Seasonal Condition of Adult Striped Bass Relative to Thermal Habitat and Forage Availability

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Abstract: Adult striped bass (*Morone saxitilis*) are vulnerable to high summer water temperatures and low dissolved oxygen (DO) in southern reservoirs, potentially resulting in poor body condition and elevated mortality. In Lake Buchanan, Texas, mean relative weights for striped bass >500 mm ranged from 77 to 84 from 2002–2007 in spring surveys when relative weight should be maximized. Two hypotheses were tested that could explain the observed poor condition of Lake Buchanan adult striped bass in spring: (1) lack of available prey, or (2) lack of suitable habitat during the previous summer. Striped bass condition was monitored monthly from August 2007 to March 2008 and additionally in October 2008 and February 2009. Sampling of vertical and horizontal forage distributions was conducted concurrently from September 2007 to March 2008. Mean striped bass relative weights increased from 68 in August 2007 to 91 in March 2008, an increase of 0.12 Wr/d; in contrast, vertical and horizontal forage distributions in the reservoir did not vary seasonally. Additional sampling in October 2008 and February 2009 corroborated this seasonal trend in condition as mean relative weights were 74 and 81 respectively. Lake Buchanan experienced prolonged periods (>2 mo) during summer when no preferred thermal habitat existed for striped bass. Low spring condition of adult striped bass in Lake Buchanan was likely due to a hold-over effect of stress caused by a lack of preferred thermal habitat (i.e., temperature <25 C and dissolved oxygen >2 mg L^{-1}) during the previous summer. For reservoirs with warmer summer temperatures or more extended warm water periods, maintaining quality striped bass fisheries may not be possible and management alternatives such as stocking the more temperature-tolerant hybrid striped bass may be preferable.

Key words: summer squeeze, reservoir, spatial distribution

Proc. Annu. Conf. Southeast. Assoc. Fish and Wildl. Agencies 66:69–74

Striped bass (*Morone saxatilis*) provide popular recreational fishing opportunities in many Texas reservoirs. Most of these are put-grow-take fisheries maintained by the Texas Parks and Wildlife Department (TPWD) through periodic stocking. Little is known about these striped bass populations, aside from the numbers stocked and limited assessments of condition and growth from standard management surveys. Striped bass are usually sampled in these reservoirs by TPWD biologists using gill nets in February and March, when water temperature and dissolved oxygen (DO) are well within the fundamental thermal niche for adult striped bass (Bettoli 2005). However, poor striped bass condition is commonly observed during spring surveys of Texas reservoirs (TPWD, unpublished data). Understanding the cause of poor springtime condition of striped bass in Texas reservoirs would allow fishery managers to select management strategies to enhance these popular fisheries.

I examined two alternative hypotheses to explain poor condition of adult striped bass in Lake Buchanan, Texas. First, limited pelagic forage availability could lead to chronic poor condition of pelagic predators including striped bass. In Lake Buchanan, striped bass may compete with abundant white bass (*Morone chrysops*), hybrid striped bass (*M. chrysops* × *M. saxatilis*), and blue catfish (*Ictalurus furcatus*) for a pelagic prey base comprised primarily of gizzard shad (*Dorosoma cepedianum*) and threadfin shad (*Dorosoma petenense*). Under this hypothesis, striped bass condition would be expected to be low throughout most of the year, with the poorest condition occurring at the end of winter (or early spring) when much of the current year-class of the forage base has been eliminated due to continual predation.

Alternatively, because large striped bass (i.e. >500 mm total length [TL]) are stressed by high summer water temperatures and low DO (Coutant 1985) causing low condition in summer, low relative weights in spring may be a residual effect of stressful conditions during the previous summer. Striped bass exhibit an ontogenetic shift in temperature tolerance with maximum temperature tolerance declining with increased fish size (Coutant 1985). Coutant (1985) described adult striped bass thermal and DO preferences and suggested that large fish (i.e. >500 mm TL) are limited to waters with temperature < 25 C and DO > 2 mg L^{-1}. In many southern reservoirs, during stratification in summer months, large striped bass are restricted to narrow bands of habitat between warm, oxygenated epilimnetic water and the cooler, anoxic hypolimnion (e.g. Coutant 1985, Matthews et al. 1985, Schaffler et al. 2002, Young and Isely 2002, Thompson et al. 2010). When severe, this restriction or "summer squeeze," can cause mortality and reduce adult striped bass growth and condition in reservoir populations (Matthews 1985, Zale et al. 1990). This summer squeeze could cause poor condition either directly through metabolic processes related to temperature, or indirectly through spatially separating striped bass from prey having differing thermal preferences. The largest impact on striped bass often occurs in late summer (August and September) when water temperatures are highest and DO values are lowest. Under this hypothesis, striped bass condition would be expected to vary seasonally, with the poorest condition occurring in late summer with a gradual recovery and increase in condition over fall and winter when thermal conditions are more favorable.

Differentiating between these two hypotheses is critical to determining appropriate management actions. For example, if prey is limiting, reducing stocking density of striped bass could improve growth and condition, whereas if temperature and DO conditions are limiting, stocking of the more temperature tolerant hybrid striped bass (Woiwode and Adelman 1991) may be preferred. Thus, the goal of this study was to determine whether poor spring condition of adult striped bass was caused by a lack of available prey, or was a hold-over effect of high temperature and low DO conditions in the previous summer related to the summer squeeze. I defined two specific objectives to address these hypotheses: (1) evaluate seasonal body condition (fall to spring) of adult striped bass in Lake Buchanan, and (2) assess seasonal forage availability and water quality (temperature and DO) in Lake Buchanan, and examine relationships between these factors and striped bass body condition.

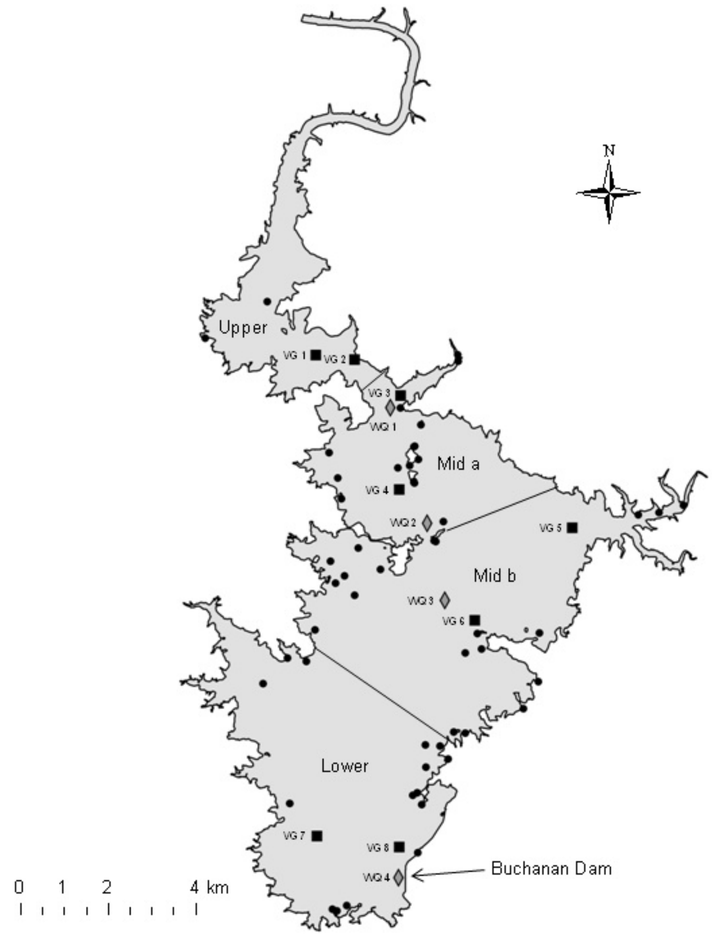

Figure 1. Map of Lake Buchanan depicting capture locations for striped bass (circles), vertical gill net forage survey stations (squares), and water quality stations (diamonds). The reservoir was stratified longitudinally into four zones for forage survey sampling and analyses.

Methods

Study Site

Lake Buchanan is an 8,989-ha impoundment of the Colorado River located in Burnet and Llano counties, Texas. It was constructed in 1937 by the Lower Colorado River Authority (LCRA) for purposes of hydroelectric power, water supply, flood control, and recreation. Due to the multiple-use nature of the reservoir and the variable precipitation patterns of the region, Lake Buchanan experiences substantial water-level fluctuations; water levels ranged from full pool to 7.5 m below full pool over the duration of the study. Striped bass were introduced into the reservoir in 1977 and have generally been stocked annually since then. Mean springtime relative weights for striped bass > 500 mm TL have been consistently low (i.e. < 85) in Lake Buchanan for the past decade (Bonds and Magnelia 2004, Magnelia and De Jesus 2008).

Striped Bass Collection and Analyses

Adult (>500 mm TL) striped bass were collected monthly from Lake Buchanan from August 2007 to March 2008 using experimental gill nets and electrofishing. Gill nets were 38.1 m by 2.4 m, consisted of five panels (25-, 38-, 51-, 64-, and 76-mm bar mesh), and were fished in overnight sets. Electrofishing was conducted during daylight with a boom-mounted electrofishing boat using a Smith-Root 7.5 generator-powered pulsator. Sampling and collection of striped bass were spread broadly throughout the reservoir each year (Figure 1). All February samples were from standard TPWD spring gill net surveys and sampling locations were randomly selected throughout the reservoir. Sampling locations for monthly samples from August 2007 to March 2008 were more haphazardly distributed to target striped bass based on habitat characteristics and areas where striped bass were found in previous months. Because few striped bass were collected in August and September with gill nets or electrofishing, additional length and weight data were acquired from fish caught by anglers. All striped bass were weighed (g) and measured (TL, mm). Additionally, a sample of striped bass was collected via electrofishing in October 2008 for comparison with the February 2009 gill-net sample to determine whether the observed seasonal pattern in fish condition was consistent among years.

Striped bass condition was quantified using relative weight (Wr; Brown and Murphy 1991). Relative weights of individual fish were plotted against capture date to examine seasonal patterns. Linear regression was applied to individual fish relative weights by date to quantify the seasonal trend from fall 2007 to spring 2008. Fall (October) 2008 and spring (February) 2009 samples were compared using a two-sample *t*-test. Relative weight differences among years for TPWD standard February gill-net samples and among months for 2007 through 2008 collections were tested using ANOVA and means compared following Tukey's adjustment for multiple comparisons (SAS Institute 2010).

Forage Fish Collection and Analyses

Vertical gill nets were deployed monthly from September 2007 to March 2008 to sample available forage concurrent with striped bass sampling. Eight fixed locations (Figure 1) were sampled monthly with 12.5-mm and 19-mm bar mesh nets (2 m by 20 m) to sample young-of-the-year (YOY) and age-1 threadfin shad and gizzard shad (Van Den Avyle et al. 1995a, 1995b). Hartman (2000) found that prey sizes of 7%–18% of striped bass length yielded the greatest bioenergetic value, indicating YOY and juvenile shad (*Dorosoma* spp.) were suitable forage for striped bass in Lake Buchanan. Fixed vertical gill-net sampling sites were stratified longitudinally through the reservoir from the upper reservoir to near the dam with two random sites selected to represent each stratum (Figure 1). Fish depth was recorded, in 2-m intervals, for all fish collected and when combined with longitudinal locations, provided a coarse three-dimensional description of forage distributions throughout the reservoir. Differences in shad CPUE among area, depth, month, and associated interactions were tested using repeated measures ANOVA and comparisons among means made after Tukey adjustment for multiple comparisons (SAS Institute 2010).

Water Quality

Seasonal availability of preferred adult striped bass habitat was examined using vertical temperature and DO profiles. Semimonthly (i.e., every 2 mo) temperature and DO profile data were obtained from the LCRA (http://waterquality.lcra.org/) at four locations (Figure 1) located along the longitudinal gradient of the reservoir. Suitable habitat for adult striped bass was defined as water with temperature <25 C and DO >2 mg L^{-1} based on values reported by Coutant (1985).

Results

A total of 524 striped bass were collected from Lake Buchanan over the course of the study, ranging in length from 500 to 865 mm TL (mean = 589 mm TL). Relative weights of 260 adult striped bass were obtained from standard TPWD February gill net surveys from 2002 to 2009 (Table 1), and monthly sampling between August 2007 and February 2009 yielded an additional 264 striped bass relative weights (Table 2).

Table 1. Sample size, mean TL (mm), and mean relative weight (Wr) of striped bass by month from TPWD February gillnet samples 2002–2009. Mean relative weight values followed by the same letter were not statistically different ($P \geq 0.05$).

Month	n	Mean TL (range)	Mean Wr (SE)
Feb 2002	47	573 (509–774)	83.7 (0.99) b
Feb 2004	27	606 (525–718)	79.6 (1.52) ab
Feb 2006	59	605 (516–835)	81.5 (0.94) ab
Feb 2007	62	601 (528–865)	77.3 (1.19) a
Feb 2008	33	576 (500–792)	93.9 (1.55) c
Feb 2009	32	609 (510–815)	81.2 (1.89) ab

Table 2. Sample size, mean TL (mm), and mean relative weight (Wr) of striped bass by month from August 2007 to February 2009. Within August 2007 to March 2008, monthly relative weight values followed by the same letter were not statistically different ($P \geq 0.05$).

Month	n	Mean TL (Range)	Mean Wr (SE)
Aug 2007	3	539 (509–580)	68.3 (5.43) ab
Sep 2007	18	574 (533–635)	70.2 (2.43) b
Oct 2007	57	567 (500–745)	75.4 (1.46) b
Nov 2007	19	583 (529–682)	73.0 (1.74) b
Dec 2007	62	580 (508–699)	75.6 (1.31) b
Jan 2008	33	602 (552–663)	85.6 (1.71) ac
Feb 2008	33	576 (500–792)	93.9 (1.55) d
Mar 2008	30	612 (525–740)	91.1 (1.52) cd
Oct 2008	42	585 (503–670)	74.1 (1.22)
Feb 2009	32	609 (510–815)	81.2 (1.89)

Mean relative weights of adult striped bass in standard TPWD February samples were generally low from 2002–2009 (Table 1). The exception was February 2008, when mean relative weight (94) was the highest recorded during the study. From fall 2007 to spring 2008 adult striped bass condition increased from a mean of 68 in August 2007 to a mean of 91 in March, which conferred a daily increase in relative weight of 0.12 Wr d^{-1} ($r^2 = 0.37$, $P < 0.01$; Figure 2). Further testing based on monthly means indicated relative weights in January–March 2008 were significantly higher than those in summer and fall 2007 (Table 2). Mean relative weight of striped bass collected in October 2008 was 74, a 19% decline from March 2008; whereas, mean relative weight in February 2009 increased to 81 and was significantly different from mean relative weight in October 2008 ($t = 2.92$; $P < 0.01$).

Shad were found throughout the water column at all oxygenated depths sampled from September 2007 to March 2008. Shad CPUE varied among reservoir areas ($F = 5.38$, df = 3,120, $P = 0.002$),

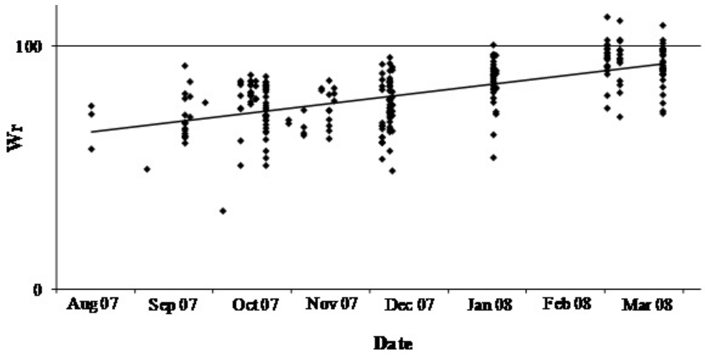

Figure 2. Relative weights (Wr) of striped bass (> 500 mm) collected from Lake Buchanan, Texas, from August 2007 to March 2008. The fitted regression line represents the increasing trend of 0.12 Wr d^{-1} ($r^2 = 0.37$, $P < 0.01$) from fall 2007 to spring 2008.

Table 3. Catch per unit effort of *Dorosoma* spp. (fish per 4 m^2 net panel) September 2007 through March 2008. Mean CPUE values followed by the same letter were not statistically different based on repeated measures ANOVA ($P \geq 0.05$).

	Upper	Mid a	Mid b	Lower	Mean
Sep 2007	17.05	14.50	9.53	0.05	10.28 b
Oct 2007	4.67	9.82	3.09	0.75	4.58 a
Nov 2007	3.11	4.95	3.41	1.19	3.17 a
Dec 2007	5.61	4.21	2.57	1.62	3.50 a
Jan 2008	3.56	1.63	1.82	1.19	2.05 a
Feb 2008	3.11	5.41	4.87	1.42	3.70 a
Mar 2008	26.83	16.05	4.77	0.42	12.02 b
Mean	9.13 y	8.08 y	4.29 yz	0.95 z	

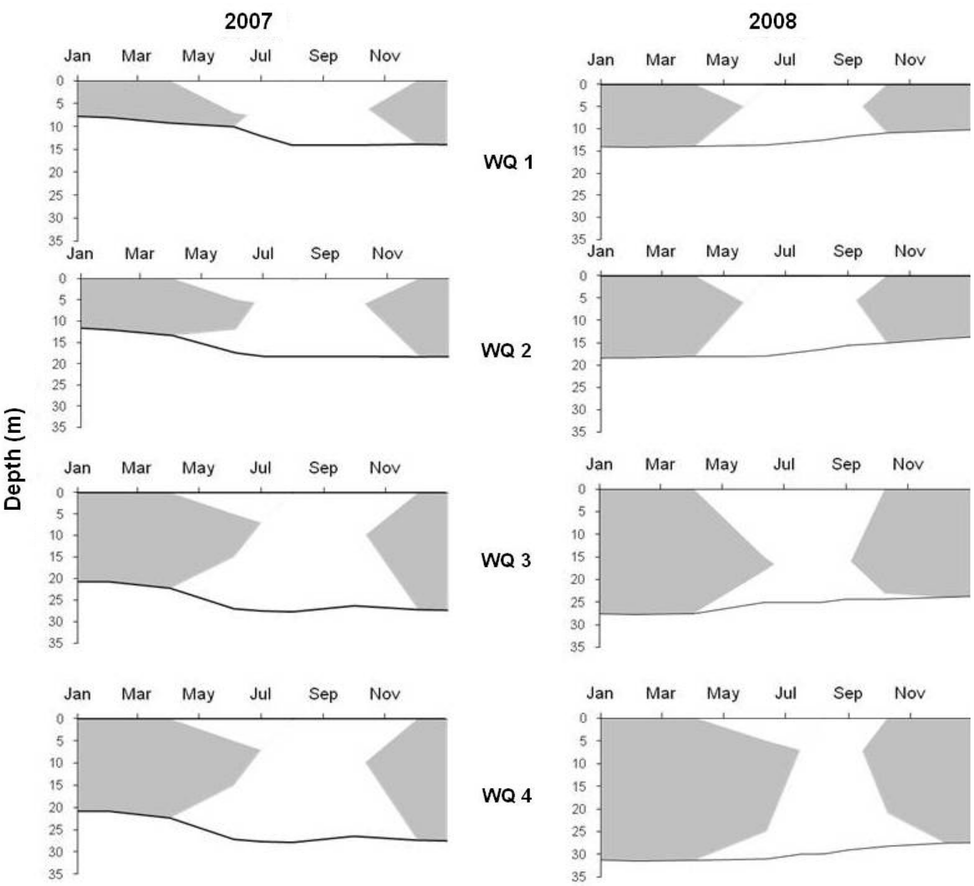

Figure 3. Preferred habitat for striped bass (shaded area; defined by temperature <25 C and dissolved oxygen >2 mg L^{-1}) estimated using semi-monthly profiles for 2007 and 2008. The bottom line represents reservoir depth which increased with filling in 2007 and declined through 2008 as water levels receded.

months ($F = 9.33$; df = 6, 626; $P < 0.001$), and the area × month interaction ($F = 3.29$, df = 18, 626, $P < 0.001$). Shad CPUE was similar in the upper and middle zones, and higher than the lower zone (Table 3). Also, shad CPUE was significantly higher in September 2007 and March 2008 than the other months. The interaction between month and reservoir zone was driven primarily by high catches in September 2007 and March 2008 in the upper two zones relative to the lower zone Table 3).

Preferred habitat for striped bass was low or absent from the reservoirs in both summers, from late June to mid-October 2007 and from July to September in 2008 (Figure 3). During these periods, there was no available striped bass habitat within Lake Buchanan and the coolest available water with adequate DO by the first week of August was 26.5 to 27 C in both years. Also, habitat restriction began in April in both years, with the shallower upper reservoir warming first and subsequently limiting striped bass to middle or lower reservoir habitats. The poorest habitat quality corresponded directly with the poorest striped bass condition in August and September (Table 2).

Discussion

Poor spring condition of adult striped bass in Lake Buchanan appeared to be related to the summer squeeze more than low forage availability. Relative weights of adult striped bass were lowest in late summer and highest in early spring. Concurrent with low relative weights, preferred habitat for adult striped bass was absent in the reservoir during summers 2007 and 2008. In the absence of preferred thermal habitat, striped bass often concentrate in the coolest water available with adequate DO (i.e. >2 mg L^{-1}; Farquhar and Gutreuter 1989, Matthews et al. 1989, Zale et al. 1990). Poor condition of striped bass in summer may be explained by the separation of striped bass from their available prey due to differing thermal preferences and the confinement of striped bass to deeper cooler waters (Farquhar and Gutreuter 1989). In Lake Buchanan, forage was available throughout the reservoir at all oxygenated depths, with the exception of the area near the dam, and there was no evidence that striped bass were concentrated near the dam while the lake was stratified. But, because the precise location of striped bass during August and September was unknown due to low catch rates, indirect effects of spatial segregation from forage cannot be ruled out as a contributor to poor condition in summer. Regardless, because temperatures were similar at the thermocline throughout the reservoir in summer months, spatial segregation of striped bass from their prey appears unlikely. These results suggest a direct effect of temperature and DO stress during summer as the likely cause of low relative weights in Lake Buchanan striped bass.

Several authors have reported that extended periods of water temperatures >25 C have caused fish kills in striped bass populations throughout the southeastern United States (e.g., Coutant 1985, Matthews 1985, Zale et al. 1990). In systems where summer temperatures are >25 C, striped bass have been found to congregate in thermal refuges where groundwater flows maintain local conditions more favorable to adult striped bass (Moss 1985, Van Den Avyle and Evans 1990, Weeks and Van Den Avyle 1998). Such thermal refuges have not been identified in Lake Buchanan. Recently, Thompson et al. (2010) proposed alternative thermal selection criteria for striped bass when no thermal refuges are available. Using telemetry, they determined that striped bass in Badin Lake, North Carolina, selected depths near the oxycline during summer. Thompson et al. (2010) included sub-adult fish (<500 mm) in their study which could explain why, contrary to my results, they did not find evidence of thermal stress on fish condition. Striped bass relative weights in Badin Lake did not vary seasonally, even though fish occupied temperatures >27 C during the summer (Thompson et al. 2010).

Lake Buchanan summer temperatures are near the thermal limit for striped bass. Located in central Texas, Lake Buchanan could be considered typical of other Texas reservoirs where striped bass are stocked. Zale et al. (1990) found that summer mortality of striped bass occurred when minimum oxygenated water temperatures remained above 27 C for periods longer than one month in Keystone Reservoir, Oklahoma. Similarly, Van Horn et al. (1998) found that adult striped bass in Lake Norman, North Carolina, could tolerate temperatures up to 28 C for short periods (<4 weeks). Minimum oxygenated temperatures in Lake Buchanan were greater than 27 C for more than a month in both 2007 and 2008. Though fish kills have not been reported in Lake Buchanan, this population appears vulnerable to mortality events based on summer thermal conditions.

The February 2008 mean relative weight of 94 was significantly higher than any other February collection from 2002–2009. Hydrologically, 2007 was not a typical year for Lake Buchanan, with the lake at near historic low water levels in spring and rapidly filling in early summer. Rises in reservoir water levels have often been associated with increases in productivity through the flooding of terrestrial vegetation and increased nutrient loading (Ploskey 1986). One explanation for the increased condition in February 2008 relative to historical averages is the increase in overall productivity of the reservoir in summer 2007 caused by the large water level rise. Alternatively, since I have shown that condition varies seasonally, and previous management surveys have been "snapshot" estimates, much of the year-to-year variation could be due to sampling at different points along the seasonal condition curve.

This research also highlights inherent problems associated with the snapshot character of standardized sampling protocols. An often overlooked aspect of this approach is whether the snapshot is an appropriate measure of a parameter that may vary seasonally as well as annually. Long-term spring gill netting in Lake Buchanan indicated consistently poor condition (i.e., $Wr < 85$) of adult striped bass at a time of year that water quality was well within species tolerances (Bettoli 2005). This could have been mistakenly attributed to a poor forage base or inadequate forage for the number of fish stocked. Monthly sampling in this study indicated that instead, condition followed an annual cycle of low summer condition and increasing condition through fall into the next spring. Because striped bass relative weights increased during fall and winter while forage densities should be declining due to predation and natural mortality, it appeared that the forage base was adequate. The approach of combining monthly samples in one year with historical spring sampling provided a context for the snapshots and increased their utility.

Limitations of preferred habitat caused primarily by high summer water temperatures are nearly universal in Texas reservoirs where striped bass are found. Summer water temperatures exceeding 25 C have been reported for all Texas reservoirs containing striped bass (TCEQ surface water quality monitoring; http://www8.tceq.state.tx.us/SwqmisWeb/public/index.faces). However, low relative weights of adult striped bass have only been noted in approximately 50% of reservoirs in Texas where striped bass are present (TPWD, unpublished data). Thus, further research is needed to examine the differences in summer water quality between reservoirs characterized by poor and good striped bass condition. For warmer reservoirs, like Lake Buchanan, management alternatives such as stocking the more temperature-tolerant hybrid striped bass (Woiwode and Adelman 1991) may be an option to fill the pelagic predator niche and maintain fishing opportunities. Alternatively, striped bass can still provide quality fisheries in many reservoirs as long as managers recognize that increased temperatures mean decreased trophy potential for striped bass because temperature preferenda generally decrease with fish size.

Acknowledgments

I would like to thank numerous biologists and technicians of the Texas Parks and Wildlife Department for assistance with field data collections. J. Moore and C. Terrill provided length and weight data of angler caught striped bass. Constructive comments on earlier versions of this manuscript were provided by B. Van-Zee, S. Magnelia, and staff at Heart of the Hills Fisheries Science Center. Further comments and suggestions were provided by the editor and three anonymous reviewers. Funding for this project was provided through the Federal Aid in Sport Fish Restoration Act (Project F-190-R) to the Texas Parks and Wildlife Department, Inland Fisheries Division.

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