Examining Hybrid Striped Bass Stocking Rates in Texas Reservoirs: A Trade-off between Abundance and Stocking Efficiency

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Abstract: Hybrid striped bass (HSB), which includes palmetto bass (female striped bass *Morone saxatilis* × male white bass *M. chrysops*) or its reciprocal sunshine bass (female white bass × male striped bass) support popular fisheries in many Texas reservoirs. Data from 41 reservoirs sampled using gill nets from 1996–2021 (total of 255 reservoir-yr) were used to develop stock-recruit models where fingerling stocking rates were used to predict CPUE of adults in gill nets. Adult relative abundance was described using two size classes based on the statewide 458-mm minimum length limit, catch of fish below ($CPUE_{SUB}$) and above ($CPUE_{458}$) the limit. A linear mixed-effect model showed stocking rate explained 41–46% of variation in CPUE estimates. Mean stocking rate from 3–4 yr prior to each gill-net sample were best for predicting recruits for the $CPUE_{458}$ size class, while stocking rate calculations from years 3–5 and 3–6 explained less variation. The cost-effectiveness of the three primary stocking rates (12, 25, and 37 fingerlings ha^{-1}) was evaluated by comparing the stocking costs to the predicted HSB CPUE for each stocking rate. Stockings were less cost-effective at progressively greater stocking rates. Biologists should consider the trade-offs between stocking for increased relative abundance and using hatchery resources efficiently. We recommend stocking HSB fingerlings at 25 fingerlings ha^{-1} as a general guideline for establishing robust fisheries while maintaining an intermediate level of cost-effectiveness. Stocking at rates higher than 25 fingerlings ha^{-1} should be reserved for reservoirs where survival of stocked HSB is adequate and documented angler effort is high enough to justify the additional costs.

Key words: fingerlings, palmetto bass, stock-recruit, sunshine bass

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Hybrid striped bass (HSB), which includes the palmetto bass (female striped bass *Morone saxatilis* × male white bass *M. chrysops*) and the sunshine bass (female white bass × male striped bass) have been widely stocked into reservoirs throughout the United States to create recreational and trophy fisheries (Bettinger and Wilde 2013). The 2016 USFWS national survey estimated 4,696,000 anglers spent 72,173,000 days of fishing for moronids in United States which places them as the 6th most popular species group (USFWS and USCB 2018). The Texas Parks and Wildlife Department (TPWD) has stocked on average 1.8 million fingerlings annually from 2002–2022 (TPWD, unpublished data) making them an important component of the overall statewide fisheries management program. As of 2022, there were 23 reservoirs that were part of the HSB stocking program in Texas, which is one of only three states, along with Illinois and Nebraska, that have twenty or more HSB fisheries (Collier et al. 2013). Creel data showed that mean directed effort for HSB was approximately 6.6% of the total fishing effort from 2004–2022 among 23 reservoirs (TPWD, unpublished data). However, directed angler effort can exceed 30% of total angler effort in the most popular *Morone* fisheries, such as Lake Tawakoni and Richland-Chambers Reservoir. Due to long-term changes in climate, declining water quality, and reservoir aging, HSB are expected to become increasingly important components of moronid fisheries in the 21st century (Bettoli 2013).

Evaluations of HSB stocking rates are rare in scientific literature. Year-class strength of stocked HSB declined when the stocking rate exceeded 23 fingerlings ha^{-1} in Monroe Reservoir, Indiana (Hoffman et al. 2013), suggesting that density-dependent processes can reduce HSB survival. Similarly, relative mortality rates of HSB increased when stocking rate exceeded 22 fingerlings ha^{-1} in Clarks Hill Reservoir, Georgia (Germann and Bunch 1983). Lower recruitment at higher stocking rates have been observed for other species. Mortality of stocked striped bass increased with stocking rate in Smith Mountain Lake, Virginia (Moore et al. 1991). Research on walleye (*Sander vitreus*) stockings have shown density-dependent processes resulted in reduced abundance after stocking rates were increased (Fayram et al. 2005, Jacobson and Anderson 2007). Conversely, Fielder (1992) reported a positive linear relationship between walleye stocking rates and abundance, suggesting stocking rate was not a limiting factor.

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Reservoirs in Texas are typically stocked with HSB fingerlings (average 38 mm TL) at rates of 12, 25, or 37 fish ha^{-1} based on the abundance of available prey resources. Additionally, TPWD limits the HSB stocking rate to 25 fish ha^{-1} for reservoirs over 4047 ha to equitably allocate statewide fingerling resources. Reservoir stocking rates can be further altered during years of below average hatchery production, increasing annual variability in stocking rates. Thus, identifying and addressing inefficiencies in the HSB stocking program could allow managers to better allocate fingerlings and create more consistent stocking rates across years.

Cost effectiveness is an important component of successful stocking programs. Significant investments in fish stocking requires stocking practices to be evaluated to ensure they provide acceptable return on investment of fisheries management funding (Hunt et al. 2017). Comparing the known cost per fish produced and the total number that are subsequently caught in a fishery provides a direct approach to examine production cost relative to yield (Leber et al. 2005). Similarly, predicted relative abundance of adult HSB derived from stock-recruit models can be used to calculate a cost-per-recruit. Understanding the cost-effectiveness of the different HSB stocking rates commonly used in Texas will aid fisheries managers in decision making and improve the overall efficiency and consistency of the stocking program. The specific objectives of our study were to 1) derive a stock-recruitment relation between HSB fingerling stocking rates and CPUE estimates from standardized gill net population surveys, and 2) evaluate cost-effectiveness of the three primary HSB stocking rates used in Texas.

Methods

Study Area

Data from 41 Texas reservoirs were included in the dataset used to develop stock-recruit models. Reservoirs covered a wide geographical area (Figure 1) and ranged in size from 363–46,337 ha with 6 reservoirs over 10,000 ha, 16 from 2000–10,000 ha, and 19 under 2000 ha. Among reservoirs, mean secchi disk depth was 0.9 m (range 0.3–3.1 m) and mean specific conductance was 659 μS cm^{-1} (range 106–8831 μS cm^{-1}). Trophic classification data was only available for 26 of the 41 reservoirs, however most reservoirs were classified as either mesotrophic or eutrophic (Texas Commission on Environmental Quality 2020). Fish communities were representative of most Texas reservoirs and consisted of sunfish (*Lepomis* spp.), largemouth bass (*Micropterus salmoides*), crappies (*Pomoxis* spp.), white bass, and various catfish (Ictaluridae) species. Gizzard shad (*Dorosoma cepedianum*) and threadfin shad (*D. petenense*) were the primary forage species for HSB. Gizzard shad occurred in all reservoirs and threadfin shad occurred in all but two reservoirs.

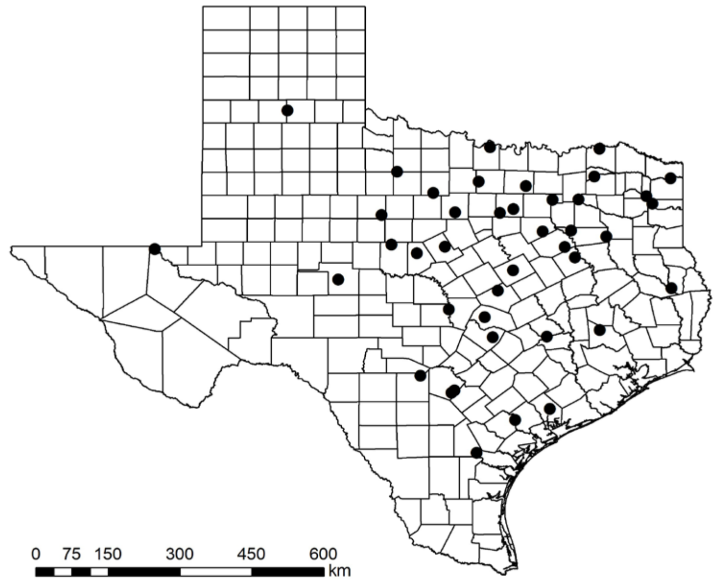

Figure 1. Geographical distribution of 41 Texas reservoirs stocked with hybrid striped bass from which data was compiled for this study. A total of 255 gill net surveys from 1996–2021 were included in the dataset.

Data Sources

Relative abundance data for HSB were collected from 1996–2021 by fisheries management personnel during standardized spring gill-net surveys following established sampling procedures (TPWD, Inland Fisheries Division, unpublished manual revised 2022). Gill nets were 38.1 m long and 2.4 m deep, and consisted of five 7.6-m monofilament panels, each with a mesh size of 25, 38, 51, 64, or 76 mm (bar measure) arranged in ascending order. Gill nets were set in the afternoon, fished overnight, and retrieved the following morning. One net fished overnight was defined as 1 net-night. Gill nets were set on the bottom perpendicular to the nearest shore, with the smallest mesh directed toward shore. We sought only to evaluate fingerling stockings, thus reservoirs that received a mix of fingerling and fry stockings within 6 yr prior to each gill-net survey were excluded from the dataset. We chose 6 yr as the cut-off as age data from Texas HSB populations shows few live beyond age 7 and thus any stockings conducted 7 yr or more before each gill-net survey would likely have negligible impacts in CPUE estimates.

Gill-net CPUE was calculated for two size classes of HSB using the statewide 458-mm minimum-length limit as the point of demarcation: the observed relative abundance of HSB below the minimum-length limit ($CPUE_{SUB}$) and the HSB relative abundance above the minimum-length limit ($CPUE_{458}$). Because age data were not available for most gill-net surveys, we were unable to pair individual yearly stocking rates with specific year-classes of HSB.

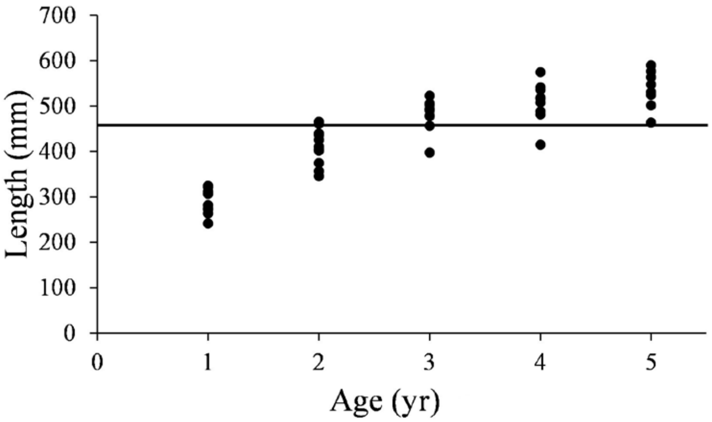

Figure 2. Mean length at age of hybrid striped bass from 12 Texas reservoirs depicting the range of observed growth rates. Eleven of the twelve reservoirs had mean length at age estimates at or above the minimum length limit by age 3. Horizontal black line indicates the minimum length limit of 458 mm.

Thus, we evaluated several mean stocking rate year combinations that should correlate with the two size classes of HSB defined in this study based on unpublished TPWD growth data. The majority of HSB in Texas reservoirs reach the minimum length limit by age 3 (Figure 2), thus we assumed stockings conducted 1–2 yr before the gill net survey would contribute to the relative abundance of sub-legal size HSB while stockings conducted 3 yr or more before the gill net survey would contribute to the relative abundance of legal-size HSB. We calculated the mean stocking rates from 3–4, 3–5, and 3–6 yr prior to each gill-net survey to determine which year-combination was best for predicting $CPUE_{458}$. Mean stocking rates (fingerlings ha^{-1}) were calculated by taking the mean number of fingerlings stocked for each year combination and dividing by the reservoir surface area (ha) at the time of the netting survey. Reservoir water level and elevation-area-capacity curves were obtained from Texas Water Development Board (2022) and USGS (2022). Data on HSB fingerling production costs were obtained from TPWD hatchery staff and used to calculate stocking costs ha^{-1}.

Data Analysis

We used a linear mixed-effect model to describe the stock-recruit relationship between stocking rates (stock) and relative abundance of HSB (recruits) collected from gill-net surveys. We included reservoir as a random effect to account for inherent differences among reservoirs. Models were run for each HSB size class and stocking-year combination.. Due to expected left skew and heterogeneous variance (Maceina and Pereira 2007), we $\log_e$-transformed our stock-recruit data prior to analysis. Because some relative abundance estimates were zero, a value of 1 was added to each CPUE estimate prior to log transformation. Fingerling production costs were calculated from data from 2010–2019. Mean fingerling production costs were calculated by taking the total HSB program costs divided by the total number of fingerlings produced each year and averaged for the entire 10-yr period. The relative cost-effectiveness for each stocking rate (12, 25, 37 fingerlings ha^{-1}) was calculated by taking the stocking costs ha^{-1} divided by the predicted HSB CPUE from the linear mixed-effect model. All statistical analysis was completed using Program R (R Core Team 2021). The nlme package (Pinheiro et al. 2021) was used to calculate the mixed-effect models, and the MuMIn package (Barton 2022) was used to approximate conditional r^2 values for the mixed-effect models. All tests were considered significant at $P \leq 0.05$.

Results

Mean $CPUE_{SUB}$ among all gill net surveys was 2.9 HSB net-night^{-1} (SD = 4.0; range 0.0–28.8). Mean $CPUE_{458}$ among all gill net surveys was 2.2 net-night^{-1} (SD = 2.9; range 0.0–20.6). Mean stocking rate was 22.6 fingerlings ha^{-1} with an interquartile range of 10.1–32.7 fingerlings ha^{-1}. Mean stocking rate from 1–2 yr prior to each gill net survey explained 41% of the variation in $CPUE_{SUB}$ ($n = 244$; $P < 0.0001$; Figure 3) with an estimated equation of $\log_e Recruit = (0.5365 \times \log_e Stock) - 0.5029$. Mean stocking rate from 3–4 yr prior to each gill net survey explained 46% of the variation in $CPUE_{458}$ ($n = 255$; $P < 0.0001$; Figure 3) with an estimated equation of $\log_e Recruit = (0.3231 \cdot \log_e Stock) - 0.0863$. The inclusion of older stocking year combinations (3–4, 3–5, 3–6) did not explain additional variation in HSB relative abundance. Stock-recruit models that included mean stocking rates calculated from 3–5 and 3–6 yr prior to each gill net survey explained slightly less variation (44–45%) compared to stocking rate from 3–4 yr prior.

From 2010 to 2019, the average cost per HSB fingerling produced was US$0.36 and ranged from $0.05 to $0.71 among years. Mean number of fingerlings produced annually during this period was just over 1.2 million. When costs for each stocking rate were compared to predicted HSB CPUE from the stock-recruit models, stockings were shown to be less cost-efficient as stocking rates increased for both size classes (Table 1). Increasing the stocking rate from 12 to 25 fish ha^{-1} resulted in a concomitant increase of 8% ($CPUE_{SUB}$) and 34% ($CPUE_{458}$) per recruit, whereas increasing the stocking rate from 25 to 37 fish ha^{-1} resulted in an increased cost-per-recruit of 10% ($CPUE_{SUB}$) and 23% ($CPUE_{458}$). Overall, increasing the stocking rate from 12 to 37 fish ha^{-1} resulted in increased cost-per-recruit of 20% ($CPUE_{SUB}$) and 64% ($CPUE_{458}$).

Table 1. Comparison of stocking costs (US$) per hectare, predicted relative abundance ($CPUE_{SUB}$ and $CPUE_{458}$; fish net-night^{-1}), and relative cost-per-recruit (stocking cost ha^{-1} divided by predicted CPUE) for three different annual stocking rates (fingerlings ha^{-1}) used by the Texas Parks and Wildlife Department for hybrid striped bass. Stocking costs were calculated from an average production cost of $0.36 per fingerling. Values in parentheses are ± 1 SE.

Annual stocking rate	Cost	Predicted CPUE	Relative cost-per-recruit
$CPUE_{SUB}$			
12	$4.46	1.33 (0.67–2.24)	$3.35 (1.99–6.66)
25	$8.89	2.45 (1.33–3.92)	$3.63 (2.27–6.68)
37	$13.36	3.33 (1.82–5.24)	$4.01 (2.55–7.34)
$CPUE_{458}$			
12	$4.46	1.07 (0.54–1.79)	$4.17 (2.49–8.26)
25	$8.89	1.59 (0.85–2.61)	$5.59 (3.41–10.46)
37	$13.36	1.95 (1.07–3.20)	$6.85 (4.18–12.49)

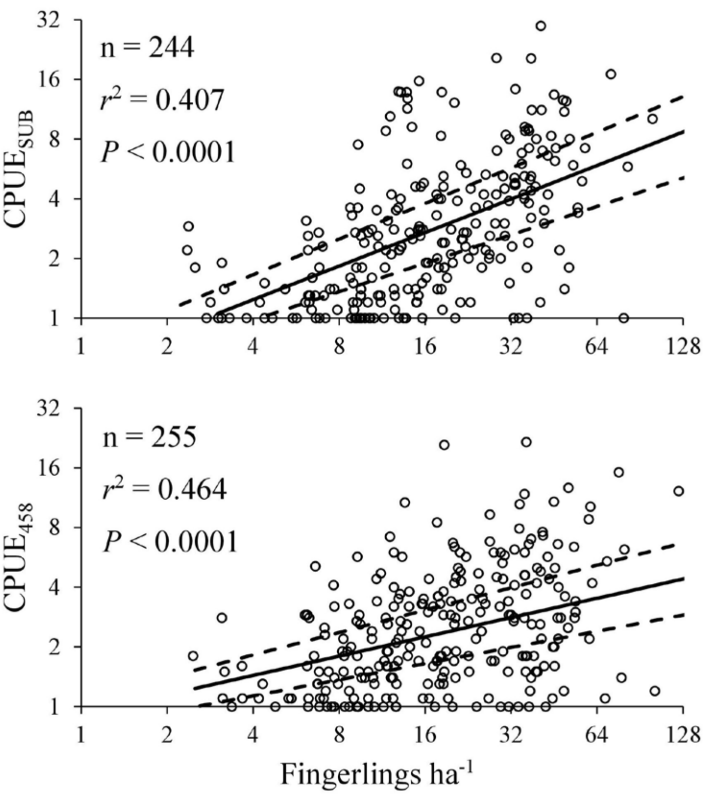

Figure 3. Gill-net catch rate (CPUE, fish net-night^{-1}) of two size classes of hybrid striped bass (SUB and 458) as a function of the mean stocking rate of fingerlings stocked prior to each gill net survey for 41 Texas reservoirs. Dashed lines indicate 1 SE from the trend line. Data is presented in log-log scale with untransformed values on the x-y axes. Note that a value of 1 was added to each CPUE value to allow for log-linear model computation.

Discussion

The amount of variation in HSB relative abundance explained by our stock-recruit models was moderate (41–46%) and similar to or in some cases slightly higher than other studies that used pooled datasets for examining stock-recruit relationships (Beard et al. 2003, Fayram et al. 2005, Bunnell et al. 2006, Siepker and Michaletz 2013). The inclusion of each reservoir as a random effect in our linear mixed-effect model allowed us to model HSB relative abundance while accounting for inherent differences among reservoirs. Reservoirs in this study varied in morphology, productivity, hydrology, and water chemistry and stocking success was likely affected by these differences. Myers et al. (1999) suggested that combining data across many stocks may reduce the uncertainty of the biological processes underlying their population dynamics. However, using spatially extensive data sets can introduce large amounts of system-specific variation (Pritt et al. 2019), thus accounting for this variation within a mixed-effect model with reservoir system as a random effect was essential in describing the overall average effect of stocking rates on HSB relative abundance.

The model for predicting relative abundance of legal-size HSB ($CPUE_{458}$) explained slightly more variation than the $CPUE_{SUB}$ model, possibly due to issues related to gill-net selectivity. Although selectivity has not been evaluated for the TPWD gill-net configuration, Shoup and Ryswyk (2016) evaluated the North American standard gill net for HSB and found relative retention probabilities exceeded 80% for HSB from 320–569 mm. The TPWD gill net configuration differs from the North American standard gill net in that it lacks the smallest mesh (19 mm) and has larger incremental increases in mesh size. It also includes a larger mesh (76 mm) that is not present on the North American standard gill net. Therefore, it is likely that the TPWD gill net configuration would be slightly more selective for larger HSB, but less selective for smaller HSB, when compared to the North American standard gill net. Because HSB >458 mm may have had higher retention probabilities in the TPWD gill net compared to smaller HSB, relative abundance estimates for $CPUE_{458}$ may have been more accurate than $CPUE_{SUB}$ and resulted in higher r^2 values. Future work regarding the selectivity of HSB in the TPWD gill-net configuration would be valuable in understanding HSB retention probabilities and obtaining more accurate CPUE and size structure estimates.

The relation between CPUE and mean fingerlings stocking rates was well represented by a linear model, suggesting that density dependence was not a limiting factor mediating stocking success in Texas reservoirs. These results differed from those of Hoffman et al. (2013) who found density-dependent impacts on HSB year-class strength as stocking rates increased. Stocking rates used in our study likely did not exceed carrying capacity in most reservoirs, as HSB fingerlings are typically stocked in Texas reservoirs known to contain abundant shad populations. For example, the stocking rate of HSB was increased from 20 fish ha^{-1} biennially to 50 fish ha^{-1} annually in two Texas reservoirs with no significant decrease in the gill net catch rate of gizzard shad (Moczygemba et al. 1991). Hoffman et al. (2013) noted that their conclusion of density-dependence was based off a single data point, which may have been spurious. Hanson et al. (1998) and Beard et al. (2003) suggested using Ricker models for walleye stock-recruit models due to walleye being cannibalistic, but this has not been reported for HSB and shad are usually their principal prey in southeastern U.S. reservoirs (Williams 1970, Ware 1974, Germann and Bunch 1985, DeMauro and Miranda 1990, Michaletz 2014). Our results suggest that fisheries managers of Texas reservoirs could choose to stock HSB at higher rates with the expectation that density-dependent factors will not significantly impact relative abundance.

Although most stock-recruit studies examine natural recruitment as a product of the abundance of sexually mature adults, our study predicted the number of fish that recruit to the fishery based off stocking rates, similar to the approach used by Fielder (1992) and Fayram et al. (2005) for walleye. However, lack of age-specific data required us to use a mean stocking rate over multiple years that generally aligned with two size classes of HSB. In general, the stock-recruit model agreed with the unpublished TPWD age data that determined the majority of HSB over 458 mm are composed primarily of 3- and 4-yr-old fish. Models that included stocking data from 5 yr or more prior to gill-net surveys generally did not improve the model fit. Thus, future studies aimed at assessing stocking efficacy of HSB in Texas reservoirs should focus on quantifying abundance of age-3 and age-4 HSB.

Stockings became less cost effective at progressively higher stocking rates. As stocking rates increased, the added costs of additional fingerlings outpaced the predicted increased in HSB relative abundance. For example, increasing the annual HSB stocking rate from 25 to 37 fingerlings ha^{-1} would increase the predicted $CPUE_{458}$ by only 23% while increasing stocking costs by 50%. Our results were similar to those of Jacobson and Anderson (2007), who found that increasing walleye stocking rates 30% would increase walleye abundance by only 3% and increase the stocking cost by 28%. Thus, lower stocking densities provide greater cost-effectiveness but might result in lower population abundances that may be undesirable to anglers.

Management Implications

Survival of stocked HSB is a complicated process with numerous variables influencing success, many of which are out of the control of fisheries managers. Despite high variability, we found stocking rate was an important factor in determining HSB relative abundance, which is directly controlled by fisheries managers. Trade-offs between stocking at higher rates to increase relative abundance and the need to use hatchery resources efficiently must be carefully considered. Based on our results, we recommend stocking HSB fingerlings at 25 fingerlings ha^{-1} as a general guideline for establishing robust fisheries while maintaining an intermediate level of cost-effectiveness. Stocking at rates higher than 25 fingerlings ha^{-1} should be reserved for reservoirs where survival of stocked HSB and angler effort are high enough to justify the additional costs.

The two primary indicators of a successful HSB fishery are the presence of an abundant population and adequate angler effort. Both HSB relative abundance and angler effort must be commensurate with the stocking rate to provide a positive return on investment. Results from this study can be used to develop minimum benchmarks for future evaluations of a HSB fisheries in Texas. Furthermore, HSB fisheries must be evaluated on a regular basis to determine if HSB relative abundance and angler effort is sufficient to support stocking at a given rate. If HSB relative abundance measures consistently fall below a minimum threshold at a given stocking rate, stocking rates should be altered, or reservoirs should be removed from the HSB stocking program.

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