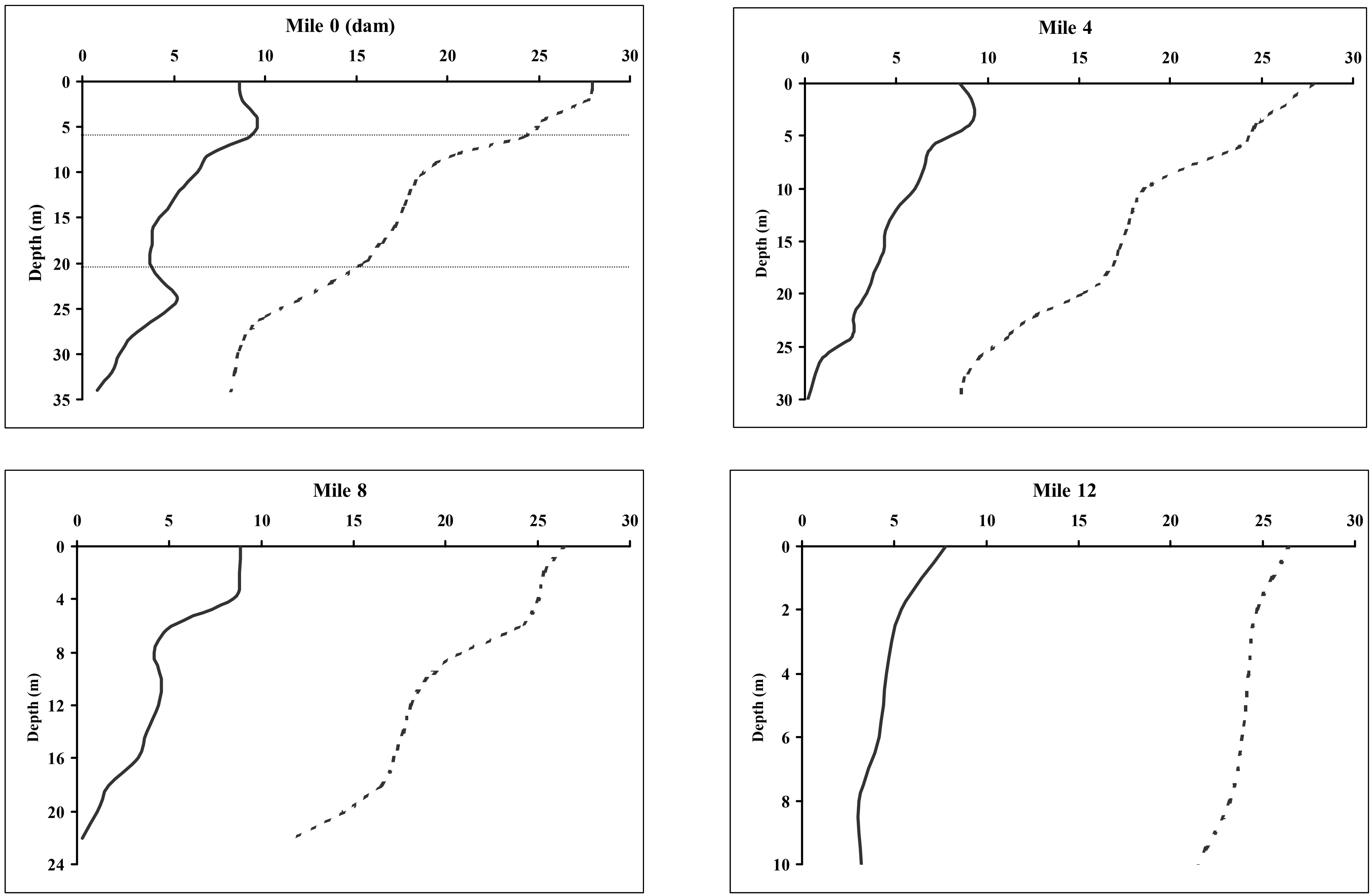
Claytor Lake Profiles, March 2002. Vertical dashed lines represent temperature (°C) and (for mile 0 profile) horizontal dashed lines represent upper and lower bounds of dam intakes. Solid lines represent dissolved oxygen (mg/L).



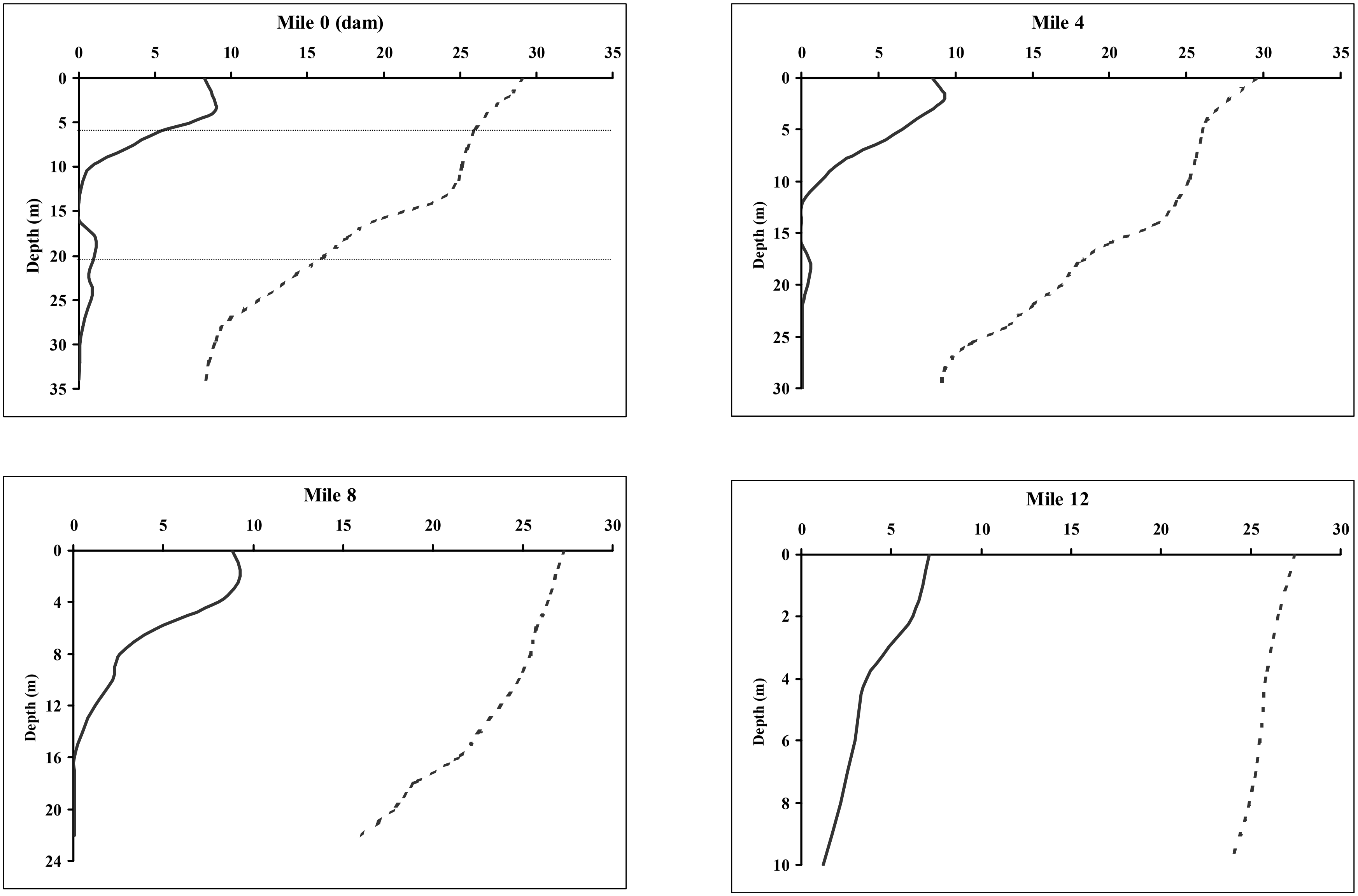
Claytor Lake Profiles, April 2002. Vertical dashed lines represent temperature (°C) and (for mile 0 profile) horizontal dashed lines represent upper and lower bounds of dam intakes. Solid lines represent dissolved oxygen (mg/L).



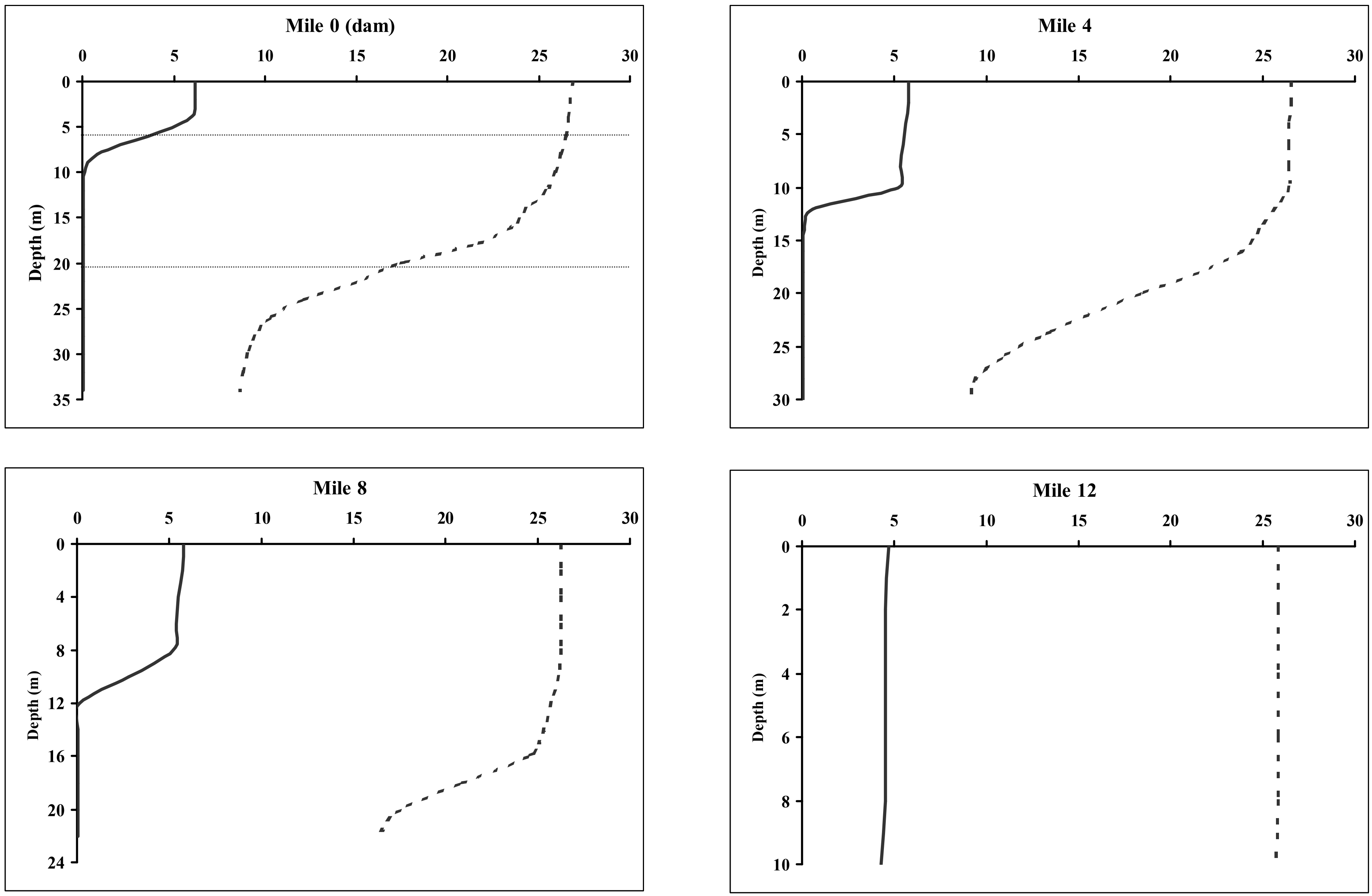
Claytor Lake Profiles, May 2002. Vertical dashed lines represent temperature (°C) and (for mile 0 profile) horizontal dashed lines represent upper and lower bounds of dam intakes. Solid lines represent dissolved oxygen (mg/L).



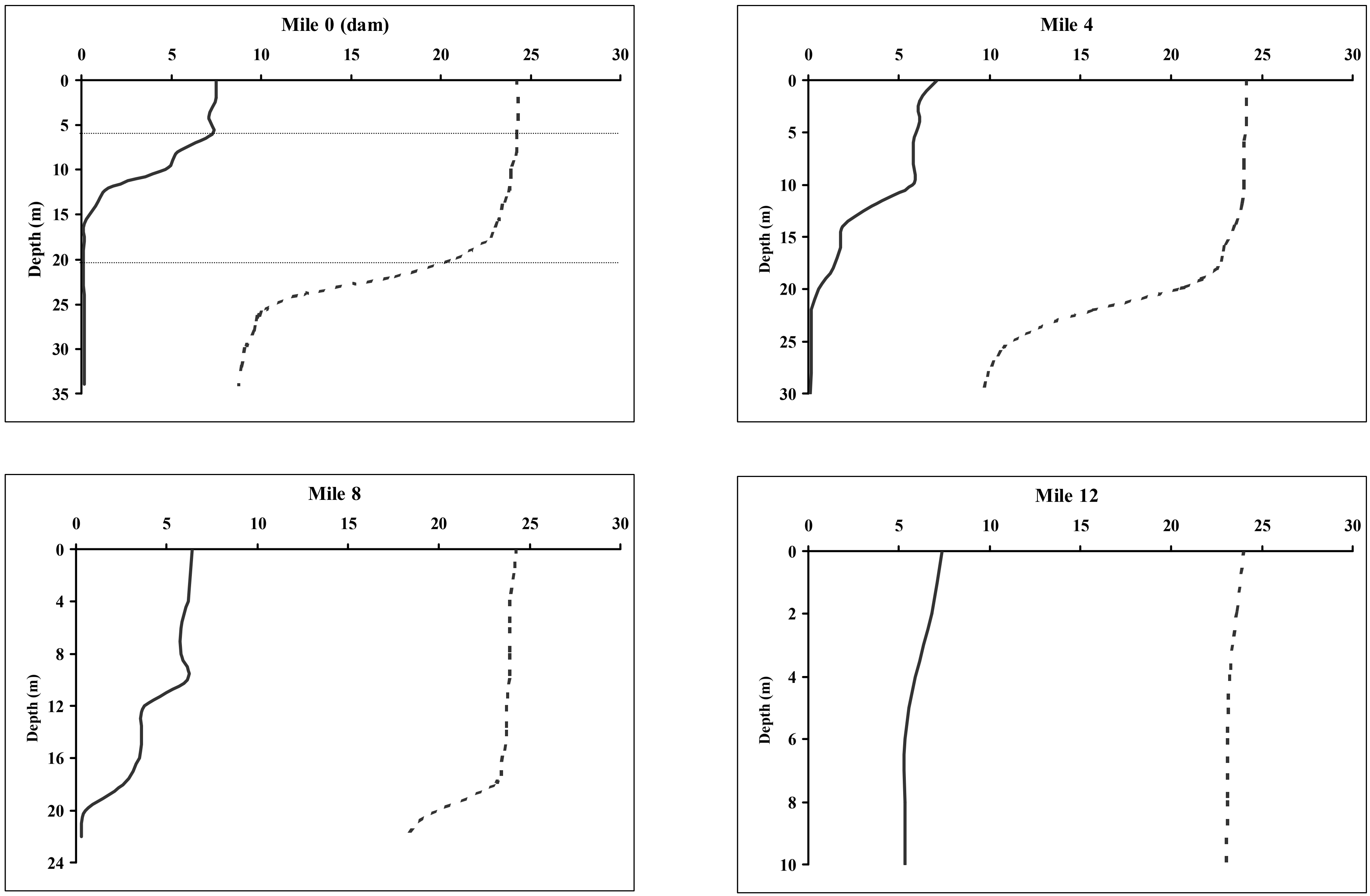
Claytor Lake Profiles, June 2002. Vertical dashed lines represent temperature (°C) and (for mile 0 profile) horizontal dashed lines represent upper and lower bounds of dam intakes. Solid lines represent dissolved oxygen (mg/L).



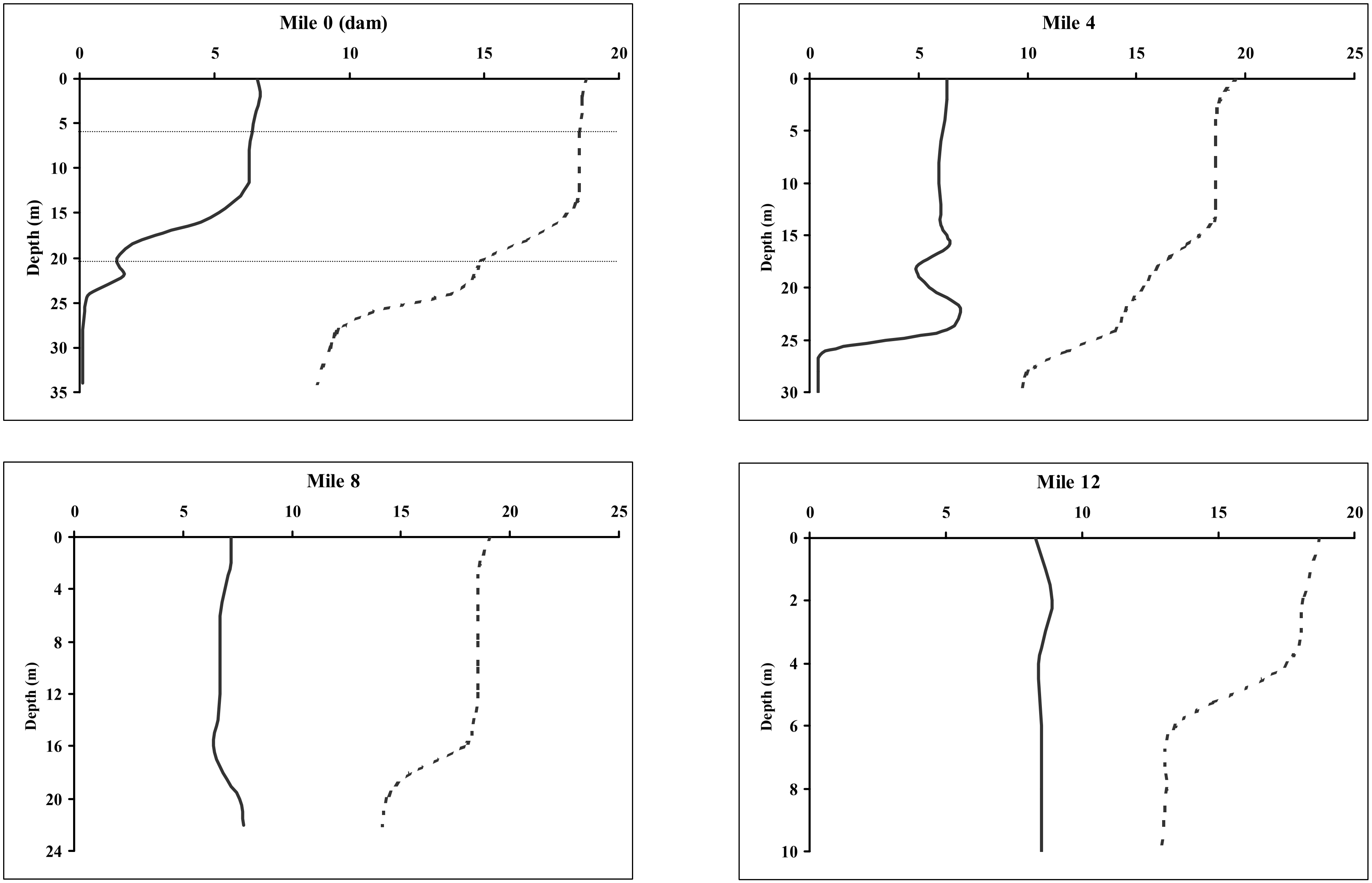
Claytor Lake Profiles, July 2002. Vertical dashed lines represent temperature (°C) and (for mile 0 profile) horizontal dashed lines represent upper and lower bounds of dam intakes. Solid lines represent dissolved oxygen (mg/L).



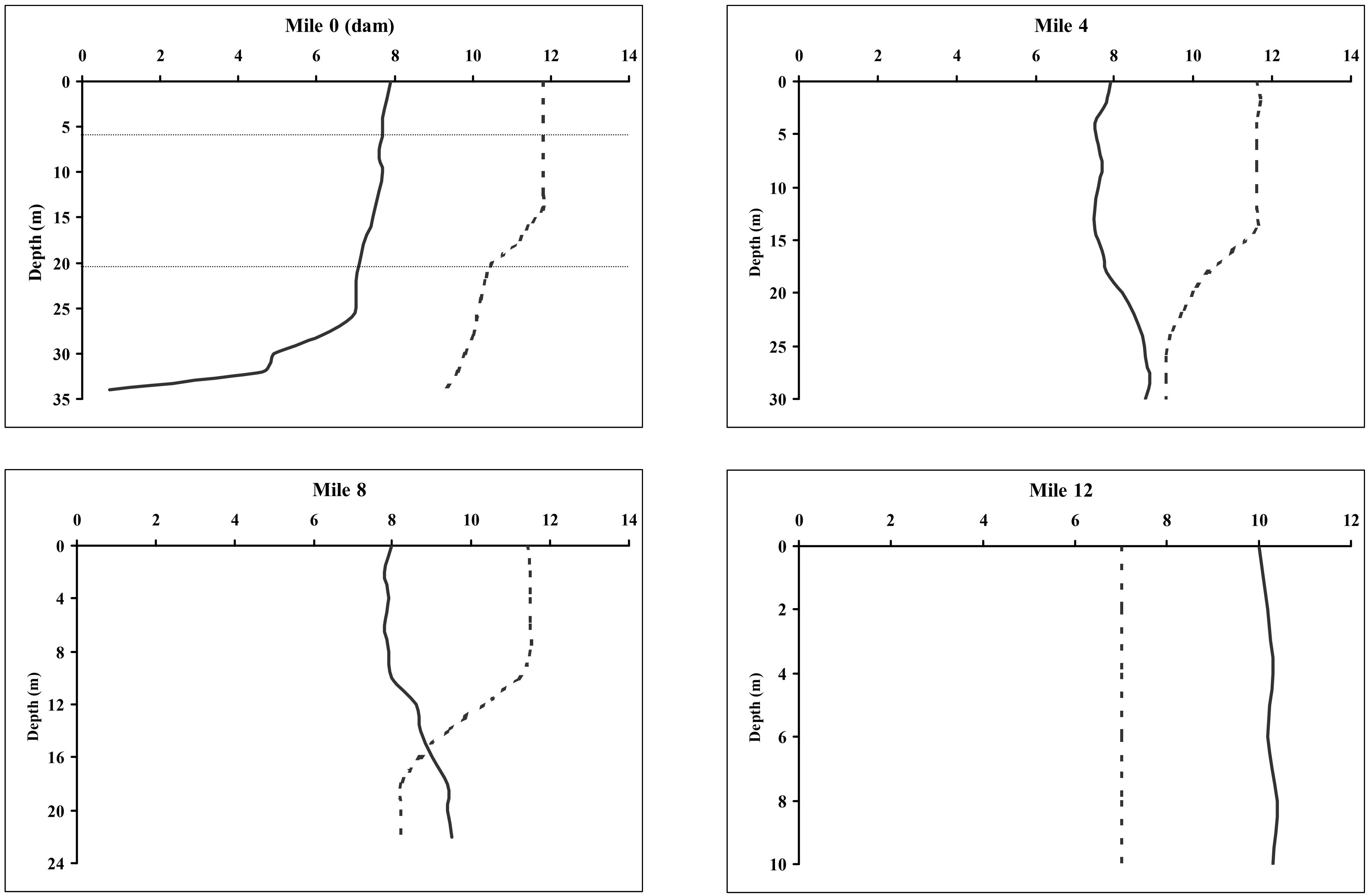
Claytor Lake Profiles, August 2002. Vertical dashed lines represent temperature (°C) and (for mile 0 profile) horizontal dashed lines represent upper and lower bounds of dam intakes. Solid lines represent dissolved oxygen (mg/L).



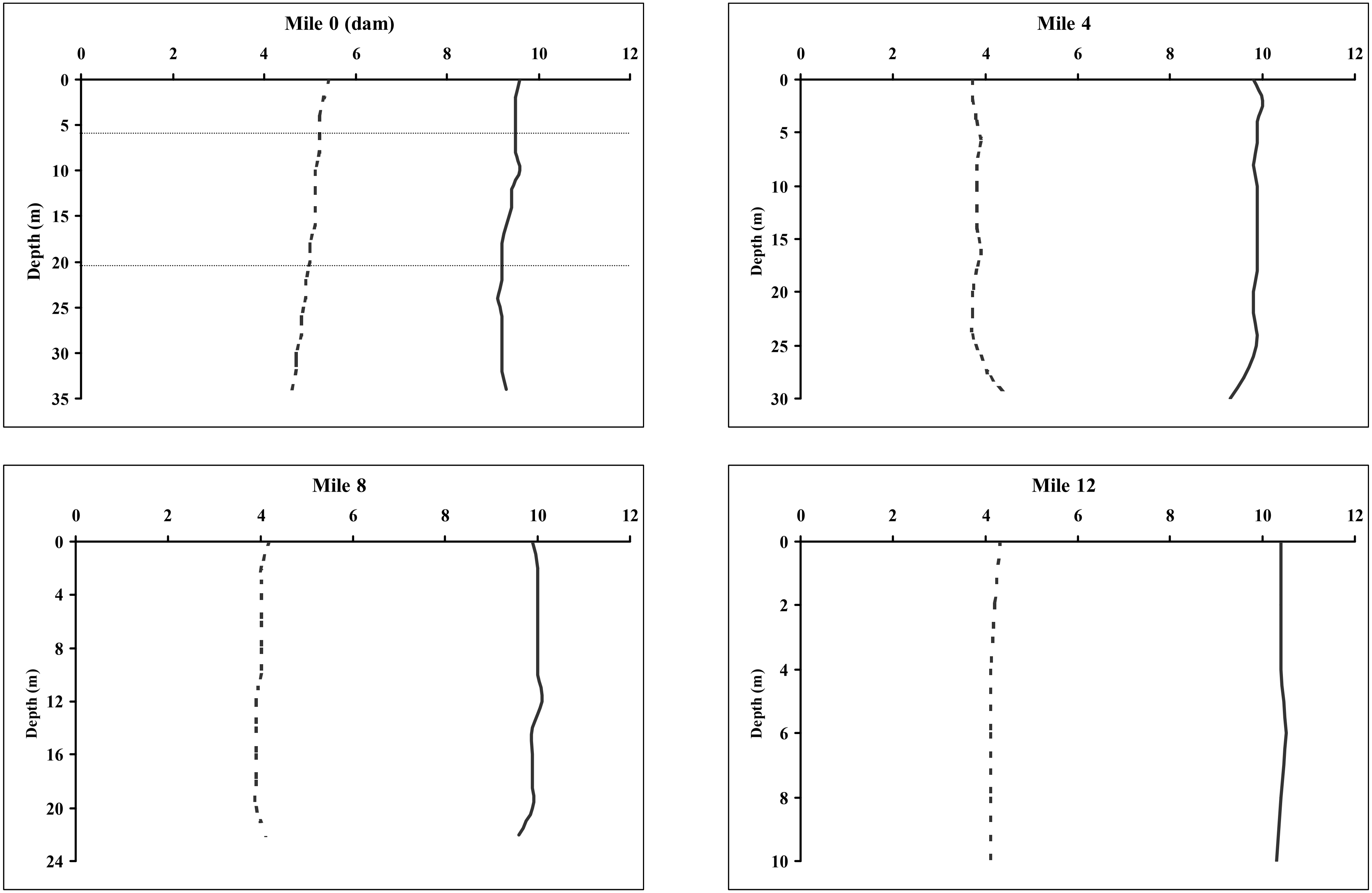
Claytor Lake Profiles, September 2002. Vertical dashed lines represent temperature (°C) and (for mile 0 profile) horizontal dashed lines represent upper and lower bounds of dam intakes. Solid lines represent dissolved oxygen (mg/L).



Claytor Lake Profiles, October 2002. Vertical dashed lines represent temperature (°C) and (for mile 0 profile) horizontal dashed lines represent upper and lower bounds of dam intakes. Solid lines represent dissolved oxygen (mg/L).

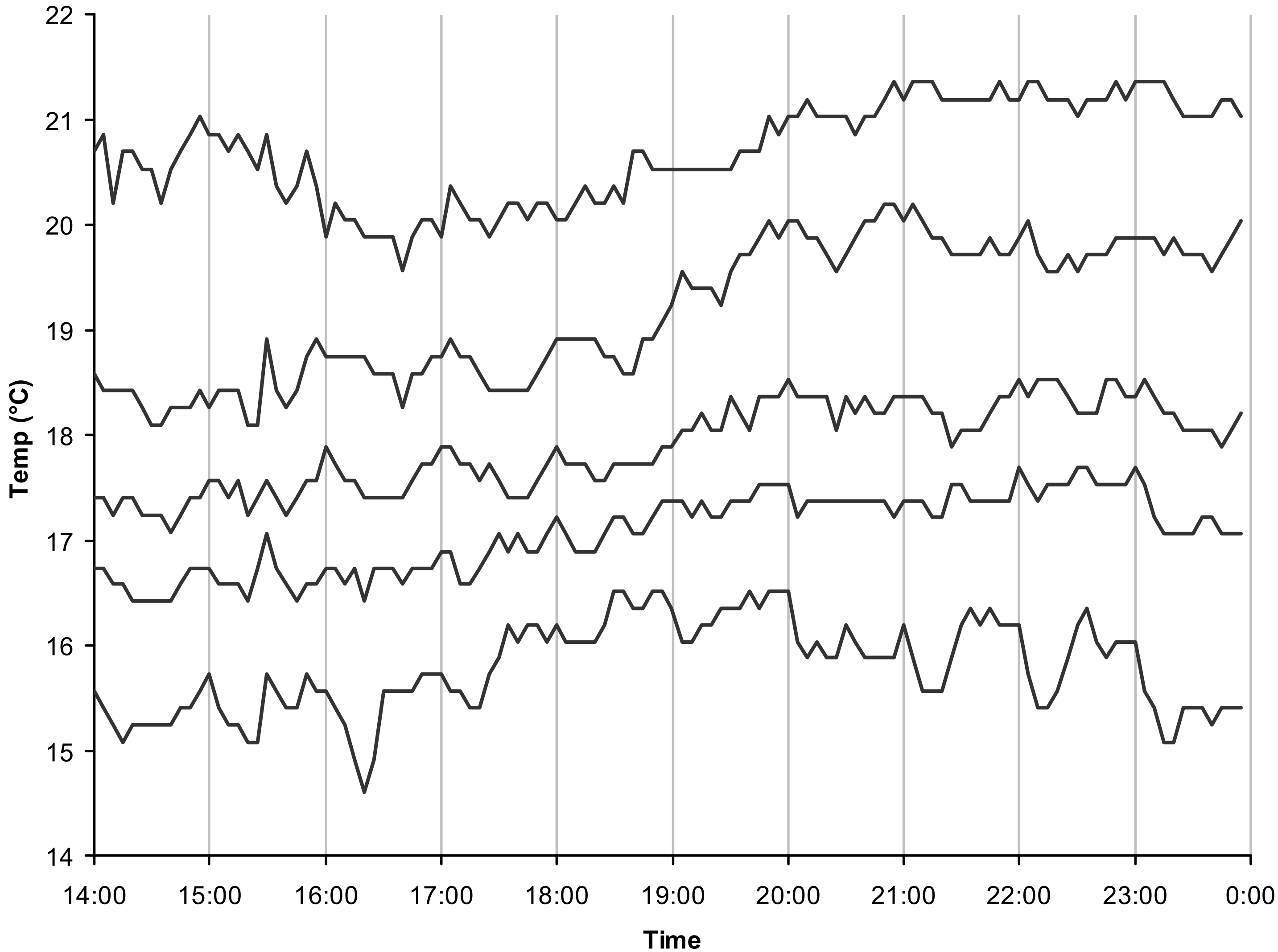


Claytor Lake Profiles, November 2002. Vertical dashed lines represent temperature (°C) and (for mile 0 profile) horizontal dashed lines represent upper and lower bounds of dam intakes. Solid lines represent dissolved oxygen (mg/L).

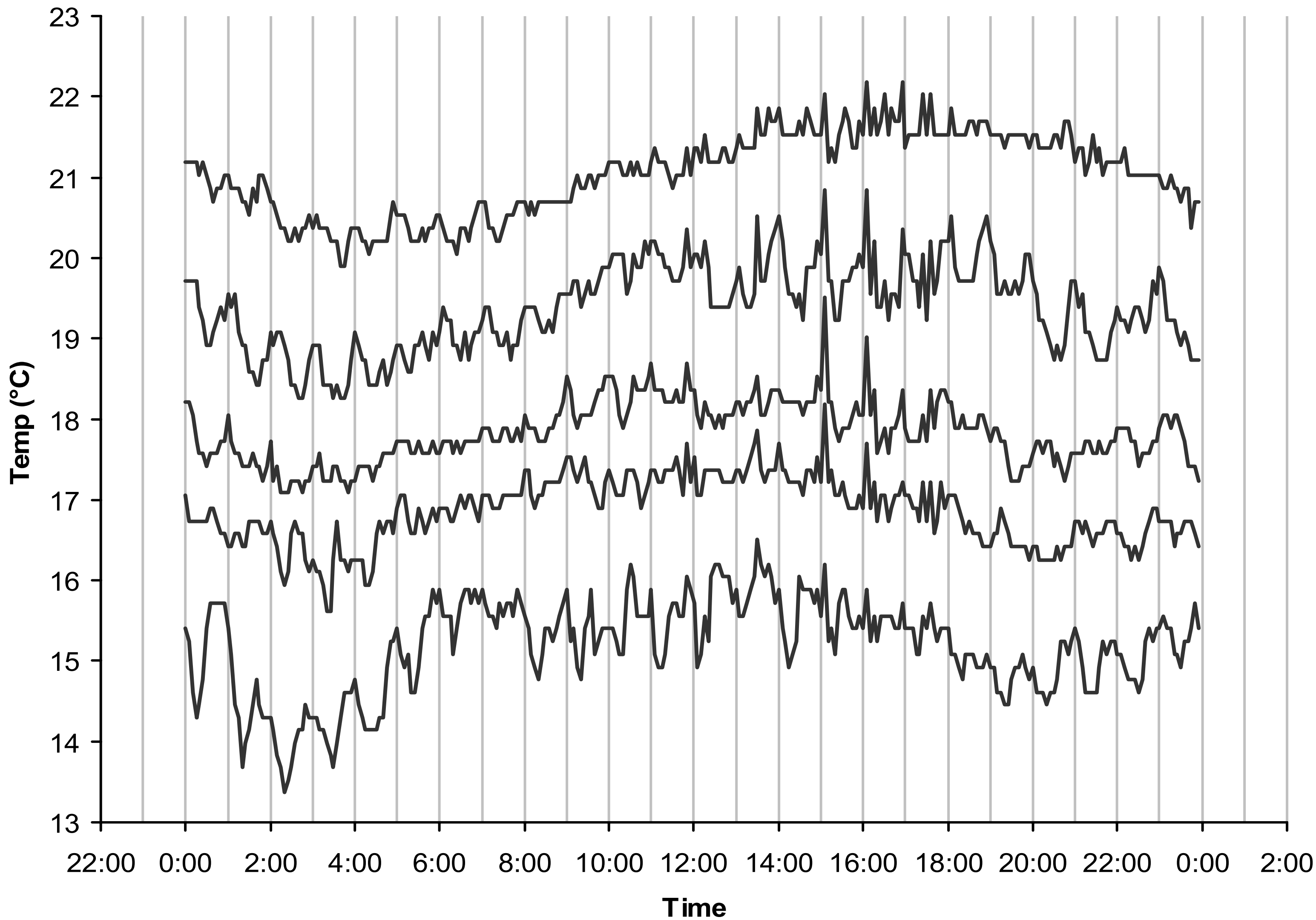


Claytor Lake Profiles, December 2002. Vertical dashed lines represent temperature (°C) and (for mile 0 profile) horizontal dashed lines represent upper and lower bounds of dam intakes. Solid lines represent dissolved oxygen (mg/L).

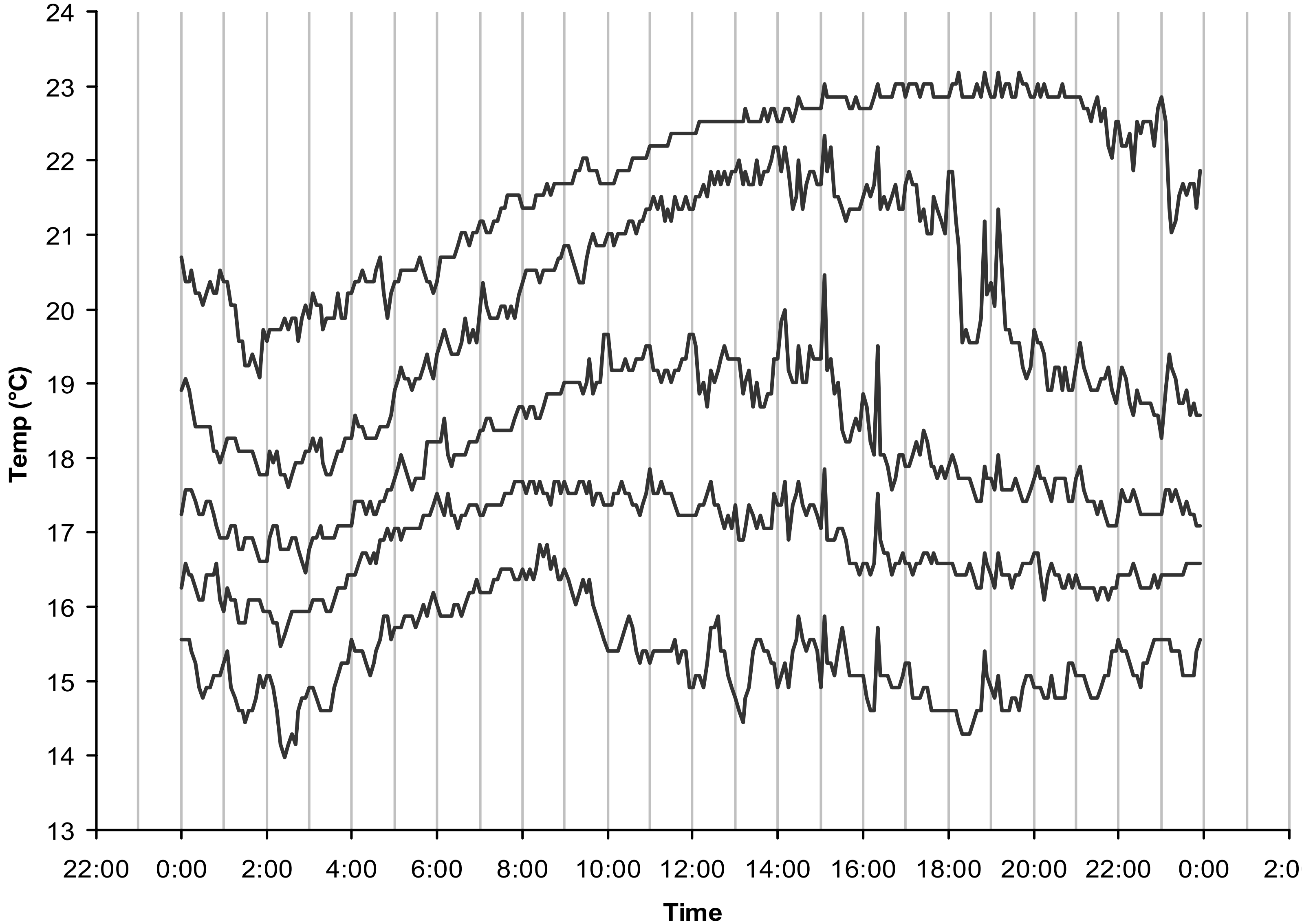
Appendix 5. Temperature changes with dam operation.



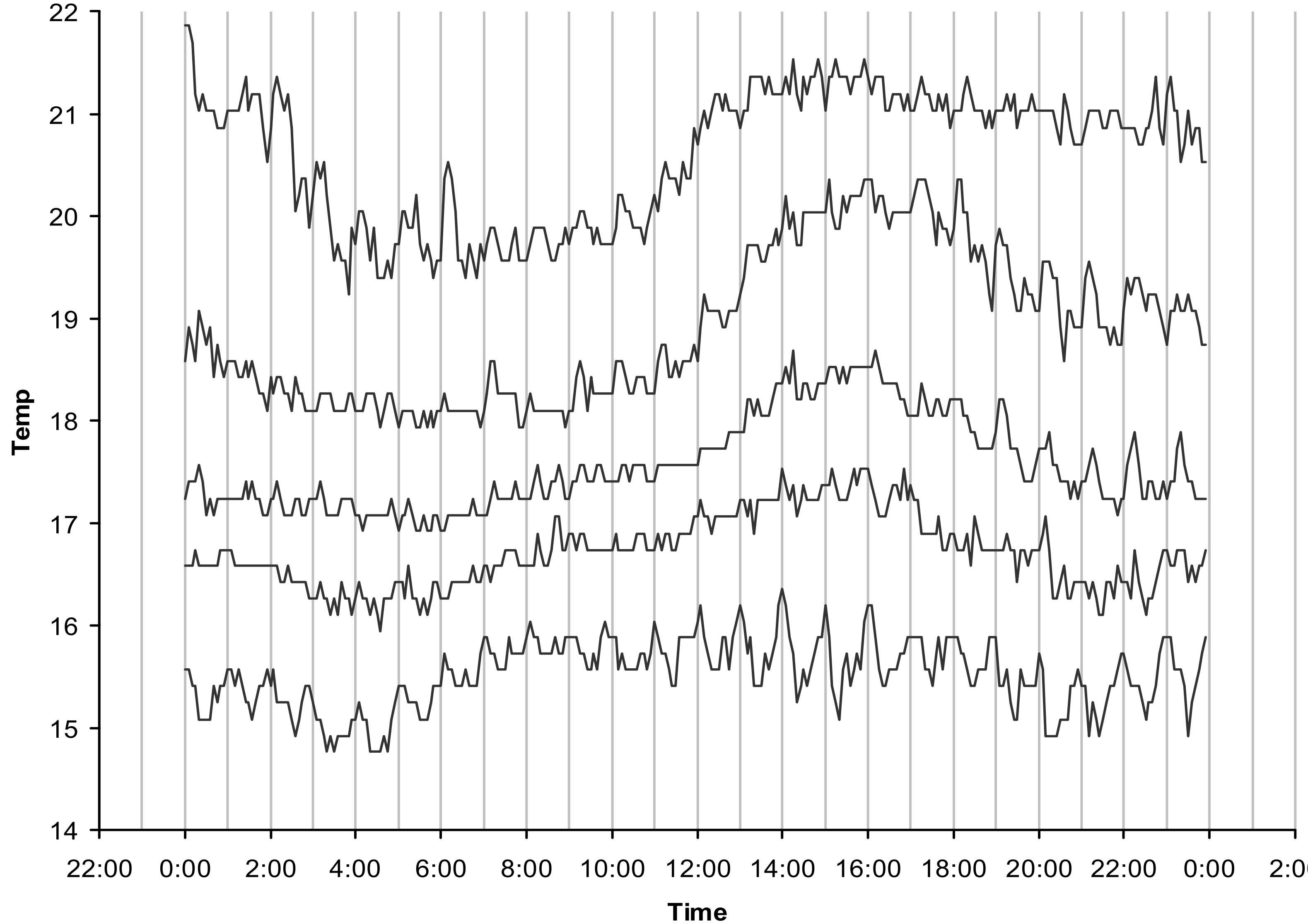
Temperature profiles from Claytor Lake, 8-5-02 at 1-m intervals, 15-19 m. Vertical bars represent start times for power generation. Each generation cycle consisted of 21 minutes of water release, beginning at the top of each hour, followed by 39 minutes of no water release.



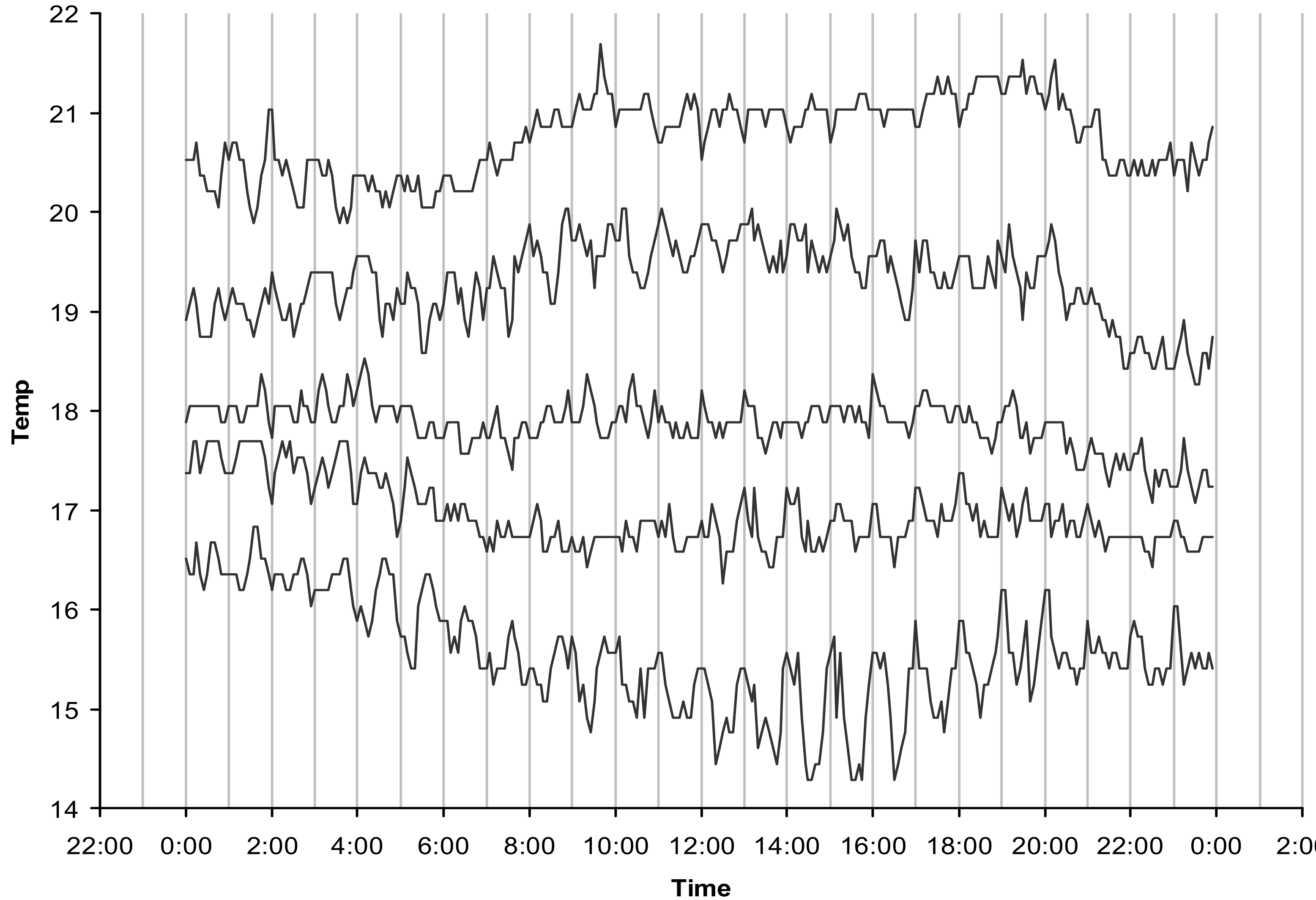
Temperature profiles from Claytor Lake, 8-6-02 at 1-m intervals, 15-19 m. Vertical bars represent start times for power generation. Each generation cycle consisted of 21 minutes of water release, beginning at the top of each hour, followed by 39 minutes of no water release.



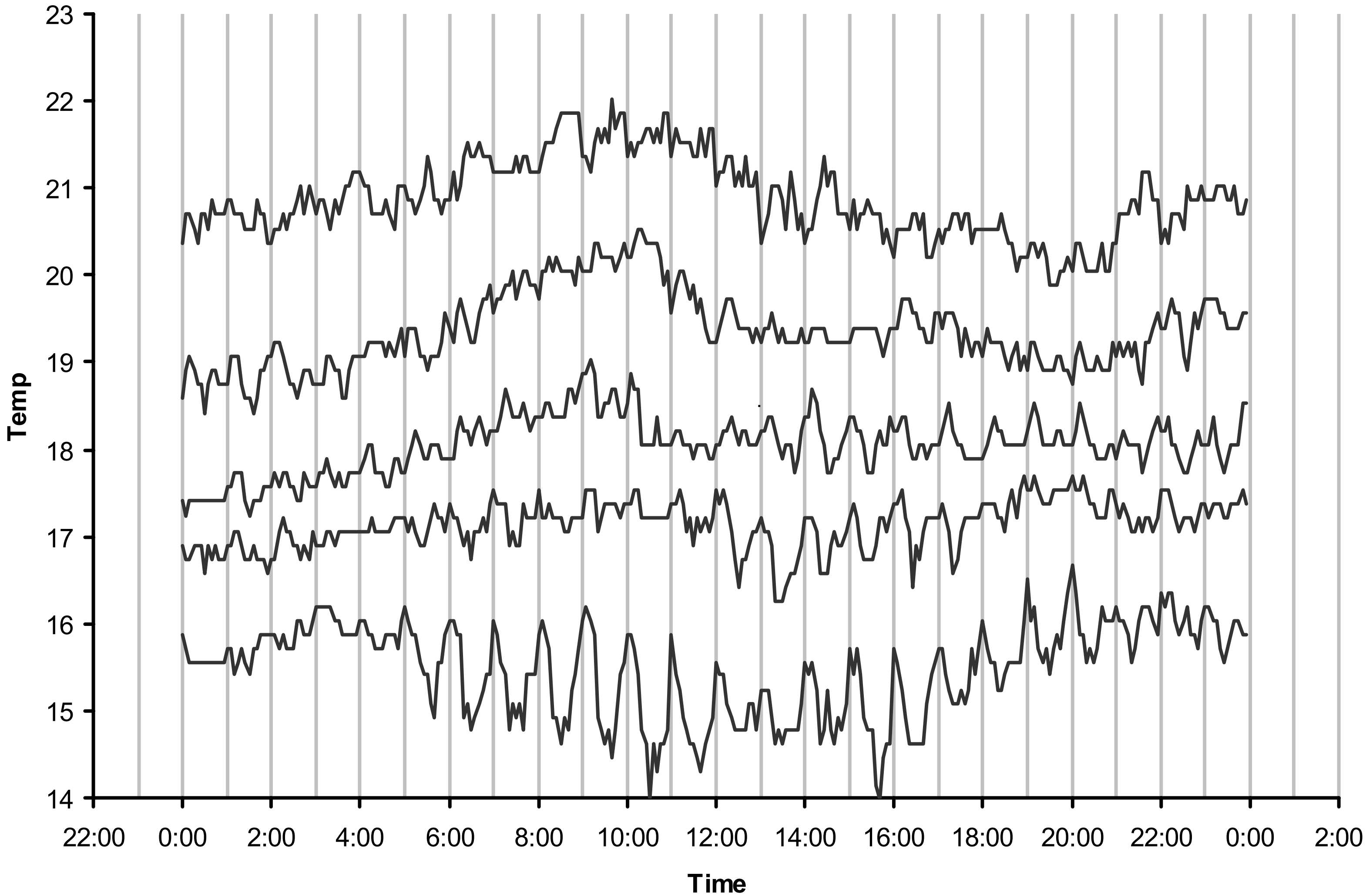
Temperature profiles from Claytor Lake, 8-7-02 at 1-m intervals, 15-19 m. Vertical bars represent start times for power generation. Each generation cycle consisted of 21 minutes of water release, beginning at the top of each hour, followed by 39 minutes of no water release.



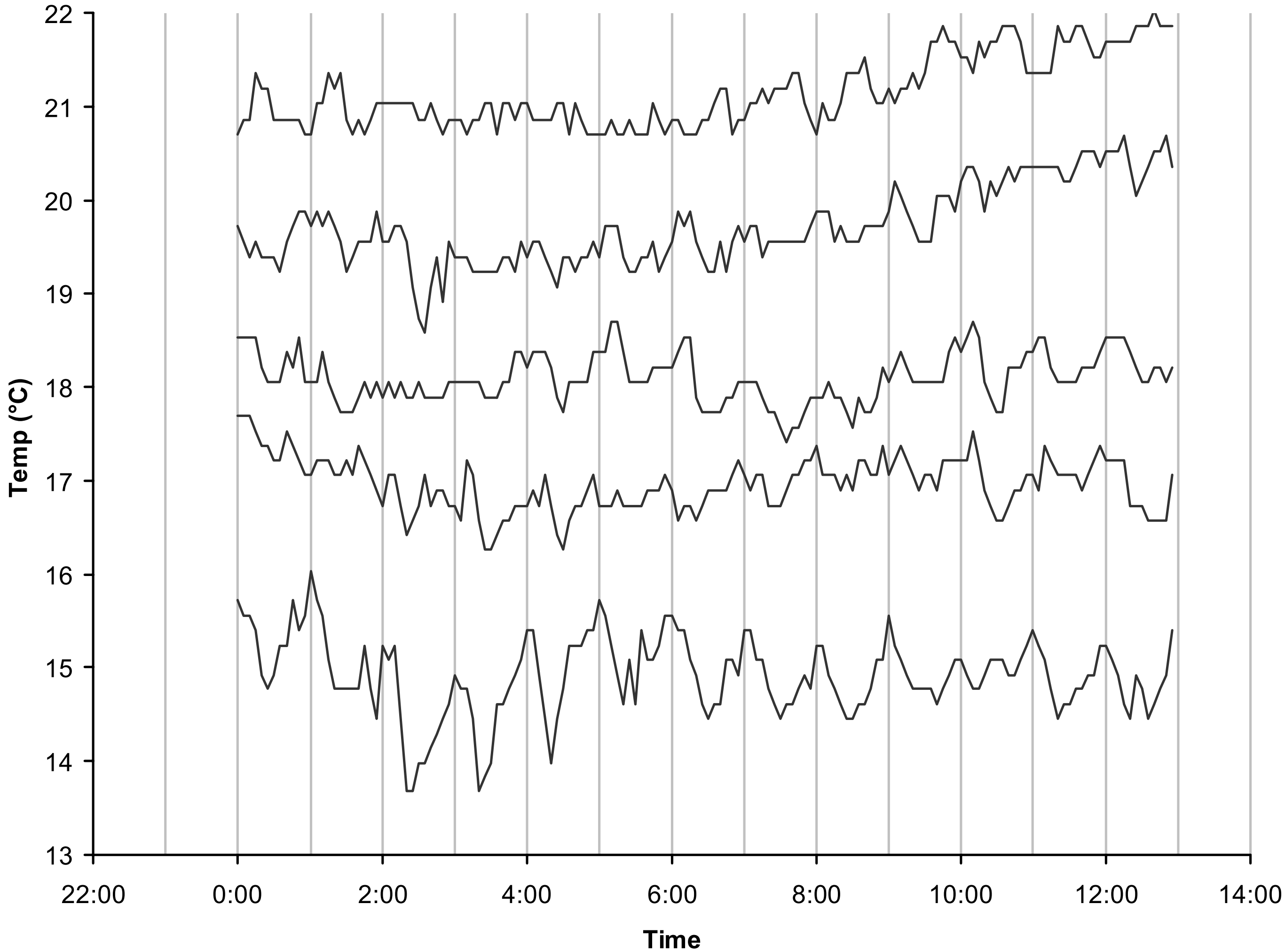
Temperature profiles from Claytor Lake, 8-8-02 at 1-m intervals, 15-19 m. Vertical bars represent start times for power generation. Each generation cycle consisted of 21 minutes of water release, beginning at the top of each hour, followed by 39 minutes of no water release.



Temperature profiles from Claytor Lake, 8-10-02 at 1-m intervals, 15-19 m. Vertical bars represent start times for power generation. Each generation cycle consisted of 21 minutes of water release, beginning at the top of each hour, followed by 39 minutes of no water release.



Temperature profiles from Claytor Lake, 8-11-02 at 1-m intervals, 15-19 m. Vertical bars represent start times for power generation. Each generation cycle consisted of 21 minutes of water release, beginning at the top of each hour, followed by 39 minutes of no water release.



Temperature profiles from Claytor Lake, 8-12-02 at 1-m intervals, 15-19 m. Vertical bars represent start times for power generation. Each generation cycle consisted of 21 minutes of water release, beginning at the top of each hour, followed by 39 minutes of no water release.

VITA

John Matthews Kilpatrick was born on April 16, 1970 in St. Louis, Missouri. His love for fishing and the aquatic world was developed by fishing in Missouri ponds, streams, and reservoirs. In 1988, John graduated from Kirkwood High School, and began his apprenticeship with the Carpenters' Disctrict Council in St. Louis, Missouri. He joined the United States Navy in 1992, and served as a Machinist Mate until December, 1998. He completed his B.S. degree from Ball State University in 2000, graduating Summa Cum Laude in Aquatic Biology and Fisheries. In June of 2000, he entered the graduate program at Virginia Polytechnic Institute and State University to complete his M.S. in Fisheries Science. During his tenure at VPI&SU, he served as both a Teachers Assistant and Research Assistant studying the comparative ecology of stocked striped bass and hybrid striped in Claytor Lake, Virginia. John took a position with the Nebraska Game and Parks Commission in May 2003.

John M. Kilpatrick