Evaluation of Hybrid Striped Bass Introductions in Iowa

Study 7043 Completion Report
Federal Aid to Sport Fish Restoration

Iowa Fisheries Research

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Study 7043
Evaluation of Hybrid Striped Bass Introductions in Iowa

OBJECTIVE

By the year 2023, develop and implement management strategies to effectively sample and manage hybrid striped bass in Iowa lakes.

APPROACH 1

Develop standard sampling protocols for hybrid striped bass.

OBJECTIVE

Develop standard sampling and laboratory protocols for Iowa's hybrid striped bass fisheries.

APPROACH 2

Hybrid striped bass cross comparison.

OBJECTIVE

Determine if there is a preferred hybrid striped bass cross for stocking into Iowa lakes.

APPROACH 3

Evaluate hybrid striped bass stocking strategies.

OBJECTIVE

Determine cost/benefit ratios of hybrid striped bass stocking strategies and identify variables that affect stocking success.

APPROACH 4

Evaluate factors affecting hybrid striped bass year-class strength.

OBJECTIVE

Utilize standard methods to evaluate hybrid striped bass year-class strength, and determine factors affecting year-class strength.

APPROACH 5

Completion report, management guidelines, and publication of result.

OBJECTIVE

Compile, analyze, and publish results in Federal Aid reports, peer-reviewed and lay journals as appropriate.

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EXECUTIVE SUMMARY

Iowa Department of Natural Resources (DNR) began stocking Hybrid Striped Bass (Striped Bass *Morone saxatilis* x White Bass *M. chrysops*) into Saylorville Reservoir in 1981. Early stockings were Palmetto Bass *M. saxatilis* ♀ x *M. chrysops* ♂, obtained through fish trades and later purchases from both private and public hatcheries. Fry were sometimes grown out to fingerling size at Rathbun Fish Hatchery and later Mount Ayr Fish Hatchery, and stocked into the large flood control reservoirs and several larger lakes and reservoirs including Lake Manawa and Three Mile Lake. More recently, Iowa DNR expanded its stocking program to smaller impoundments and urban ponds as well, and obtained Sunshine Bass *M. chrysops* ♀ x *M. saxatilis* ♂ along with Palmetto Bass. Prior to this study, little was known about Hybrid Striped Bass performance, behavior, and sampling strategies in Iowa in general, and best practices had not yet been determined. Previous research in Iowa had focused on marking efficacy and appropriate sampling methods; this study built upon and expanded that work.

As Hybrid Striped Bass fisheries grew more popular and desired in new locations, assessment methodology became more important as a protocol for sampling Hybrid Striped Bass in Iowa did not yet exist for fishery management. Fisheries management requires accurate and precise sampling methods for data collection, thorough understanding of the factors affecting population dynamics, and ability to predict outcomes of management actions such as length-based regulation. Specifically, four sampling gears were compared regarding fish capture efficiency, precision of catch rate estimates, and representativeness of fish size distribution. After determining that experimental gill nets yielded high quality data in all metrics, additional work was conducted to test mesh size selectivity and shorter net set durations. Likewise, four calcified structures were compared regarding age estimation accuracy and consistency in terms of reader agreement. Finally, tagging and handling protocols were examined for advanced Hybrid Striped Bass, and a best practices guide was developed.

In addition, factors affecting successful establishment of a fishery became relevant to guide stocking and culture priorities. Specifically, the genetic crosses (Palmetto and Sunshine) could differ in cost, feasibility, and survival to the stock. For instance, Sunshine Bass may be easier to produce or obtain from neighboring states because eggs can be obtained from native White Bass, whereas Palmetto Bass must be produced in a coastal state and shipped as fry. They may differ in early growth and ontogenetic shifts, resilience to culture and transport, and ultimately in adult growth, movement, and survival. We studied both genetic crosses at five locations to compare survival to the first fall, growth rate, and body condition. We also examined size-at-stocking, fingerling stocking rate, and weather conditions at the time of stocking at two reservoirs with well-established Hybrid Striped Bass fisheries (Lake Macbride and Three Mile Lake).

Management Recommendations

- Sampling gear and deployment
  - Standard American Fisheries Society (AFS) experimental gill nets with large-mesh add-on panels should be used to assess populations of Hybrid Striped Bass. These nets are described in detail by Bonar et al. (2009). The standard net is an 8-panel net with panels 3.1-m long by 1.8-m deep, with mesh sizes 19, 25, 32, 38, 44, 51, 57, and 64 mm bar. The large-mesh add-on is a series of 3 panels 3.1-m long by 1.8-m deep, with mesh sizes 76, 89, and 102 mm. This add-on should be attached to the end of the core net.
  - The AFS standard deployment is to set nets during late afternoon and retrieve them the following day, encompassing two crepuscular periods. Although this can result in high mortality rates, overnight nets can capture a higher total number of fish and may be more convenient for staff.
  - Data recorded should be separated by mesh size, in order to share data in the future by standard net specification. This entails not only separating catch between the main net and the large-mesh panel, but between each individual mesh panel. This is necessary to make mesh selectivity-based adjustments.
  - Sampling should occur in fall, ideally October when water temperatures were below 25°C, with a minimum sampling effort of 8 net-nights or more, depending on surface area. Approximately 27 net-nights would be needed to detect a 25% change in catch rate with $\alpha = 0.10$, based on the waterbodies studied. We recommend beginning with a surface-area-based amount of effort for annual sampling (ranging between 8 and 36 net-nights), but strongly recommend more samples when assessing the effect of a management action. If data are available for the waterbody of interest, a minimum recommended sample size specific to that waterbody can be determined using the relative standard error approach.

- Lab protocols
  - We recommend use of sectioned dorsal spines for nonlethal age estimation of Hybrid Striped Bass, based on sampling a younger population (most fish <6 years). If the population is older, sagittal otoliths can also be taken and were considered the most accurate age estimation structure for older fish. We do not recommend the use of scales.
  - Hybrid Striped Bass which have been cultured may be safely harvested from earthen ponds by seining, and do not need to be held overnight prior to additional handling. However, harvest should be delayed until water temperatures are below 12.8°C and fish exceed 200 mm TL. If those fish are placed in raceways, the raceways should be salted immediately after stocking at a rate of 1.5 to 3.0 ppt salt solution, and salted again daily thereafter to minimize fish stress and reduce fungal infections.
  - Hybrid Striped Bass should be handled with fish handling gloves to avoid damaging the slime coat, and should only be weighed if necessary. If weighed, they should be weighed in water.
  - Hybrid Striped Bass may be tagged (i.e., with a 32-mm PIT tag) in the body cavity without anesthesia. Again, raceways receiving tagged fish should be salted immediately thereafter to minimize stress and boost fish recovery. Fish may be stocked immediately or held overnight.
- Genetic cross
  - The ratio of Palmetto Bass and Sunshine Bass recaptured later did not differ substantially from the ratio stocked. In other words, one strain did not survive to stock size at a different rate than the other.
  - Cross was not an important factor affecting von Bertalanffy growth models. In other words, one strain did not grow significantly larger or faster than the other, with minor differences converging within the first two years of life. Continued tracking of Hybrid Striped Bass beyond Age 6 could alter this conclusion.
  - Cross was not an important factor affecting length-weight models. One strain did not grow relatively heavier than the other. Likewise, body condition did not differ between crosses.
  - Given the lack of meaningful differences between genetic crosses of Hybrid Striped Bass in terms of stocking return, growth, and condition, the more cost-effective cross is recommended for future culture and stocking in Iowa. Generally speaking, the Palmetto Bass is less expensive to produce to fingerling size; however, other factors affect accessibility of each cross annually: availability of fish trades, cost of purchase from other hatcheries, timing, and fish availability.
- Stocking
  - The size of fish at stocking was an important factor affecting the catch curve at Lake Macbride. Stocking fry rather than fingerling Hybrid Striped Bass at that location reduced return to gill nets by 19.3% on average. In terms of year-class strength, fingerlings were also slightly more reliable in establishing year-classes of fish.
  - Fingerling stocking rate was an important factor affecting the catch curve at Three Mile Lake. We suggest that a stocking rate of 5 fish/acre may not yield adequate returns to gill net catch later on, but 10 fish/acre might be acceptable and 15 fish/acre may yield a desirable total catch per net-night at this location. Generally, fingerling rates used in other states are similar or higher than Iowa's historical stocking rates of fingerling Hybrid Striped Bass.
  - Limited data were available for assessing environmental conditions at the time of stocking in this study. However, stronger fingerling year-classes were associated with warmer maximum daily temperatures, which could have reflected broader weather patterns in which a warmer spring is conducive to better fish growth and survival. Stronger fry year-classes were associated with warmer maximum daily temperatures on the day of stocking, 48-hour temperature change post-stocking, and precipitation on the day of stocking such that greater rainfall had a positive effect. Again, the data were quite limited and this finding could be spurious, but reduced light conditions for newly stocked fry has been found to reduce predation especially by Largemouth Bass. Further investigation of environmental conditions at the time of stocking is merited if it affects stocking decisions (e.g., cancellation or re-direction of stocking). However, we suggest that, based on the existing literature, the greater priority is to measure water chemistry and temper the fry based on dissolved oxygen, pH, and possibly conductivity as well as water temperature. At a minimum, these chemical parameters should be documented at the time of stocking, as they may provide explanation in the event of failed stockings.
  - We also recommend potential stocking locations be examined in terms of potential for emigration (e.g., outflows, spillway design, fish barrier presence), dissolved oxygen-temperature habitat squeezes, and

predator and prey composition and densities, before deeming them appropriate for Hybrid Striped Bass fishery development. These factors were not examined in the current study.

- We were limited in our ability to make conclusions about Hybrid Striped Bass populations in large flood control reservoirs. We recommend analysis of available datasets (e.g., Rathbun Reservoir) to better examine Hybrid Striped Bass growth in the flood control reservoirs. Such work should be integrated with the growth information from this study to test the effectiveness of special regulations to protect Hybrid Striped Bass fisheries, if found to be appropriate and needful.

We observed variability among study locations in terms of the number of fish recaptured, and we suspect a large part of the explanation related to differences in outflows for each location. Hybrid Striped Bass are prone to emigration from reservoirs, and none of the study locations had a fish barrier of any kind although they did differ in outlet and spillway structure. We believe a physical barrier could reduce emigration of adult Hybrid Striped Bass, but know relatively little about the effectiveness of barrier use on Hybrid Striped Bass. Furthermore, fish movement and probability of emigration may differ between crosses. To determine whether this difference is ecologically significant, a movement and emigration study of both crosses is recommended for future work.

Suggested citation format, American Fisheries Society Style Guide:

Krogman, RM. 2023. Evaluation of Hybrid Striped Bass Introductions in Iowa. Iowa Department of Natural Resources. Federal Aid in Sport Fish Restoration, Completion Report, Des Moines.

Approach 1: Develop standard sampling protocols for hybrid striped bass.

INTRODUCTION

Iowa Department of Natural Resources (DNR) began stocking Hybrid Striped Bass (Striped Bass *Morone saxatilis* x White Bass *M. chrysops*) into Saylorville Reservoir in 1981 (Mayhew 1987). Early stockings were Palmetto Bass *M. saxatilis* ♀ x *M. chrysops* ♂, obtained through fish trades and later purchases from both private and public hatcheries. Fry were sometimes grown out to fingerling size at Rathbun Fish Hatchery and later Mount Ayr Fish Hatchery, and stocked into the large flood control reservoirs and several larger lakes and reservoirs including Lake Manawa and Three Mile Lake. More recently, Iowa DNR expanded its stocking program to smaller impoundments and urban ponds as well, and obtained Sunshine Bass *M. chrysops* ♀ x *M. saxatilis* ♂ along with Palmetto Bass.

Hybrid Striped Bass are an important component of Iowa's fisheries, as they have high potential to provide trophy fishing opportunities and utilize forage species that are otherwise unavailable to most predators. They exhibit rapid growth, achieving lengths over 381 mm by Age 3 and over 420 mm by Age 4 in southern Midwest reservoirs (Kuklinski 2014). Hybrid Striped Bass are aggressive feeders and considered to have superior "fighting abilities" which contribute to a quality trophy fishery (Jahn et al. 1987). As larger-bodied predators, they may be capable of restructuring panfish communities (Layzer and Clady 1984; Jahn et al. 1987; Neal et al. 1999; Hutt et al. 2008) and controlling abundant prey species like Gizzard Shad *Dorosoma cepedianum* (Dettmers et al. 1998), but may also compete with native predators like Largemouth Bass *Micropterus salmoides* (Hickey and Kohler 2004).

Fisheries management requires accurate and precise sampling methods for data collection, thorough understanding of the factors affecting population dynamics, and ability to predict outcomes of management actions such as length-based regulation. Formal sampling and handling protocols for Hybrid Striped Bass were not prioritized for development until more waterbodies were identified for potential stocking, creating new Hybrid Striped Bass fisheries in more locations across the state. Little was known about Hybrid Striped Bass performance, behavior, and management in Iowa in general, and best practices had not yet been determined. Previous research in Iowa has focused on marking efficacy and appropriate sampling methods (Schultz 2012); this study built upon and expanded that work.

Field sampling methods being considered included electrofishing and gill netting, but gear deployment and timing could affect catch drastically. For instance, timing of electrofishing can alter catch rates and size structure, with nighttime generally yielding higher catch rates for all size classes and yielding larger size structure for other fishes (Paragamian 1989; Dumont and Dennis 1997). Mesh size in gill nets can alter size structure through mesh-specific size selectivity, and failure to adjust for size selectivity may yield less accurate estimates of relative abundance for various size classes of a species (e.g., White Perch *Morone americana*: Sowards et al. 2021). In addition to variation in catch efficiency and precision, each gear entails a different application of staff time and resources. For instance, electrofishing at night requires evening work outside of typical working hours, and typical gill net sets entail two days of work: one day to set nets and one day to retrieve them. Management biologists also reported high mortality from overnight sets, but continued to utilize the longer period because staff hours were used more efficiently that way. (Shorter sets required staying on-site during the net soak time.) Thus, optimal sampling gear choice and subsequent deployment specifications depend on the gear's efficiency, precision, representativeness of the true population, fish health and mortality effects, and staff efficiency.

In addition, laboratory and live fish handling practices had not been determined for Iowa at the beginning of this study. For example, age estimation using calcified structures was desired, but a non-lethal structure was desirable if it provided reasonably accurate age estimates. Otoliths have been verified up to Age 5 using known-age Hybrid Striped Bass in Florida (Snyder et al. 1983) and up to Age 7 in Striped Bass (Secor et al. 1995). They are generally considered the most accurate structure for *Morone* species, but require sacrifice of the fish. Otolith annulus formation has been verified with known-age fish in White Perch (Porta and Snow 2017). Although scales may be subject to numerous issues such as false annuli and low age estimation, as shown for Striped Bass (Snyder et al. 1983; Bryce and Shelton 1985; Heidinger and Clodfelter 1987; Secor et al. 1995), a majority of management agencies in more northern latitudes have used scales for Hybrid Striped Bass (Maceina et al. 2007; Schultz et al. 2013). Scale annulus formation has been verified in White Perch (Sheri and Power 1969), but scales tended to underestimate age in fish over 6 years in South Dakota White Bass (Soupir et al. 1997) and Striped Bass in Arkansas (Kilambi and Prabhakaran 1987). Similarly, scales tended to underestimate age in older Striped Bass in Chesapeake Bay, resulting in underestimates of population abundance and overestimates of fishing-related mortality (Liao et al. 2012). Furthermore, the erroneous data made strong Age 1 recruitment appear to be weaker and weak recruitment stronger than it truly was, which could affect fishery management decision making. Alternative calcified structures such as spines were also of interest due to their accuracy relative to otoliths demonstrated in other species (e.g., Walleye *Sander vitreus*: Isermann et al. 2003; Smallmouth Bass *Micropterus dolomieu*: Rude et al. 2013) and non-lethality. Anal spines yielded age estimates within one year of otolith-based ages in Striped Bass up to 900 mm total length (Welch et al. 1993). Opercles from White Bass in South Dakota performed similarly to otoliths up to Age 12 (Soupir et al. 1997). Sectioned dorsal spines yielded the clearest annuli relative to scales and opercles in Striped Bass in Arkansas (Kilambi and Prabhakaran 1987). Thus, dorsal or anal spines were also considered for non-lethal age estimation in Hybrid Striped Bass in Iowa.

Lastly, tagging and handling practices had not been determined for Hybrid Striped Bass, particularly hatchery-raised fish which needed to endure tagging prior to stocking. Hybrid Striped Bass surgically implanted with larger transmitters at lengths of 227-410 mm experienced greater mortality in hatchery trials compared to control fish which were handled but not tagged. However, mortality depended on temperature, with high temperature (22-29°C) correlating to increased incision irritation, infection, and mortality and low temperature (12-18°C) resulting in no mortality (Walsh et al. 2000). The tags used in that study were larger than what is typically needed in Iowa (e.g., needle-injected passive integrated transponder tags), although larger acoustic tags requiring surgery were also possible. Few guidelines existed regarding how to safely handle Hybrid Striped Bass at an advanced fingerling size (8-10”), including water chemistry and remediation, harvest method, weighing method, anesthesia, and the tagging effect itself. In order to conduct studies in the future requiring tagged fish, information was needed regarding best practices, potential for tag loss, and potential for post-tagging mortality.

Objectives

Therefore, the objectives of this study were to 1) compare Hybrid Striped Bass catch-related metrics among four sampling gears, 2) compare accuracy of alternate calcified structures for Hybrid Striped Bass age estimation, 3) determine fish handling practices for Hybrid Striped Bass, and 4) establish a standard sampling protocol for Hybrid Striped Bass in Iowa.

METHODS

Study Locations

Study locations included both smaller and larger reservoirs and lakes where Hybrid Striped Bass had been stocked (Table 1). Four locations were sampled most often, due to their role in establishing standard sampling gears and age estimation structures: Badger Creek Lake, Easter Lake, Lake Icaria, and West Lake Osceola. Lake Wapello was added to the study later, but stocking ended due to plans for renovation. Other locations were targeted for specific portions of the study.

Table 1. Study locations where Hybrid Striped Bass were stocked and sampled.

Location	Surface Area (acres)	County	Management Region	Years Stocked*	Years Sampled
Badger Creek Lake	276	Madison	Mount Ayr	2012-2017	2013-2017
Easter Lake	178	Polk	Boone	2012-2013	2014-2015
Lake Icaria	648	Adams	Mount Ayr	2012-2017	2013-2017
West Lake Osceola	320	Clarke	Mount Ayr	2012-2017	2014-2017
Lake Wapello	289	Davis	Rathbun	2012-2016	2016-2019
Three Mile Lake	880	Union	Mount Ayr	2007-2012	2009-2016
Lake Macbride	889	Johnson	Macbride	2006-2018	2009-2019
Lake Manawa	747	Pottawattamie	Cold Springs	2013-2018	2018
Red Rock Reservoir	15,250	Marion	Boone	2001, 2008-2019	2019

* Stocking continued at some locations outside the scope of this study.

Gear Type

Four gear deployments were tested during field protocol development: nighttime electrofishing, daytime electrofishing, single-mesh gill nets, and experimental mesh gill nets. Electrofishing was conducted using a boat with two anode spider-style droppers and pulsed DC current. Electrofishing transects were at fixed sites across years, and typically 15 minutes in duration of power-on time. Daytime transects were completed during daylight hours, and nighttime transects were completed beginning 30 minutes after sunset. Single-mesh gill nets were made of monofilament panels hung 1.8-m deep with 64-mm bar mesh, totaling 48.8 m in length. Experimental gill nets were made of eight 3.1-m monofilament panels hung 1.8-m deep, each with a different mesh size (19, 25, 32, 38, 44, 51, 57, and 64 mm bar), totaling 38 m in length. Nets were set at fixed sites across years, and set overnight to encompass two crepuscular periods (dusk and dawn). All samples were collected during autumn when water temperatures were below 25°C, typically in October.

All Hybrid Striped Bass captured were measured (total length [TL, mm]), weighed (g), and counted. As described below in the section *Standard Laboratory Protocol Development*, a variety of calcified structures were taken for a number of years as well. Dorsal spines, specifically, were always removed from up to 10 fish/10-cm length bin throughout this study.

Gear efficiency was measured by catch rate, calculated as fish/site where a site was either an overnight net deployment or a 15-minute electrofishing run. Mean catch rates were calculated using the least-square means method from a general linear mixed model predicting catch rate by gear. Catch rate was log-transformed prior to model fitting. Year, waterbody, and site were treated as random effects, with site nested within waterbody. Differences between gears were tested by pairwise comparison using t-tests with Bonferroni correction (α = 0.05).

Precision was calculated using relative standard error of the mean log-transformed catch by each gear (RSE = 100 × sample standard error/mean), as has been done in numerous gear comparison studies (e.g., Van Den Avyle et al. 1995; Dumont and Dennis 1997; Koch et al. 2014; Flammang et al. 2016; Porta et al. 2021).

The number of replicates (i.e., sites sampled with a particular gear) required to detect a 10% or 25% change in catch rate was calculated as:

$$n = 2\left(t_{1-\alpha/2} + t_{1-\beta}\right)^2 / d^2$$

where *n* was the estimated sampling effort and *d* is the desired effect size (10 or 25% of the observed back-transformed mean) divided by the sample standard deviation (Campbell et al. 1995), as done in numerous gear comparison studies (Van Den Avyle et al. 1995; Sullivan et al. 2019). Significance levels of α = 0.05 and α = 0.10 were used because although 0.05 is most common, Type I errors were considered more acceptable if they resulted in conservative fishery protection or management actions (Sullivan et al. 2019).

In addition, mean total length (mm) was compared using the least-square means method from a general linear mixed model predicting fish length by gear. Year, waterbody, and site were treated as random effects, with site nested within waterbody. Differences between gears were tested by pairwise comparison using t-tests with Bonferroni correction (α = 0.05). Recognizing length was not normally or even unimodally distributed, we also calculated median total length (mm) and Proportional Size Structure (PSS) metrics by gear. Minimum proportional size categories followed Dumont and Neely (2011): Stock = 254, Quality = 406, Preferred = 508, Memorable = 610, and Trophy = 711 mm. Finally, length frequencies captured by each gear were compared using pairwise Kolmogorov-Smirnov tests, with a Bonferroni adjustment to establish statistically significant results (α = 0.05 across 6 comparisons). Median weight was also calculated.

Net Set Duration

Appropriate gill net sampling methods were further investigated at Lake Macbride through intensive sampling with the addition of standard large-mesh add-ons which expanded the range of mesh sizes for gill nets; these nets were set for 2-4 hours rather than overnight. Set duration was investigated by comparing catch rates between overnight sets (~24 hours) from Lake Macbride and other sample lakes and short sets (~2-4 hours). Short sets were timed to cover the dusk crepuscular period.

Mesh Selectivity and Representativeness of Gill Nets

Mesh selectivity was assessed for large-mesh standard AFS panels as that information was not available in the peer-reviewed literature. Gill net mesh sizes between 19 and 102 mm (19, 25, 32, 38, 44, 51, 57, 64, 76, 89, and 102 mm bar) were tested at Lake Macbride for their size selectivity of Hybrid Striped Bass. Fish caught were recorded by panel. Selectivity curves were fitted using the "select" function in the TropFishR package of R Studio Statistical software.

Representativeness of the true fish population was assessed by comparing length frequency distribution of unadjusted and adjusted data to *Morone* species retrieved after a piscicide application. During fall 2016, standard sampling recommendations (i.e., to use experimental gill nets with the large-mesh add-on) were tested at Three Mile Lake (Union County), which had been stocked with Hybrid Striped Bass since 2004. Prior to a rotenone application, experimental gill nets were deployed at Three Mile Lake. Fish collected during gill netting were measured, weighed, and structures were removed for age estimation. Following rotenone application, all dead and moribund Hybrid Striped Bass were again collected, measured, weighed, and structures removed for age estimation. The representativeness of fish length data collected by the experimental gill net with large-mesh add-on panels was assessed by comparing length frequency distribution of sampled fish with the distribution of dead *Morone* collected after rotenone application using a Kolmogorov-Smirnov test ($\alpha = 0.05$).

Standard Laboratory Protocol Development

From 2013-2016, a variety of structures were collected from Hybrid Striped Bass (up to 10 fish/10-mm length bin): sagittal otoliths, dorsal spines, anal spines, and scales (Table 2). Scales were typically removed from the left side behind the pectoral fin, unless the fish had scarring or injury in that spot; in that case the right side was used. Because these sampled populations were younger, additional dorsal spines and otoliths were collected from Three Mile Lake and Lake Macbride, which had older populations.

Table 2. Number of samples from Hybrid Striped Bass, from which four calcified structures (sagittal otoliths, dorsal spines, anal spines, and scales) were removed for comparison of age estimates, by location.

Location	County	Fish	Scales	Anal Spines	Dorsal Spines	Otoliths
Badger Creek Lake	Madison	67	56	46	61	67
Easter Lake	Polk	22	21	21	22	22
Lake Icaria	Adams	130	115	92	125	130
Lake Macbride		24	22	1	23	24
Three Mile Lake	Union	45	37	0	43	45
Lake Wapello	Davis	52	0	0	52	52
West Lake Osceola	Clarke	143	89	88	132	143

Spines were set in epoxy and sectioned using a diamond-edge high-precision saw, whereas both scales and otoliths were read whole. All structures were prepared for reading and digitally imaged under a microscope with power 3-10x. A double-blind reading process was used for each structure, and structures from the same fish were not examined together to avoid bias in age estimation. Disagreements between readers were resolved by reading the saved imagery together, re-assessing age estimates individually without additional metadata, and then coming to an agreement with available metadata (e.g., fish total length). If an agreement could not be reached, the structure was discarded due to poor quality.

We assumed sagittal otoliths would provide the least biased age estimates; each nonlethal structure was compared to it as a standard. Selection of a standard calcified structure for age and growth estimation depended on accuracy (based on otoliths) and consistency in reader agreement. Accuracy was assessed with linear regression of age estimates from each nonlethal structure with otolith age, slope of the fitted regression line (and if it differs from 1), and the amount of variance explained by the model (as measured by R^2).

Standard Fish Handling Practices

During 2017 and 2018, Rathbun Fish Hatchery grew out Hybrid Striped Bass to advanced fingerling size for the purpose of stocking into Big Creek Lake (funded through the Culture grant). In October, fish were harvested from earthen ponds outside and placed in an indoor pass-through raceway, allowed to rest overnight, then tagged with a 32-mm passive integrated transponder (PIT) tag. Methods differed between years.

In 2017, a sample of 100 fish were first collected from ponds via angling instead of seining in order to reduce net-related stress. Each fish was measured and weighed, then assigned randomly to one of three treatments: control, dorsal tagging, and body cavity tagging. PIT tags were inserted in the body cavity, anterior to the anus and to the left side to avoid damaging the fish's intestines, or into the dorsal muscle. A control group was handled but not tagged. One individual tagged all fish. No anesthesia was used for any of the treatments. These fish were held for 2 weeks to monitor bruising, disease, and other signs of stress related to the handling and tagging, and for post-tagging mortality and tag loss.

After establishing adequate survival and tag retention, a larger-scale tagging effort was made by draining and seining the earthen pond and repeating the tagging experiment. Tags were inserted into the body cavity by four different taggers working out of three raceway tanks. A stepwise logistic model was fitted to predict fish mortality using tagger, length, a binary indicator of whether the fish was weighed, and condition as input variables.

In 2018, several adjustments were made to improve post-tagging survival. First, fish were grown out longer until they exceeded 200 mm and water temperatures were cooler (Walsh et al. 2000). Fish were then seined and placed into raceways. Water in all raceway tanks was treated with 1.5-3.0 ppt salt solution immediately following tagging and daily thereafter. Anesthesia was tested using 100 ppm clove oil, which allowed for immediate fish release after recovery (MS-222 could not be used as it would disallow subsequent fish stocking). Treatment groups included anesthetized and tagged, tagged only, and handled only as a control. All fish were measured and weighed in air. Three taggers tagged fish, with each tagger replicating each treatment. Fish were held for three days to monitor post-tagging mortality. Mortality rates were compared among treatments using a stratified chi-square test, controlling for tagger (Cochran-Mantel-Haenszel test, $\alpha = 0.05$).

After this test, a second round of fish were tagged using the recommended anesthesia treatment when water was cooler. These fish were harvested using either seining or backpack electrofishing. Treatment groups included electrofished and tagged, seined and tagged, electrofished and handled, and seined and handled. The first fifty fish from each raceway were weighed in water to minimize unnecessary handling. A single individual tagged all fish. Fish were held for three days to monitor post-tagging mortality.

Finally, a large batch of fish were tagged using the recommended anesthesia treatment and harvest method. Two taggers tagged all fish. Fish were held for three days to monitor post-tagging mortality.

RESULTS AND DISCUSSION

Standard Field Sampling Protocol Development

Gear Type

Sampling occurred in September, October, and November with an average surface water temperature of 18.8°C. A total of 1,279 Hybrid Striped Bass were captured from the four primary study locations, with stocks varying substantially among locations (113 from Badger Creek Lake, 25 from Easter Lake, 789 from Lake Icaria, and 352 from West Lake Osceola). Catch varied greatly among gears as well: 23 by daytime electrofishing, 606 by nighttime electrofishing, 249 by experimental gill net, and 401 by single-mesh gill net.

Based on a general linear mixed model predicting catch by gear, gear type affected catch rate (Type III $F = 16.13$, $df = 4$, p-value < 0.0001), with gill nets catching more Hybrid Striped Bass per site than did electrofishing (Figure 1). Furthermore, gill nets yielded higher precision as indicated by lower RSEs, thereby requiring fewer samples to detect a change in mean catch rate (Table 3).

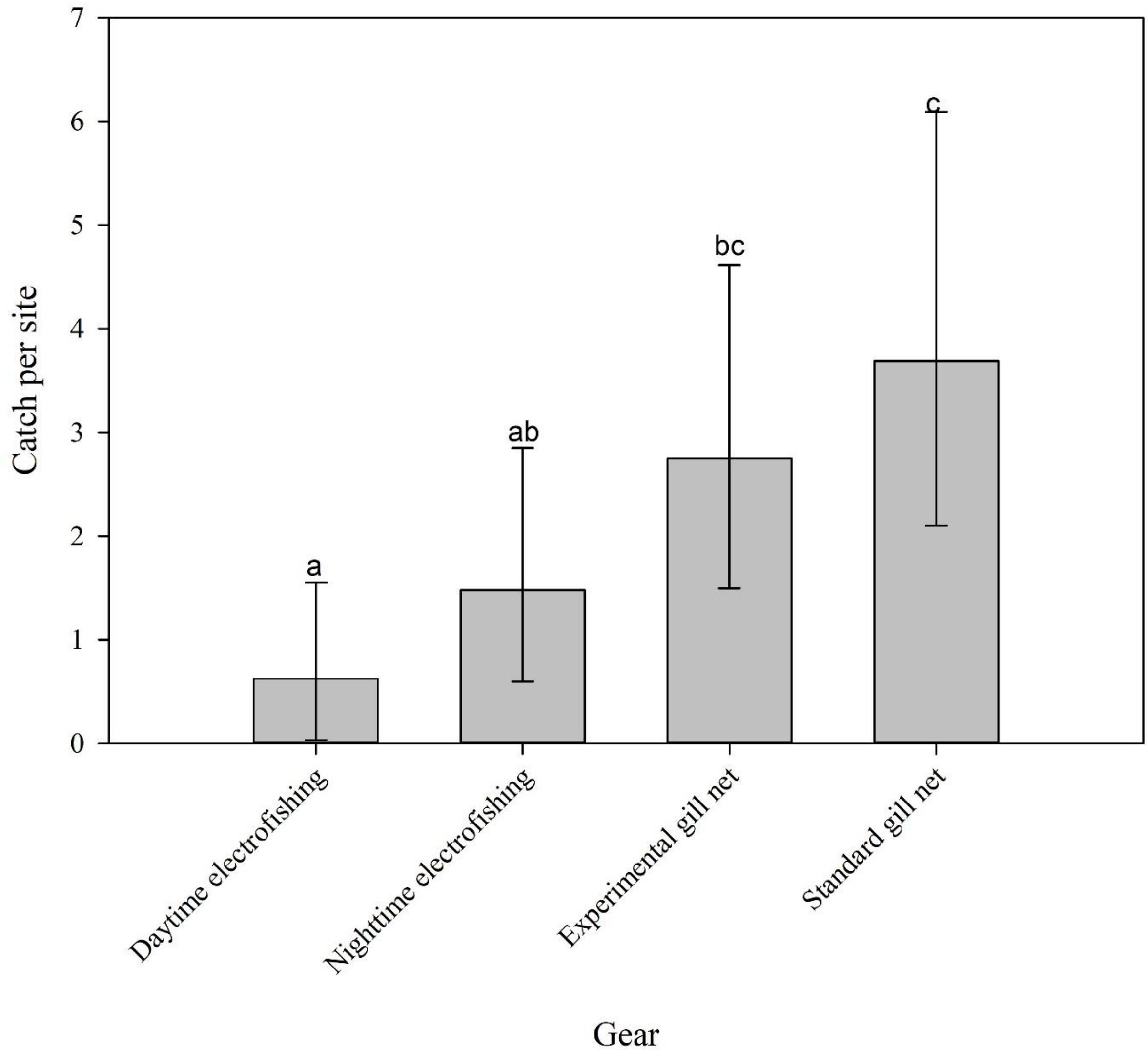

Figure 1. Mean catch rate (fish caught per site) of Hybrid Striped Bass, by gear type sampled in four reservoirs between 2014 and 2017. Gill net sites were defined with an effort of 18-24 hours (encompassing two crepuscular periods overnight), whereas electrofishing site effort was 15 minutes power-on time. Error bars indicate 95% confidence intervals, and letters indicate pairwise differences.

Table 3. Total fish caught, relative standard error (RSE), and number of sites needed to detect a 10% or 25% change in catch rate with 95% confidence (α = 0.05) or 90% confidence (α = 0.10). Type II error was held constant (β = 0.20).

Gear	Total Fish Caught	RSE	$n_\alpha = 0.05$		$n_\alpha = 0.10$	
			10%	25%	10%	25%
Daytime electrofishing	57	47	4123	660	3228	617
Nighttime electrofishing	636	24	736	118	576	93
Experimental gill net	273	15	214	35	168	27
Standard gill net	407	13	119	19	93	15

A total of 1,274 Hybrid Striped Bass were captured during gear comparison sampling and were measured for total length. Based on a general linear mixed model predicting fish length by gear, gear type affected the mean length caught (Type III F = 67.60, df = 4, p-value < 0.0001), wherein gill nets captured larger fish on average than did electrofishing (Figure 2). Experimental gill nets caught the largest fish.

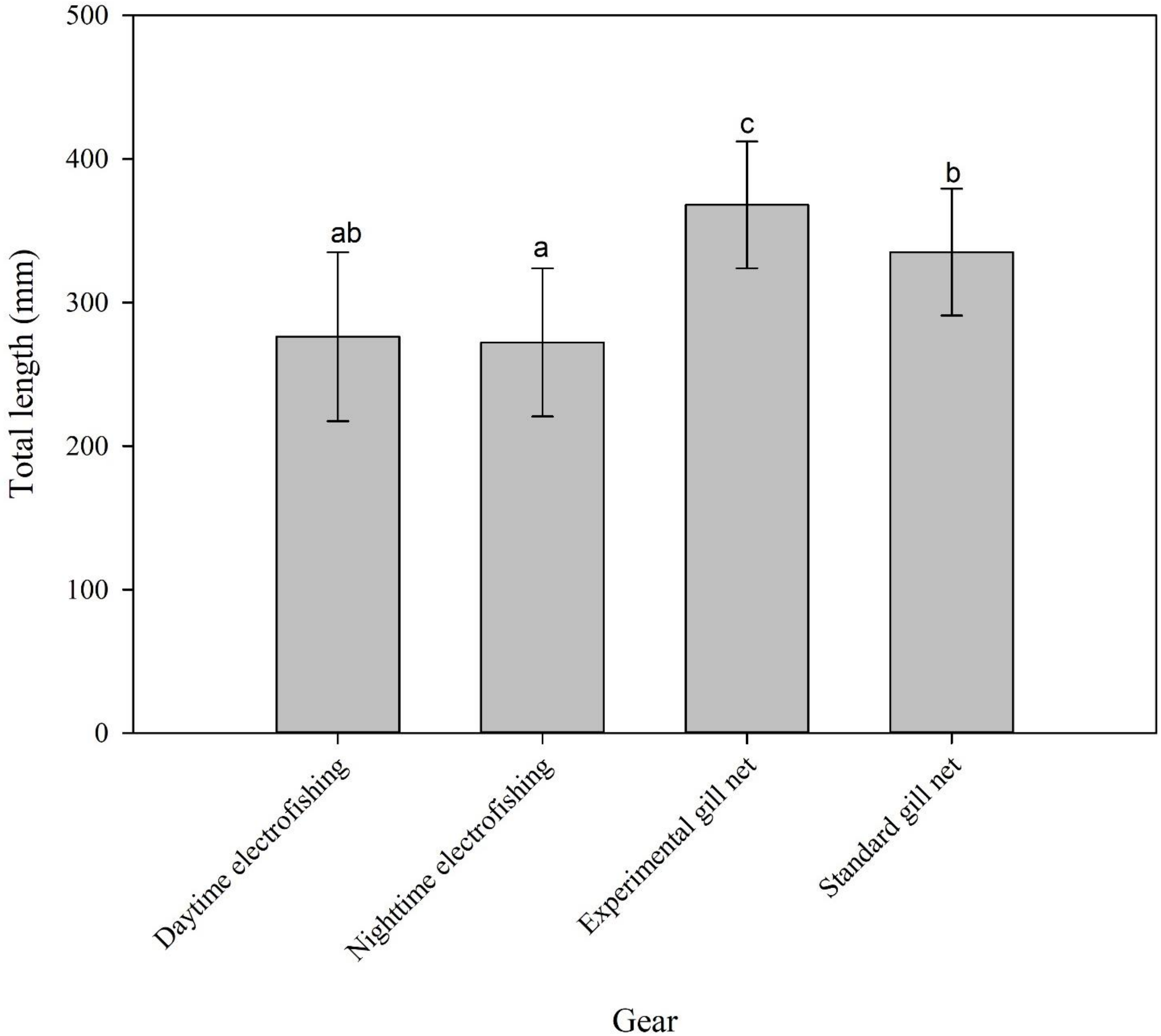

Figure 2. Mean total length of Hybrid Striped Bass captured by four gears in four reservoirs between 2014 and 2017. Error bars indicate 95% confidence intervals, and letters indicate pairwise differences.

Table 4. Hybrid Striped Bass total length (mm), weight (g), and proportional size structure indices (PSS) captured by four gears at four reservoirs between 2014 and 2017. Q = Quality, P = Preferred, M = Memorable, T = Trophy

Gear	N	Total Length			Median Weight	PSSQ	PSSP	PSSM	PSST
		Median	Minimum	Maximum					
Daytime electrofishing	22	276	105	373	198	0	0	0	0
Nighttime electrofishing	605	200	113	491	99	10	0	0	0
Experimental gill net	248	333	137	605	415	36	3	0	0
Standard gill net	399	362	137	598	557	44	2	0	0

A total of 515 fish were Stock size (≥254 mm; Figure 3). We did not capture fish above Memorable size during this portion of the study due to their young age. However, gill nets captured a wider range of lengths including larger fish compared to electrofishing. Electrofishing was more efficient for capturing Age-0 individuals below stock size.

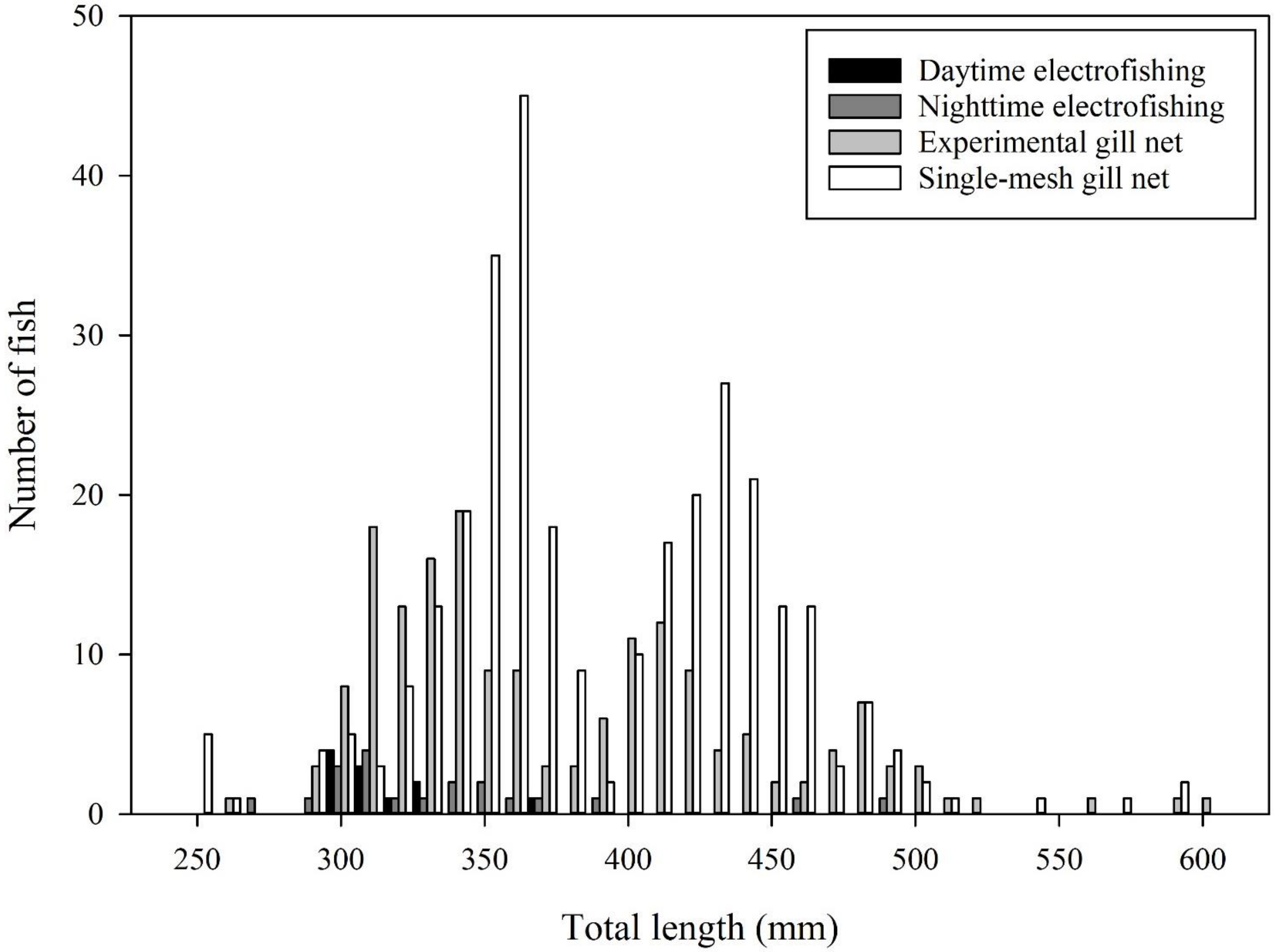

Figure 3. Length frequency of Hybrid Striped Bass stock size or greater captured by four gears at four reservoirs from 2014-2017.

Pairwise Kolmogorov-Smirnov tests indicated that daytime electrofishing yielded different size distributions than gill nets in general, and nighttime electrofishing yielded different size distributions than experimental gill nets (Table 5). Statistical significance is easier to achieve with higher catch rates, such as those achieved with gill nets. Nevertheless, it is clear that gill nets also sampled a different portion of the Hybrid Striped Bass population than did electrofishing.

Table 5. Pairwise comparisons of Hybrid Striped Bass length distribution between four sampling gears, based on the Kolmogorov-Smirnov test. Test statistic are provided, with p-values in parentheses. Significant differences are bolded based on Bonferroni correction.

Gear	Nighttime electrofishing	Experimental gill net	Standard gill net
Daytime electrofishing	0.172 (0.319)	0.135 (**0.0023**)	0.143 (**<0.0001**)
Nighttime electrofishing	-	0.091 (0.0790)	0.125 (**<0.0001**)
Experimental gill net	-	-	0.124 (**<0.0001**)

Given the greater precision of catch rate and more representative size distribution yielded by experimental gill nets, we recommend their use for standard sampling of Hybrid Striped Bass (McRae et al. 2013). We estimated that 27 net-nights would be needed to detect a 25% change in catch rate with $\alpha = 0.10$, but that estimate was derived from a subset of stocking locations. Every waterbody could differ based on fish density, surface area, and habitat complexity. Although we did not test sampling effort in relation to surface area, we do suggest that effort would need to be increased in larger waterbodies and could be decreased in smaller waterbodies. Mosher et al. (2004) recommended sampling effort for experimental gill nets ranging from 8 to 36 net-nights, depending on surface area of the target waterbody (Table 6). We suggest starting with these recommendations as a guideline, but effort can be tailored to the lake after catch rate RSE is determined; minimum sample sizes for conducting t-tests should be calculated based on desired detectable change and probability of Type I error. For instance, McRae et al. (2013) found that relatively few net-nights were needed to detect 30 or 50% change, which was all they were targeting at the time. All of these sampling recommendations were based primarily on sampling which occurred in October, when Hybrid Striped Bass are effectively captured.

Table 6. Recommended sampling effort (net-nights of experimental gill netting) for assessing Hybrid Striped Bass populations.

Surface Area (acres)	Minimum Effort	Recommended Effort
<300	4	8
300-2000	8	12
2000-6000	16	20
6000-9000	20	32
>9000	24	36

Net Set Duration

Although total fish catch reached a greater maximum with overnight sets of experimental gill nets than with shorter-duration sets (i.e., up to 53 fish captured at a single site at Lake Macbride), hourly catch rate was higher for short-set nets (up to nearly 3 fish/hour). Short-set nets caught an average of 0.76 fish/hour, whereas overnight nets caught an average of 0.22 fish/hour. In addition, the distribution of total fish caught did not significantly differ between set times (Kolmogorov-Smirnov test statistic = 0.0523, p-value = 0.5326). Statistical testing was limited by the fact that all short-set net data were collected at a single lake. Nonetheless, it appears that short-set nets could be used effectively if staff do not have multiple days to dedicate to Hybrid Striped Bass sampling. Furthermore, short-set nets caused no mortality during testing, with only 1 fish of 155 considered moribund after capture and removal from the net.

If fish mortality is a significant concern or if multiple days are not available for sample collection, then short-set nets can be used effectively. To minimize fish mortality, nets should be set for approximately 2-3 hours and retrieved, and can be accomplished throughout the day. Catch rates are higher, making this approach fairly efficient despite the short duration of soak time. This is a recommendation suggested in other states (Nelson et al. 2008) based on guidelines for smaller waterbodies (Mosher et al. 2004). Note that short-set nets would **not** align with the overall standard sampling protocol.

Mesh Selectivity and Representativeness of Gill Nets

After the enhanced efficiency and precision of gill netting was established, we investigated mesh selectivity and attempted to determine whether experimental gill nets provided more or less representative length frequency distributions than did standard gill nets. A total of 155 hybrid striped bass were collected across 52 experimental gill nets with large-mesh add-ons. Capture probabilities of mesh sizes were calculated for 20 mm length groups using a normal scale model. Generally, as mesh size increased, the optimum length group captured by that mesh size also increased (Figure 4). Without the large-mesh add-on, fish over 600 mm could easily be undersampled.

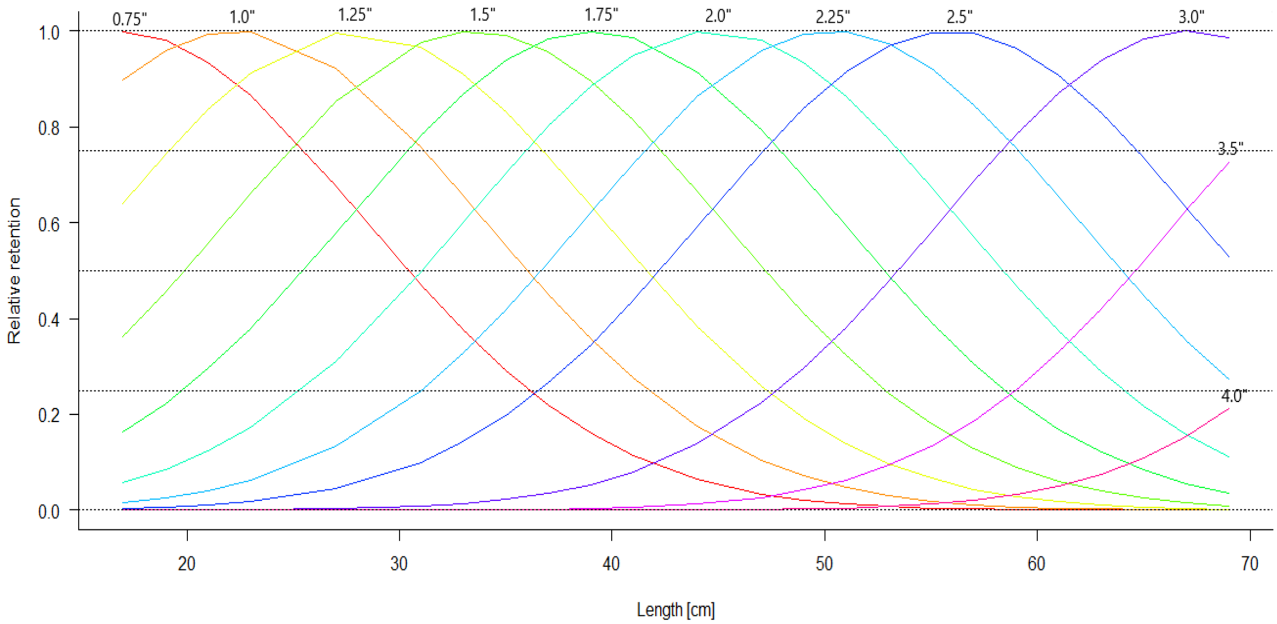

Figure 4. Selectivity curves for the eleven mesh sizes used in an experimental gill net with a large-mesh add-on, based on sampling of Hybrid Striped Bass at Lake Macbride in Fall 2018. The peak of each curve represents the "optimum" length of fish captured by that mesh size. Length measurements are recorded in centimeters (cm) for the purposes of this figure.

Although drawdown may have interfered with catch rates and made boat entry and net setting somewhat difficult, experimental gill netting resulted in a catch rate of 2.67 fish/net-night (SE = 0.33). A total of 47 dead fish were collected and processed. The size range collected using experimental gill nets was similar to the size range collected after rotenone application (Kolmogorov-Smirnov test D = 0.8974, p-value = 0.4087). Thus, experimental gill nets performed well in terms of collecting a representative sample of fish sizes from the available population. This test was limited by the absence of smaller Hybrid Striped Bass in the reservoir. However, high catch of Yellow Bass ranging between 150 and 250 mm was observed, and we assume that Hybrid Striped Bass in the same size range would have been captured if present. Furthermore, single-mesh gill nets captured a different size range of fish from that of experimental gills nets (Kolmogorov-Smirnov test D = 0.2580, p-value < 0.0001), capturing larger fish and missing the young year-classes.

Monofilament gill nets are the typical gear used to assess Hybrid Striped Bass in other states (Nelson et al. 2008; Perrion et al. 2020; Odenkirk et al. 2021). However, use of single-mesh versus experimental gill nets has been inconsistent. Given the substantial selectivity of various mesh sizes, we recommend use of the AFS standard experimental gill net with the large-mesh add-on for typical Hybrid Striped Bass population sampling, for complete representation of all size classes. Catch should be recorded by mesh size in order to apply selectivity curves during data analysis.

Standard Laboratory Protocol Development

A total of 483 otoliths were available to compare to scales, anal spines, and dorsal spines. Many fish from Badger Creek Lake, Easter Lake, Lake Icaria, and West Lake Osceola had all four structures available for comparison (Figure 5). Reader agreement ranged from 71.0% (i.e., for scales) to 86.6% (i.e., for dorsal spines). Anal spines also had high initial reader agreement (84.6%), and otoliths had intermediate initial reader agreement (75.6%). Most disagreements resulted from estimates differing by one year, and nearly all disagreements were easily resolved for the final age estimate. A very few structures were considered poor quality and discarded. Reader agreement rates can be one indicator of age estimation utility for calcified structures, in addition to accuracy and processing time (Isermann et al. 2003). Reader experience can also be important for fish above 4 years (Rude et al. 2013). We suggest that double-blind reading can greatly improve data quality by revealing inconsistent age estimation between readers, which can be addressed through remedial training. However, we also suggest that older Hybrid Striped Bass populations' structures be read by more experienced readers whenever possible.

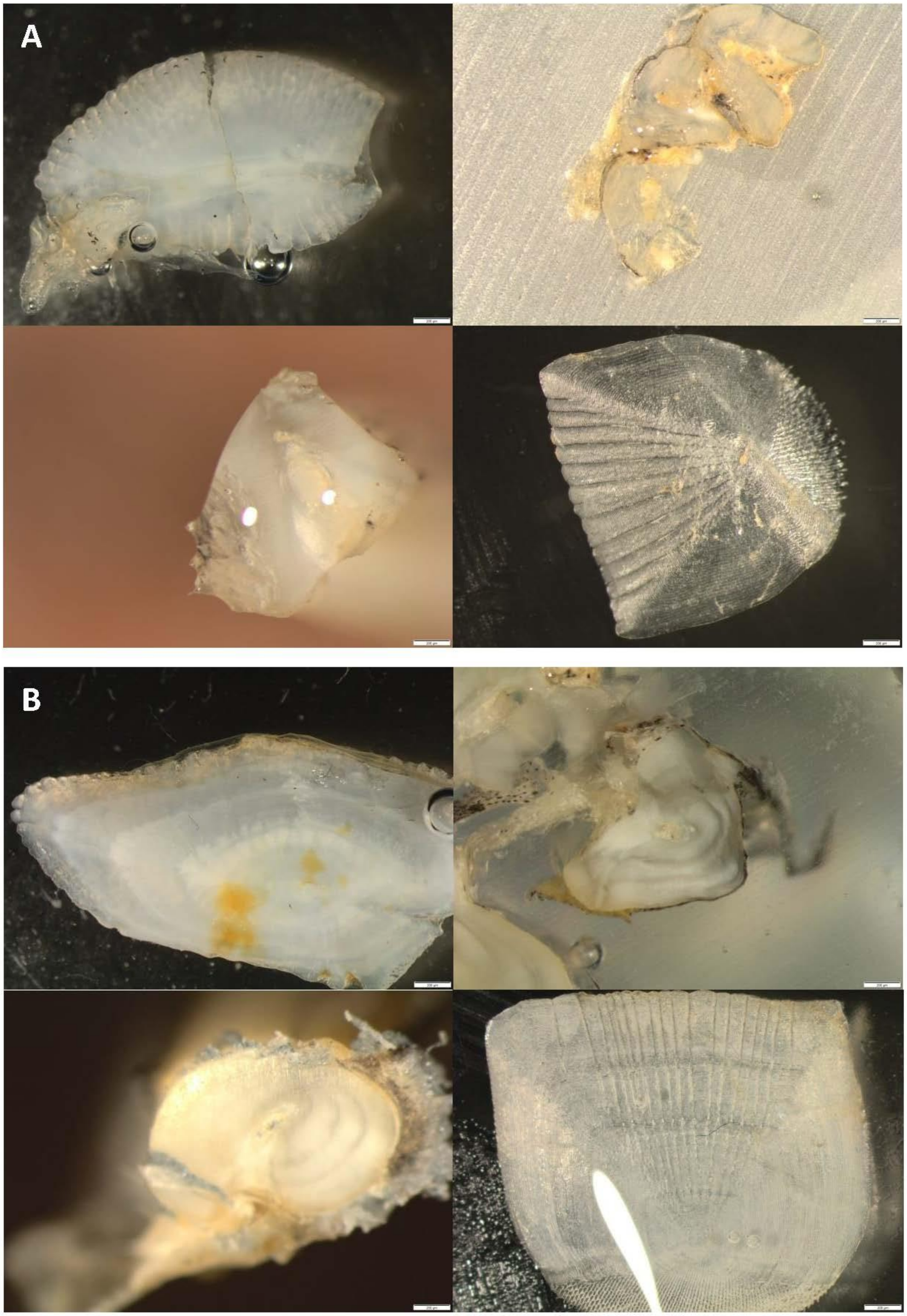

Figure 5. Example sagittal otoliths, dorsal spines, anal spines, and scales from two Hybrid Striped Bass from Lake Icaria (A) and Badger Creek Lake (B).

Age estimates from scales and anal spines aligned with estimates from otoliths 42% of the time, whereas estimates from dorsal spines aligned with estimates from otoliths 73% of the time. Estimates from scales tended to be lower than estimates from otoliths ($Age_{Scale} = 0.238 + 0.979 * Age_{Otolith}, n = 340, r^2 = 0.85$). Estimates from anal spines also tended to be lower ($Age_{Anal\ Spine} = 0.089 + 0.834 * Age_{Otolith}, n = 248, r^2 = 0.81$). Estimates from dorsal spines tended to be higher but aligned better than other non-lethal structures ($Age_{Dorsal\ Spine} = -0.058 + 1.023 *$

$Age_{Otolith}, n = 458, r^2 = 0.90$); the intercept parameter estimate was not significantly different than 0. These linear relationships were relatively strong, indicating the non-lethal structures could be used in place of otoliths.

Although scales were once popular in more northern latitudes for Moronidae (Maceina et al. 2007), our study indicated that spines performed better in terms of age estimate accuracy and reader agreement. Processing time may also be a consideration, with scales often requiring slightly less time to process than sectioned dorsal spines (e.g., Isermann et al. 2003). Dorsal spine sectioning may take 12.5 additional minutes of processing time (Isermann et al. 2003) compared to reading whole otoliths, and may take more processing time than either scales or whole-view otoliths (Isermann et al. 2003). However, we did not feel scales outperformed dorsal spines enough to justify the reduced accuracy. Based upon these findings, we recommended use of the sectioned dorsal spine for nonlethal age estimation of Hybrid Striped Bass.

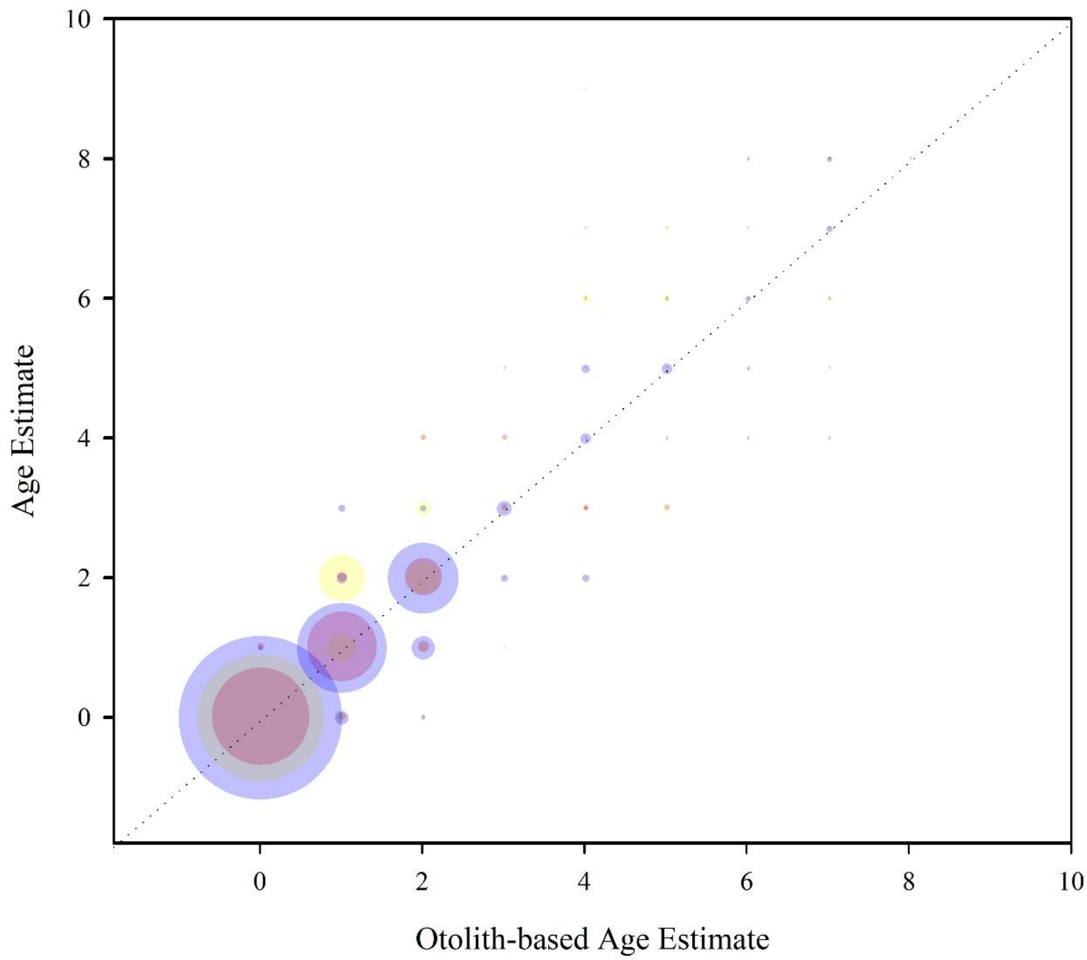

Figure 6. Estimates of age of Hybrid Striped Bass derived from dorsal spines (blue), anal spines (red), and scales (yellow) compared to estimates derived from a whole sagittal otolith.

Standard Fish Handling Practices

Advanced fingerling Hybrid Striped Bass reached approximately 189 mm by 10/2/2017, when the first sample of fish were angled and tagged. Water temperature was 21.1°C in the earthen pond and 21.7°C in the indoor raceway. The treatment groups did not differ in mean total length, weight, or condition. After two weeks, mortality did not differ between tagged fish and the control fish ($\chi^2 = 2.523, p\text{-value} = 0.641$), and most mortalities occurred within one day. However, fish tagged in the dorsal muscle were bruised and torpid for two days before recovering; dorsal muscle tagging was also not preferred due to the risk of angler consumption. Tag loss after two weeks was also very low across treatments (Table 7).

Table 7. Sample size, mean total length (TL [mm]), mean weight (W [g]), number of mortalities, and number of tags lost after two weeks by advanced fingerling Hybrid Striped Bass, by tag location treatment group. 95% confidence intervals are shown in parentheses.

Treatment	Sample Size	Mean TL	Mean W	Condition	Mortalities	Lost Tags
Control	33	190.6 (186.7 - 194.6)	101.3 (94.0 - 108.6)	110.3 (107.7 - 112.9)	5	n/a
Dorsal Muscle	34	188.9 (184.2 - 193.7)	99.3 (92.0 - 106.7)	111.2 (108.9 - 113.4)	4	0
Body Cavity	33	187.2 (182.7 - 191.8)	96.2 (88.5 - 103.9)	110.4 (107.8 - 112.9)	3	1

Therefore, the large-scale tagging effort began with fishing being seined from the earthen pond and brought indoors; this occurred in early October 2017 when pond temperatures were 20°C. Although Tagger 2 worked with smaller fish, their condition was fairly similar to other taggers. However, since condition did vary between tanks, it was included in modeling as a covariate.

This resulted in mass mortality of study fish over three days. Possible factors affecting mortality in general and tagging-related mortality included fish size, fish condition, tagger (person), handling time due to weighing, pond temperature, and lack of anesthesia. The first day post-tagging had 36.4% of the mortalities, second day 8.4%, and third day 55.2%. Because all fish eventually died, we fitted the logistic model using mortality after one day in order to identify which variables may have been most important.

Table 8. Sample size, mean total length (TL [mm]), mean weight (W [g]), number of mortalities, and number of tags lost after two weeks by advanced fingerling Hybrid Striped Bass, by tagger. 95% confidence intervals are shown in parentheses.

Tagger	Tank	Sample Size	Mean TL	Mean W	Condition	Mortalities	Lost Tags	Tag Broken
1	1	421	184.0 (182.0 - 185.9)	103.4 (97.3 - 109.4)	107.3 (106.1 - 108.5)	420	0	1
2	2	211	181.1 (178.1 - 184.1)	70.8 (63.7 - 77.9)	101.5 (99.7 - 103.3)	208	2	1
3	3	400	186.9 (185.8 - 187.9)	92.3 (86.6 - 98.1)	113.9 (112.3 - 115.5)	395	0	5
4	2	213	193.4 (191.8 - 194.9)	104.5 (100.5 - 108.6)	104.2 (102.9 - 105.5)	213	0	0

The stepwise logistic model indicated that tagger, fish length, and fish condition were important variables affecting mortality within 24 hours of tagging (all Type III χ^2 p-values < 0.05). Although tagger did matter, with one tagger yielding a lower mortality rate than others, the most important and useful factor was total length (Figure 7). Condition as indicated by relative weight was also important. General environmental conditions aside, future tagging operations would need to occur after advanced fingerlings have grown to at least 200 mm (i.e., nearly 8 inches). This means fish must be grown out through October and possibly November; this also would also allow the pond and raceway water temperature to get cooler.

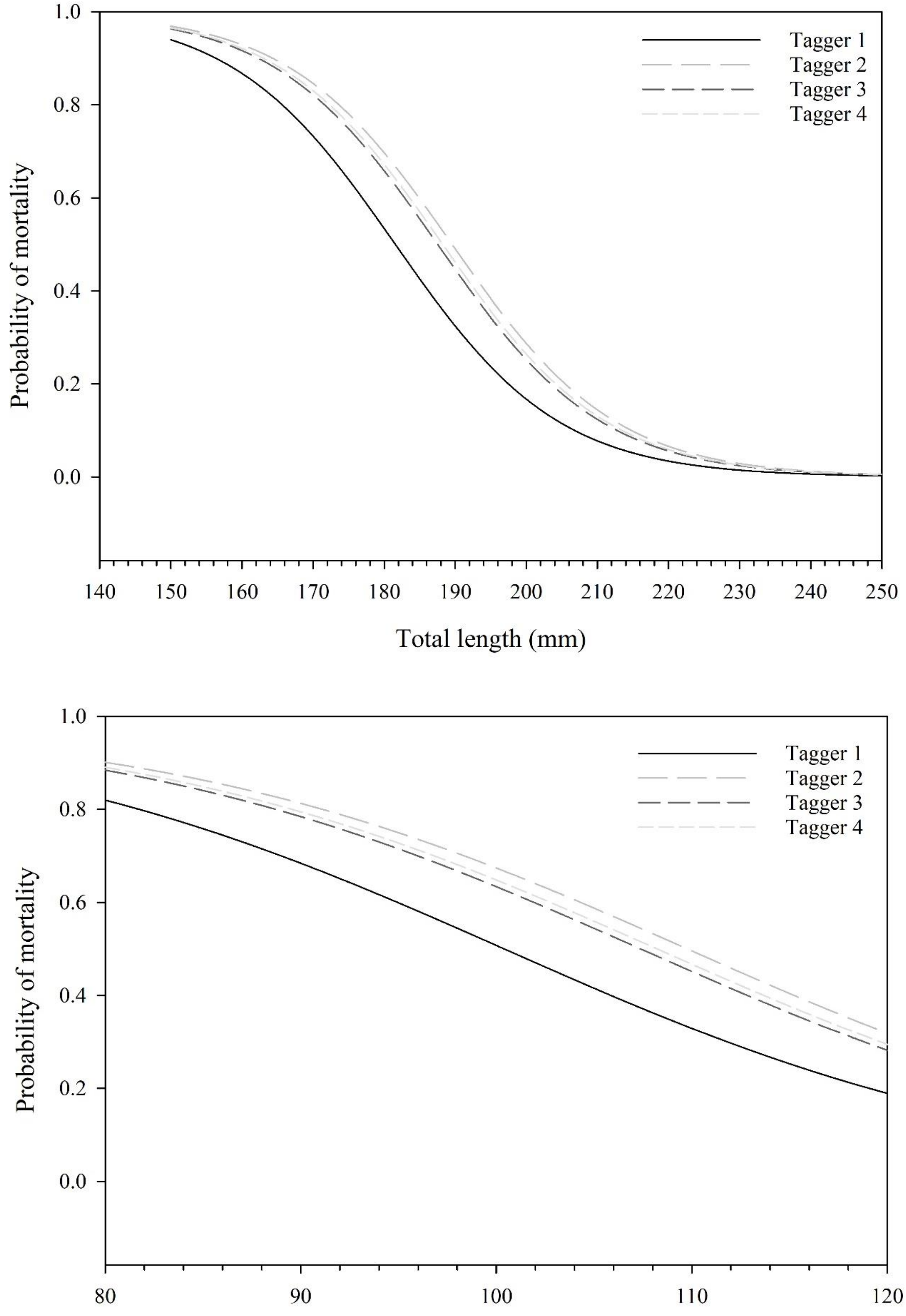

Figure 7. Probability of 24-hour post-tagging mortality of advanced fingerling Hybrid Striped Bass by total length and relative weight, with variation by tagger. Panel A shows probability with relative weight held as its mean. Panel B shows probability with total length held at its mean.

In 2018, the effect of fish anesthesia was tested in late October (10/23/18). A total of 231 fish were included in the experiment. Taggers varied in their results, but treatment was significant when controlling for tagger as a replicate using the Cochran-Mantel-Haenszel test (CMH = 31.5, p-value < 0.0001; Table 9). Control fish had a 79.7% mortality rate, tagged fish had a 41.3% mortality rate, and anesthetized-and-tagged fish had a 68.8% mortality rate overall.

It is unclear why control fish had such a high mortality rate, but the key lesson was that anesthesia using clove oil did not benefit the tagged fish. This may be due to the extra handling associated with moving fish into and out of treated water, or could have been an effect of the anesthesia itself. We also noted fungal issues associated with cooler water, specifically *Saprolegnia* with can emerge below 20°C. The impact of spine injuries leading to *Columnaris* and *Saprolegnia* infection could be seen as "finger marks" which appeared, ultimately leading to delayed mortality despite remedial salt and hydrogen peroxide treatments (>60% delayed mortality by the end of this experiment).

Table 9. Mortalities of Hybrid Striped Bass in associated with an anesthesia treatment.

Tagger	Control		Tagged Only		Anesthetized and Tagged	
	Alive	Dead	Alive	Dead	Alive	Dead
1	1	24	8	17	3	24
2	12	14	25	0	13	12
3	3	25	11	14	8	17
Overall	**16**	**63**	**44**	**31**	**24**	**53**

Harvest method was tested in mid-November when water temperatures had fallen below 12.8°C (11/15/18). A total of 957 fish were included in the experiment. We documented no mortalities from this experiment regardless of tagging or harvest method. However, we did document some electrofishing-related damage that could contribute to fish stress, including a burn mark and bruising. Therefore, we recommended seining as an appropriate harvest method, and holding fish overnight after seining was not required.

The final method was applied to 1,071 fish in late November (11/27/18). Fish were seined from the earthen pond and tagged in the body cavity without anesthesia. The first fifty fish in each tank were weighed in water, but the rest were only measured for length. All tanks were heavily salted immediately afterward and daily thereafter. Only three mortalities were recorded within 3 days post-tagging (Table 10), and fish were successfully stocked into a lake.

Table 10. Mortalities of Hybrid Striped Bass using final tagging method.

Tagger	Alive	Dead
1	548	1
2	520	2

As a result of these experiments, a simple guide was put together to guide any Hybrid Striped Bass tagging effort in the future (Figure 8). As indicated in the guide, routine handling should entail working with the fish at lower temperatures and with generous salt treatment. Salinity has been found to significantly improve survival from handling in Striped Bass as well (Wallin and Van Den Avyle 1995). Tagging will inevitably reduce survival rates, but smaller fish are more likely to experience mortality than larger fish from the handling alone (Wallin and Van Den Avyle 1995). Thus, fish should not be tagged with a PIT tag until they exceed around 200 mm.

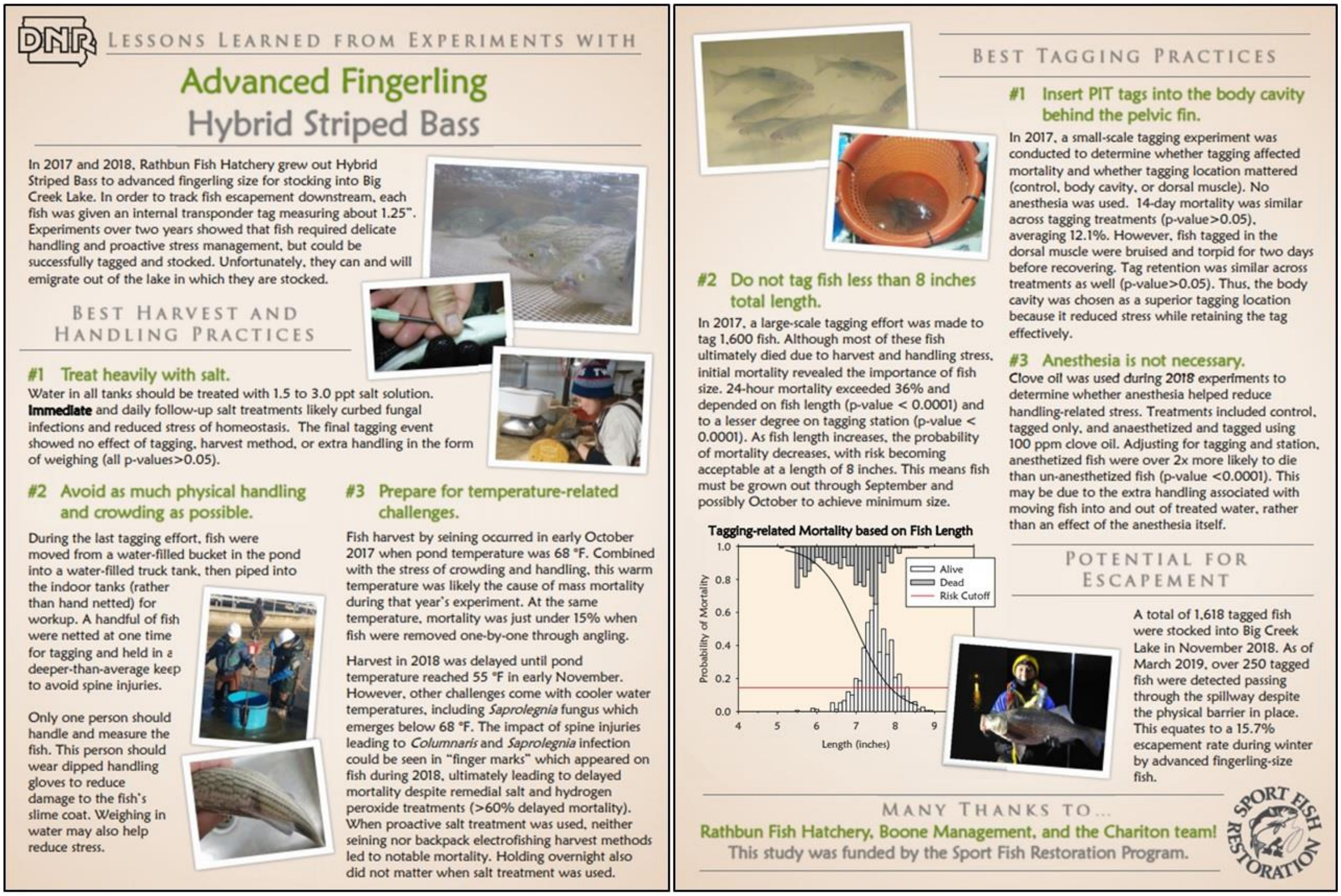

Figure 8. Summary of best practices for handling and tagging advanced fingerling Hybrid Striped Bass as determined by experiments in 2017 and 2018.

MANAGEMENT IMPLICATIONS

The following recommendations derive from this study's investigations of appropriate field, laboratory, and hatchery fish handling processes, and may be incorporated into a standard protocol for Hybrid Striped Bass managed in Iowa.

- Sampling gear and deployment
  - Standard American Fisheries Society (AFS) experimental gill nets with large-mesh add-on panels should be used to assess populations of Hybrid Striped Bass. These nets are described in detail by Bonar et al. (2009). The standard net is an 8-panel net with panels 3.1-m long by 1.8-m deep, with mesh sizes 19, 25, 32, 38, 44, 51, 57, and 64 mm bar. The large-mesh add-on is a series of 3 panels 3.1-m long by 1.8-m deep, with mesh sizes 76, 89, and 102 mm. This add-on should be attached to the end of the core net.
  - The AFS standard deployment is to set nets during late afternoon and retrieve them the following day, encompassing two crepuscular periods. Although this can result in high mortality rates, overnight nets can capture a higher total number of fish and may be more convenient for staff.
  - If fish mortality is a significant concern or if multiple days are not available for sample collection, then short-set nets can be used effectively. To minimize fish mortality, nets should be set for approximately 2-3 hours and retrieved, and can be accomplished throughout the day. Catch rates are higher, making this approach fairly efficient despite the short duration of soak time. The guidelines regarding number of net sets are similar to standard overnight sets. However, data derived from short-set nets are *not* standard data!
  - Data recorded should be separated by mesh size, in order to share data in the future by standard net specification. This entails not only separating catch between the main net and the large-mesh panel, but between each individual mesh panel. This is necessary to make mesh selectivity-based adjustments.
  - Sampling should occur in fall, ideally October, with a minimum sampling effort of 8 net-nights or more, depending on surface area.

- Age estimation
    - Dorsal spines should be removed from the front of the dorsal spines for age estimation of Hybrid Striped Bass in Iowa.
    - Spines should be set in epoxy and sectioned thin using a diamond-edge high-precision saw, then read under a microscope using power 3-10x. A double-blind reading process should be used for each structure to avoid bias in age estimation.
- Handling and tagging
    - Hybrid Striped Bass which have been cultured may be safely harvested from earthen ponds by seining, and do not need to be held overnight prior to additional handling. However, harvest should be delayed until water temperatures are below 12.8°C and fish exceed 200 mm TL. If those fish are placed in raceways, the raceways should be salted immediately after stocking at a rate of 1.5 to 3.0 ppt salt solution, and salted again daily thereafter to minimize fish stress and reduce fungal infections.
    - Hybrid Striped Bass should be handled with fish handling gloves to avoid damaging the slime coat, and should only be weighed if necessary. If weighed, they should be weighed in water.
    - Hybrid Striped Bass may be tagged (i.e., with a 32-mm PIT tag) in the body cavity without anesthesia. Again, raceways receiving tagged fish should be salted immediately thereafter to minimize stress and boost fish recovery. Fish may be stocked immediately or held overnight.

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APPROACH 2: HYBRID STRIPED BASS CROSS COMPARISON.

INTRODUCTION

Iowa Department of Natural Resources (DNR) began stocking Hybrid Striped Bass *Morone saxatilis* x *M. chrysops* into Saylorville Reservoir in 1981 (Mayhew 1987). Early stockings were Palmetto Bass *M. saxatilis* ♀ x *M. chrysops* ♂, obtained through fish trades and later purchases from both private and public hatcheries. Fry were sometimes grown out to fingerling size at Rathbun Fish Hatchery and later Mount Ayr Fish Hatchery, and stocked into the large flood control reservoirs and several larger lakes and reservoirs including Lake Manawa and Three Mile Lake. More recently, Iowa DNR expanded its stocking program to smaller impoundments and urban ponds, producing all fingerling Hybrid Striped Bass in-house by obtaining hybridized fry and growing them out in earthen ponds. However, obtaining Palmetto Bass fry and Sunshine Bass fry differed in cost and feasibility. Sunshine Bass *M. chrysops* ♀ x *M. saxatilis* ♂ could be easier to produce in future culture efforts, as the eggs can be obtained from native White Bass and the semen can be shipped from coastal states (Morris et al. 1999; McEntire et al. 2015). Palmetto Bass, on the other hand, must be produced from Striped Bass eggs, which are difficult to obtain and transport (Davis and McEntire 2009); therefore procuring Palmetto Bass means procuring fry that have been produced elsewhere. There was also high interannual variability in the availability of fry of each strain.

According to a recent survey of primarily state agencies, about 58% of hatcheries that produced Hybrid Striped Bass cultured the Palmetto, 30% produced Sunshine, and 12% raised both (Wamboldt 2012). Although Sunshine Bass had lower pond survival, Wamboldt did not report obvious differences in harvest size or growth by the end of Phase 1 (fingerling size or approximately 60 days) from data reported by survey participants. In some cases, Sunshine Bass may outperform Palmetto Bass in terms of mean daily growth rate and relative weight during grow-out (Rudacille and Kohler 2000). Most typically, the crosses differ slightly in terms of mean initial weight, with Sunshine Bass being *smaller* than Palmetto Bass, but can converge in mean and total weight produced over time (backcross hybrids: Jenkins et al. 1998; McEntire et al. 2015). These initial differences may derive from maternal influence on egg and larval size, swim-up timing, gape size, and ontogenetic diet shift timing (Bosworth et al. 1997; Ludwig 2004).

In addition to potential production cost differences between the two crosses (Schultz 2012), little was known regarding their relative survival and growth in Iowa waters. The crosses may differ as adults in recruitment to stock size, overall growth, and movement and emigration from reservoirs, as found in an Oklahoma reservoir where both were stocked concurrently (Kuklinski 2014). They have also been shown to differ from parent species in terms of temperature tolerance (Kelly and Kohler 1999) and cortisol response to stressors (Davis and McEntire 2009), with the hybrid being more similar to its maternal species. If these differences are found in Iowa populations, then Iowa DNR may have reason to choose one or the other for culture and stocking. For example, Iowa is on the northern edge of Hybrid Stripes Bass distribution due to their thermal preferences. Palmetto Bass are known to have a lower cold tolerance than Sunshine Bass, a maternal effect which could translate to lower fry or fingerling survival in the event of a cold snap after stocking (Kelly and Kohler 1999).

Therefore, our objective was to compare Palmetto and Sunshine Bass stocked into Iowa lakes in terms of survival to the first fall, growth rate, and body condition.

METHODS

Study Locations

Five locations were stocked with both crosses of Hybrid Striped Bass from 2012 to 2018 (Figure 11). The Palmetto cross (*Morone saxatilis* ♀ × *M. chrysops* ♂) and Sunshine cross (*M. chrysops* ♀ × *M. saxatilis* ♂) were stocked as fingerlings at a rate of approximately 25 fish/ha (10 fish/acre) each. Stocking ended early at Easter Lake due to a fishery renovation.

Table 11. Study locations where Hybrid Striped Bass were stocked and sampled. The target number of fish stocked is the number for each cross.

Location	Surface Area (ha)	County	Management Region	Target Number Stocked
Badger Creek Lake	112	Madison	Mount Ayr	2,760
Easter Lake	72	Polk	Boone	1,780
Lake Icaria	262	Adams	Mount Ayr	6,480
Lake Wapello	117	Davis	Rathbun	2,890
West Lake Osceola	129	Clarke	Mount Ayr	3,200

Data Collection

Fish were sampled using a variety of gears: nighttime electrofishing, daytime electrofishing, single-mesh gill nets, and experimental mesh gill nets. Electrofishing was conducted using a boat with two anode spider-style droppers and pulsed DC current. Electrofishing transects were at fixed sites across years, and typically 15 minutes in duration of power-on time. Daytime transects were completed during daylight hours, and nighttime transects were completed beginning 30 minutes after sunset. Single-mesh gill nets were made of monofilament panels hung 1.8-m deep with 64-mm bar mesh, totaling 48.8 m in length. Experimental gill nets were made of eight 3.1-m monofilament panels hung 1.8-m deep, each with a different mesh size (19, 25, 32, 38, 44, 51, 57, and 64 mm bar), totaling 38 m in length. Nets were set at fixed sites across years, and set overnight to encompass two crepuscular periods (dusk and dawn). All samples were collected during autumn when water temperatures were below 25°C, typically in October.

All Hybrid Striped Bass captured were measured (total length [TL, mm]), weighed (g), and counted. Both sagittal otoliths and dorsal spines were collected for the first several years of the study, then only dorsal spines. Structures were removed from up to 10 fish/10-cm length bin throughout this study. Genetic tissue was removed from each fish by clipping the left pectoral fin and storing it in sealed vials. If that fin was missing or damaged, the right pectoral fin was used. If the fish were especially small (i.e., Age-0), a larger portion of the caudal fin was removed to ensure adequate genetic tissue volume. Samples were placed on ice in the field, then moved to a freezer for storage until processing.

Data Analysis

Cross Identification

Genetic samples were sent to an outside laboratory for completion of all genetic analyses. First, a methodology for identifying the crosses was developed using genetic tissues collected directly from the culture ponds (i.e., known cross) in 2012. Genomic DNA was extracted from frozen tissue using standard proteinase K/SDS digestion and blood and tissue kits. An ~1,100 base pair region of mitochondrial cytochrome b gene was amplified using PCR primers from Song et al. (1998), and then thermal cycling was used for double-stranded amplification as follows: 95°C for 40 sec, followed by 52°C for 60 sec, and 72°C for 90 sec for a total of 35 cycles. Purified PCR products were then used as a template for cycle sequencing reactions, which were cleaned, resuspended in 10 μL of formamide, and read by an ABI 3100 automated sequencer. Aligned sequences were then compared and scored for quality, yielding an indicator of maternal parent.

After the cross identification methodology was established, all genetic samples from Hybrid Striped Bass could be processed the same way. Genetic tissue sample analysis continued through 2023 (due to delays related to COVID).

Return to Stock

The relative return to stock by cross was assessed using a stratified χ^2 test called the Cochran-Mantel-Haenszel test (CMH). The test was applied with lake-years as strata and cross as the categorical outcome ($\alpha = 0.05$). Instead of a treatment factor, the observed versus expected numbers of fish were used based on stocking records and number of recaptured fish.

Growth and Condition

To determine age, sagittal otoliths were used preferentially to dorsal spines. Otoliths were read whole, while dorsal spines were set in epoxy and sectioned using a diamond-edge high-precision saw. All structures were prepared for reading and digitally imaged under a microscope with power 3-10x. A double-blind reading process was used for each structure, and structures from the same fish were not examined together to avoid bias in age estimation. Disagreements between readers were resolved by reading the saved imagery together, re-assessing age estimates individually without additional metadata, and then coming to an agreement with available metadata (e.g., fish total length). If an agreement could not be reached, the structure was discarded due to poor quality. We assumed sagittal otoliths would provide the least biased age estimates; the estimate derived from an otolith was used if available. Otherwise the estimate from a dorsal spine was used.

A series of von Bertalanffy growth curves were fitted to the data as $L_t = L_\infty\left(1 - e^{-K(t-t_0)}\right)$, where L_t = total length at time t, L_∞ = asymptotic length, K = growth coefficient, and t_0 = time when length equals zero. Models allowed one or more parameters to vary by cross, or allowed none of the parameters to vary by cross. Akaike's information criterion (AIC) was determined for each model, and the model with the lowest AIC was retained as the best model. Data from all gears were used to fit each model. We used nonlinear regression with starting parameter values established for Hybrid Striped Bass in Midwestern lakes by Schultz et al. (2013); starting values were kept constant across modeling efforts (NLMIXED Procedure, SAS 9.4).

Similarly, length-weight relationships were fitted as $W = aL^b$, where W = weight (g), L = total length (mm), b = growth coefficient, and a = arbitrary intercept value, base 10. We used linear regression with log-transformed lengths and weights (GLMSELECT Procedure, SAS 9.4), inputting data from all gears. Several models were tested, allowing one or both parameters to vary by cross, or allowing neither to vary by cross. Again, AIC was determined for each model, and the model with the lowest AIC was retained as the best model. Condition, as measured by relative weight, was also compared between crosses using a t-test for differences in least-square means. Relative weight (Wr) was calculated as $W_r = 100 * W/W_S$ using the standard weights suggested by Brown and Murphy (1991).

RESULTS AND DISCUSSION

Return to Stock

Both crosses were stocked from 2012 to 2016 into each study lake at a known ratio (Table 12). The number of fish recaptured differed by cross, lake, and across years, with almost 60% of the recaptured fish being Palmettos (Table 13). Rather than using the raw number of fish stocked in the stratified χ^2 tests to establish the expected ratio of Palmettos:Sunshines, we applied the ratio stocked and multiplied it by an arbitrary number needed to achieve a similar number of total fish "stocked" as the total number recaptured during field sampling. This helped reduce the effect on the test statistic of high stocking numbers relative to the number of fish recaptured (Table 14). Incorporation of the ratio stocked was important because it was not consistently 1:1, but rather tended to be heavier on Palmettos, making the expected likelihood of recapture higher for Palmettos during field sampling.

Table 12. Number and ratio of two crosses of Hybrid Striped Bass stocked into five Iowa reservoirs from 2012 to 2016.

Location	Year	Date Stocked	Palmetto	Date Stocked	Sunshine	Ratio Stocked
Badger Creek Lake	2012	6/28	2,891	6/28	1,575	1.84:1
	2013[1]	-	2,891	-	1,575	1.84:1
	2014	6/17	4,437	6/17	3,808	1.17:1
	2015	6/16	2,758	6/29	2,756	1.00:1
	2016	6/16	2,784	6/16	3,656	1:1.31
	2017[3]	n/a	0	6/29	2,842	n/a
Easter Lake	2012	6/28	2,535	6/28	1,005	2.52:1
	2013	-	3,163	-	1,707	1.85:1
Lake Icaria	2012	6/28	6,819	6/28	3,686	1.85:1
	2013[1]	-	5,121	-	2,765	1.85:1
	2014	6/17	10,567	6/17	8,995	1.17:1
	2015	6/16	6,609	6/29	6,470	1.02:1
	2016	6/16	6,821	6/16	7,670	1:1.12

Location	Year	Date Stocked	Palmetto	Date Stocked	Sunshine	Ratio Stocked
	2018[3]	n/a	0	6/27	6,708	n/a
Lake Wapello	2012	6/28	3,114	6/28	2,044	1.52:1
	2013[1]	9/27			889[2]	n/a
	2014	6/17-6/18	3,541	6/17/-6/18	3,541	1:1
	2015	6/16	2,730	6/29	2,715	1.01:1
	2016	6/16	3,132	6/16	3,130	1:1
West Lake Osceola	2012	6/28	3,336	6/28	1,810	1.84:1
	2013[1]	-	2,502	-	1,357	1.84:1
	2014	6/17	5,296	6/17	4,458	1.19:1
	2015	6/16	3,232	6/29	3,363	1:1.04
	2016	6/16	3384	6/16	3881	1:1.15
	2017[3]	n/a	0	6/29	3,654	n/a
	2018[3]	n/a	0	6/27	3,246	n/a

[1]In 2013, a lack of Palmetto Bass and a shortage of Sunshine Bass produced by Iowa DNR led to altered stocking using fingerlings procured directly from outside sources (i.e., Kansas and Arkansas); complete stocking records including dates were not kept.
[2]Due to Lake Wapello's late inclusion in this study, fish were not obtained for it during 2013, and the lake was instead stocked with an unverified cross of advanced fingerling Hybrid Striped Bass which had been grown out. The cross was most likely Sunshine Bass produced by Mount Ayr Fish Hatchery.
[3]Stocking for the purposes of this study was ended after 2016. However, some lakes continued to receive stockings of one cross or the other to continue developing a fishery. Thus, it is possible for these year-classes to appear in the sampling data.

Table 13. Percentages and total number of two crosses of Hybrid Striped Bass recaptured from five Iowa reservoirs from 2013 to 2019.

Location	Year	% Palmetto	% Sunshine	Total N
	2013	0	100	1
	2014	28.6	71.4	14
Badger Creek Lake	2015	62.5	37.5	40
	2017	87.5	12.5	16
	2018	83.3	16.67	6
Easter Lake	2014	54.6	45.5	11
	2015	66.7	33.3	3
	2013	81.5	18.5	54
	2014	58.3	41.7	127
	2015	47.4	52.6	154
Lake Icaria	2016	42.9	57.1	14
	2017	44.3	55.7	61
	2018	73.5	26.5	34
	2019	85.7	14.3	14
	2016	42.3	57.7	52
Lake Wapello	2017	53.6	46.4	28
	2018	68.8	31.3	32
	2019	0	100	1

Location	Year	% Palmetto	% Sunshine	Total N
	2014	64.7	35.3	17
	2015	59.8	40.2	82
West Lake Osceola	2017	53.5	46.5	127
	2018	68.0	32.0	100
	2019	82.3	17.7	62
Total		**59.3**	**40.7**	**1,050**

Table 14. Observed and expected number of Palmetto and Sunshine Bass used to examined relative cross survival success.

Observed and Expected	Cross	
	Palmetto	Sunshine
Proportional number stocked	646	375
Number recaptured	608	413

The stratified χ^2 test indicated that the ratio of Palmetto Bass to Sunshine Bass did not differ significantly from the ratio stocked (CMH = 1.2259, *p*-value = 0.2682). In examining relative risk of each column value, Sunshine Bass had a slightly higher risk of being recaptured relative to their stocking rate than did Palmetto Bass, but all relative risks overlapped with 1 (Table 15). Odds can be calculated by dividing the "risks" in each cell (e.g., Sunshine Bass had 13% greater odds of being recaptured than would have been expected based on their stocking rate), but again, odds ratios overlapped with 1.

Thus, we did not find a difference in the return of one cross versus the other in field sampling for fish up to Age 6. Similarly, both crosses were stocked into an Oklahoma reservoir in equal numbers, and catch rates of stock-size fish did not differ in subsequent sampling (Kuklinski 2014).

Table 15. Relative "risk" of Palmetto and Sunshine Bass being stocked and being recaptured later, given variance between locations and years of sampling.

Observed and Expected	Cross	
	Palmetto	Sunshine
Stocked	1.0421	0.9381
Recaptured	0.9596	1.0660

Growth and Condition

When a von Bertalanffy growth model was fitted to one cross at a time, Palmetto Bass had a slightly higher asymptotic length and lower growth coefficient (Table 16). However, the best-fitting and most parsimonious growth model, based on an information-theoretic approach, indicated that cross was not an essential factor affecting model parameterization (Table 17). Hybrid Striped Bass in Iowa lakes had the following growth curve:

$$L_t = 575.2 * \left(1 - e^{-0.3924(t+1.2163)}\right)$$

Thus, we did not find a difference in overall growth between crosses, with individually-fitted growth curves converging within the first two years of life (Figure 9). Moss and Lawson (1982) found no differences between crosses in mean length at Ages 1, 2, or 3 in Alabama lakes, and likewise fitted a single growth curve. Our finding differed from Kuklinski (2014), who found that Palmetto Bass grew faster and to a greater asymptotic length than Sunshine Bass in an Oklahoma reservoir. In an Oklahoma reservoir with a shad forage base, Hybrid Striped Bass achieved lengths over 381 mm by Age 3 and over 508 mm by Age 4 (Kuklinski 2014). In Kansas, Hybrid Striped Bass tended to achieve lengths over 381 mm by Age 2 and over 508 mm by Age 4 (Nelson et al. 2008); again, many of those fisheries had shad forage bases. We found that both crosses converged to about 400 mm by Age 2 in the fall, but due to the lower asymptotic length did not exceed 508 mm until closer to Age 5. This was very similar to growth documented for Palmetto Bass in Spring Lake, Illinois, where fish reached 432 mm around 2.3 years (Jahn et al. 1987). Spring Lake also had a centrarchid forage base. The parameter estimates from the von Bertalanffy curve differed somewhat from those found for some other Midwestern lakes, with the asymptotic length being low and growth coefficient being high (Schultz et al. 2013). Nevertheless, the Hybrid Striped Bass studied grew much larger relative to pure White Bass in North America (standard growth model $L_t = 396.6 * \left(1 - e^{-0.565(t+0.113)}\right)$: Jackson et al. 2008). This model outcome could easily change given representation of older fish in the dataset, but for the purposes of the current study comparing crosses, older fish were not available. Waterbody was treated as a random variable in the modeling process, with some lakes showing slightly slower or faster growth rates than others (Figure 10).

Table 16. Von Bertalanffy growth parameters for three models of Hybrid Striped Bass in Iowa: Palmetto Bass, Sunshine Bass, and combined models. L_∞ = asymptotic length, K = growth coefficient, and t_0 = time when length equals zero

Model	L_∞	K	t_0
Palmetto	587.88	0.3582	-1.3807
Sunshine	580.13	0.4000	-1.0725
Combined	575.20	0.3924	-1.2163

Table 17. Akaike's Information Criterion (AIC), ΔAIC, weight (W_i), and number of parameters (K) of length-weight and von Bertalanffy growth models for Hybrid Striped Bass in Iowa.

Model	AIC	ΔAIC	W_i	K
Growth				
$L_{\infty(\text{Cross})} + K_{(\text{Cross})} + t_{0(\text{Cross})}$	11491	3226.8	0.00	7
$L_{\infty(\text{Cross})} + K + t_{0(\text{Cross})}$	11489	3224.8	0.00	6
$L_{\infty(\text{Cross})} + K_{(\text{Cross})} + t_0$	11489	3224.8	0.00	6
$L_\infty + K_{(\text{Cross})} + t_{0(\text{Cross})}$	11489	3224.8	0.00	6
$L_{\infty(\text{Cross})} + K + t_0$	11487	3222.8	0.00	5
$L_\infty + K_{(\text{Cross})} + t_0$	11487	3222.8	0.00	5
$L_\infty + K + t_{0(\text{Cross})}$	9811.4	1547.2	0.00	5
$L_\infty + K + t_0$	8264.2	0	1.00	4
Length-weight				
$a_{(\text{Cross})}L^{b(\text{Cross})}$	-5252.1	3	0.08	4
$aL^{b(\text{Cross})}$	-5253.4	1.7	0.16	3
$a_{(\text{Cross})}L^{b}$	-5255.1	0	0.38	3
aL^b	-5255.1	0	0.38	2

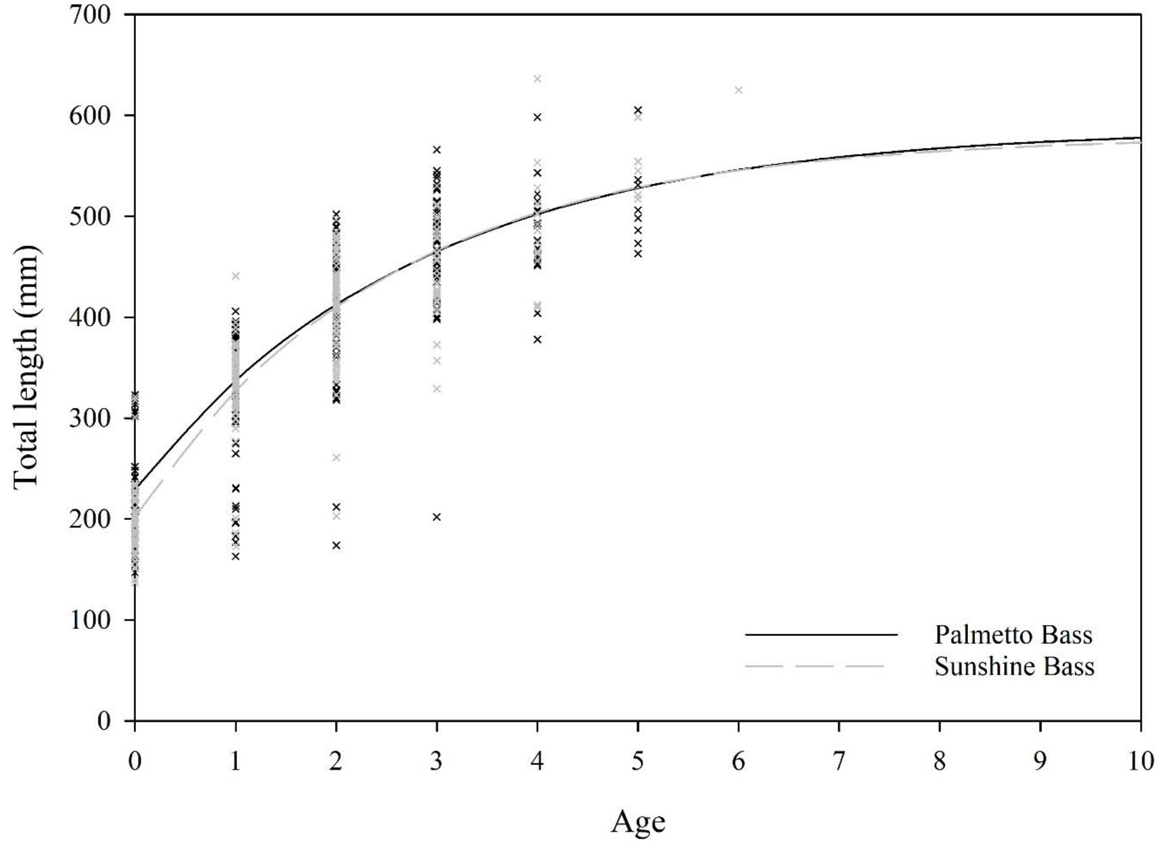

Figure 9. Von Bertalanffy growth curves for two crosses of Hybrid Striped Bass in Iowa, captured in fall.

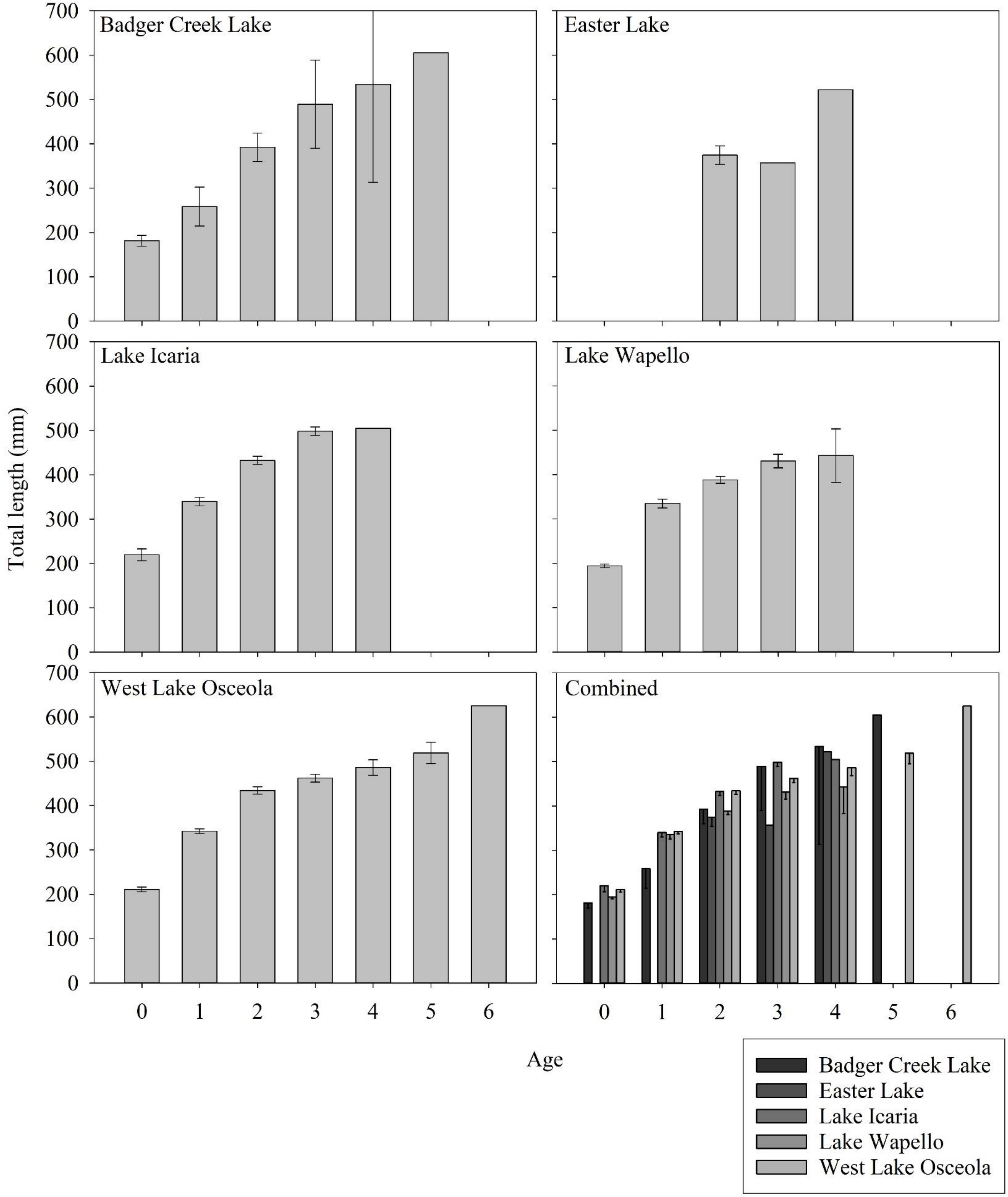

Figure 10. Length-at-age of Hybrid Striped Bass stocked into five Iowa reservoirs and recaptured from 2013-2019.

Likewise, length-weight relationships did not differ between crosses (Table 17). The best-fitting and most parsimonious length-weight model, based on an information-theoretic approach, indicated that cross was not an essential factor affecting model parameterization (Figure 11). Hybrid Striped Bass in Iowa lakes had the following length-weight relationships:

$$W = 10^{-4.807} * L^{2.956}$$

Condition did not differ between crosses (t = 0.21, p-value = 0.8347). Hybrid Striped Bass in Iowa had a mean relative weight of 88.35 (95% confidence interval: 87.08 - 89.60).

Thus we did not find a difference in length-weight relationship or relative weight between crosses. Likewise, Moss and Lawson (1982) fitted a joint length-weight relationship for Hybrid Striped Bass of both crosses stocked into Alabama public lakes. We are not aware of any other field-based studies comparing the two crosses growth patterns.

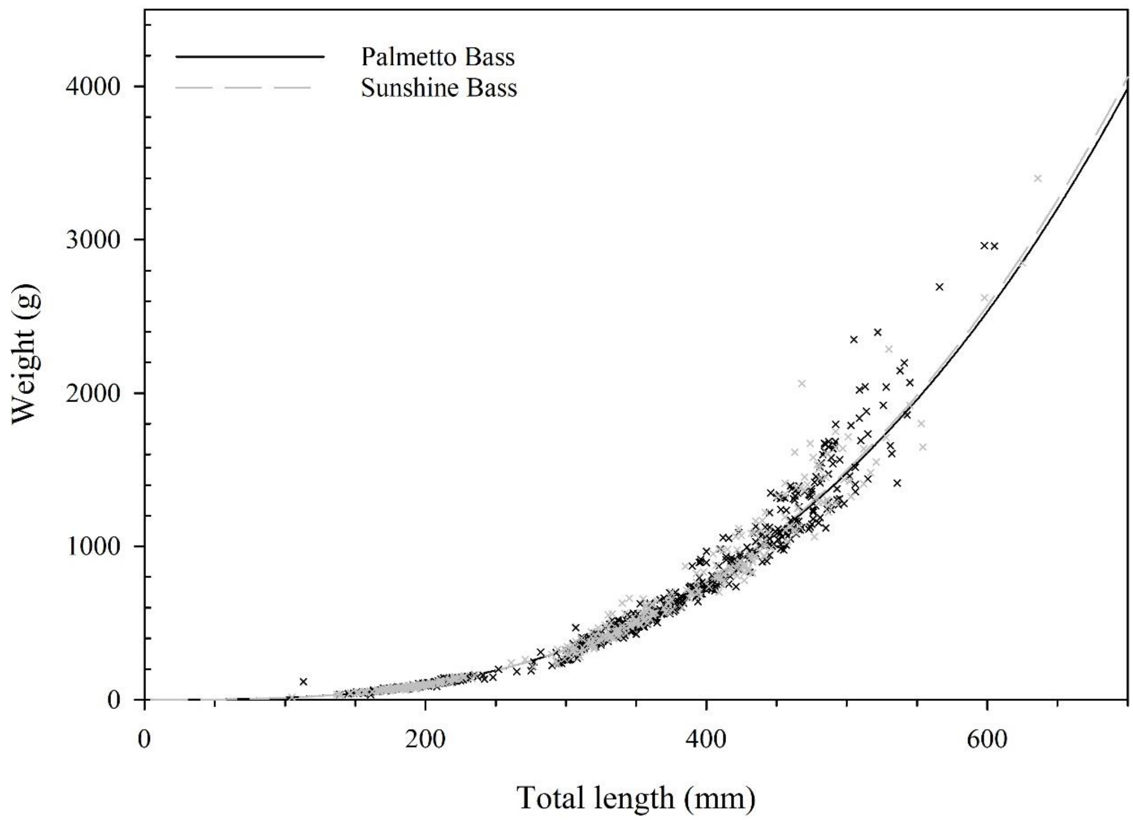

Figure 11. Length-weight relationships of Palmetto Bass and Sunshine Bass in Iowa.

The number of fish that were recaptured varied greatly by lake (Figure 12), and we suspect a large part of the explanation related to differences in outflows for each location. Hybrid Striped Bass recruitment to the first fall can depend on flows during or just after stocking (Henley 2006), and adult Hybrid Striped Bass had high probabilities of emigration from a reservoir without any sort of barrier to escapement (Kuklinski 2014). Although none of the study locations had a barrier, they did differ somewhat in terms of outlet and spillway structure, which could have caused a difference among locations in escapement probability. For instance, Easter Lake had consistently low mean catch rates; its spillway prior to renovation did not have any sort of barrier to emigration. A physical barrier fence could drastically reduce emigration of sport fishes, which could maintain a better fishery in the future (Lewis et al. 2023).

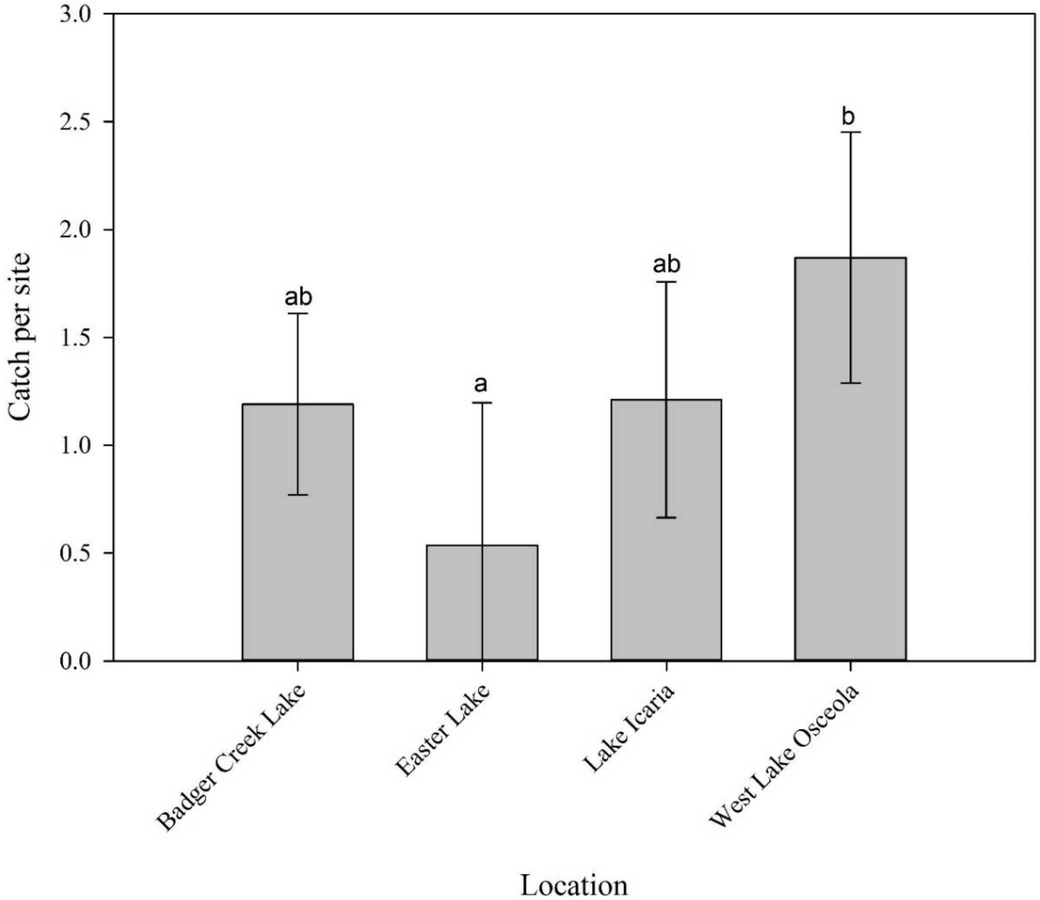

Figure 12. Mean catch rate of Hybrid Striped Bass by experimental gill nets set overnight at four Iowa reservoirs, stocked beginning in 2012 and sampled from 2013-2019.

Recommendations and Future Work

Given the lack of meaningful differences between genetic crosses of Hybrid Striped Bass in terms of stocking return, growth, and condition, the more cost-effective cross is recommended for future culture and stocking in typical reservoirs in Iowa. Based on culture records for Iowa DNR's Rathbun and Mount Ayr fish hatcheries from 2013 to 2021, the Palmetto Bass is generally less expensive to produce to fingerling size than the Sunshine Bass (Table 18).However, other factors affect the accessibility of each cross annually: availability of fish trades from agencies with captive broodstock, cost of private or public hatchery purchase of fish, timing and fish availability. Again, because the crosses did not differ substantially in terms of recruitment to the recreational fishery or adult size, the optimal cross of choice depends on cost and accessibility of fry each year.

Table 18. Cost per 1,000 fingerlings produced of each cross of Hybrid Striped Bass by Iowa Department of Natural Resources from 2013-2021.

Year	Palmetto	Sunshine
2021	n/a	$45.27
2019	$38.60	n/a
2018	$17.85	n/a
2017	$23.20	n/a
2016	n/a	$19.06
2015	n/a	$122.35
2014	n/a	$14.95
2013	n/a	$59.65
Average	**$26.55**	**$52.26**

That said, there is still a possibility that the two crosses differ in tendency to emigrate from reservoirs without barriers (Kuklinski 2014). Specifically, the Palmetto cross may inherit more maternal behaviors, including that of large-scale spawning movements of adults, and thus may be more likely to pass over a dam. In general, Hybrid Striped Bass are known to have a tendency to emigrate, making reservoir fishery management more challenging (Axon and Whitehurst 1985). To determine whether this difference is ecologically significant, a movement and emigration study of both crosses is recommended for future work.

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APPROACH 3: EVALUATE HYBRID STRIPED BASS STOCKING STRATEGIES.
APPROACH 4: EVALUATE FACTORS AFFECTING HYBRID STRIPED BASS YEAR-CLASS STRENGTH.

INTRODUCTION

Hybrid Striped Bass are an important component of Iowa's fisheries, as they have high potential to provide trophy fishing opportunities and utilize forage species that are otherwise unavailable to most predators. Hybrid Striped Bass are aggressive feeders and considered to have superior "fighting abilities" which contribute to a quality trophy fishery (Jahn et al. 1987). As larger-bodied predators, they may be capable of restructuring panfish communities (Layzer and Clady 1984; Jahn et al. 1987; Neal et al. 1999; Hutt et al. 2008) and controlling abundant prey species like Gizzard Shad *Dorosoma cepedianum* (Dettmers et al. 1998), but may also compete with native predators like Largemouth Bass *Micropterus salmoides* (Hickey and Kohler 2004).

Hybrid Striped Bass fisheries are established by stocking various sizes of a combination of Striped Bass and White Bass. Iowa Department of Natural Resources (DNR) began stocking Hybrid Striped Bass *Morone saxatilis* x *M. chrysops* into Saylorville Reservoir in 1981 (Mayhew 1987). Early stockings were Palmetto Bass *M. saxatilis* ♀ x *M. chrysops* ♂, obtained through fish trades and later purchases from both private and public hatcheries. Fry were sometimes grown out to fingerling size at Rathbun Fish Hatchery and later Mount Ayr Fish Hatchery, and stocked into the large flood control reservoirs and several larger lakes and reservoirs including Lake Manawa and Three Mile Lake. More recently, Iowa DNR expanded its stocking program to smaller impoundments and urban ponds, producing all fingerling Hybrid Striped Bass in-house by obtaining hybridized fry and growing them out in earthen ponds.

Various factors may affect stocking success, including but not limited to the fish size and condition stocked (Johnson et al. 1996); environmental and forage conditions at the time of stocking (Donovan et al. 1997); culture, harvest, and transportation factors (Durniak 1991; Wallin and Van Den Avyle 1995; Yow et al. 2013); stocking rate and timing (Donovan et al. 1997; Doll et al. 2015); location of stocking and associated habitat; and forage and predator species composition and density (Donovan et al. 1997; Dettmers et al. 1998; Michaelson et al. 2001; Bauer 2002).

Size at the time of stocking is one of the most common questions, and Iowa has a history of using both sizes, sometimes in combination. Fry tend to have much lower survival rates than fingerlings with more variable stocking success, as demonstrated for Walleye in Lake Mendota, Wisconsin (Johnson et al. 1996). Nevertheless, fingerlings and even advanced fingerlings may still be subject to high predation immediately post-stocking (e.g., to Largemouth Bass: Lundgren et al. 2014). In fact, advanced fingerlings may perform worse than smaller fingerlings in terms of return to stock (Perrion et al. 2020). Size also entails differential cost, as fry can be obtained more cheaply per fish but may not survive to stock size. Closely related to this question is stocking rate. Given a consistent size of fish (e.g., fingerlings typically range from 40-50 mm), the density per surface area must be enough to produce returns in management sampling later on, as part of fishery assessment. For instance, in Kansas, a typical fingerling stocking rate is 25 fish/ha (10 fish/acre). If this stocking rate fails to yield 2 stock-size fish per net-night over five years, stocking of Hybrid Striped Bass is discontinued at that waterbody (Nelson et al. 2008).

Environmental variables can also affect stocking success, with both immediate factors (e.g., the weather that day) and lake characteristics (e.g., summer water column chemistry or lake turnover rate) contributing to stocking success (Donovan et al. 1997; Doll et al. 2015). Certain locations may not be appropriate for stocking due to poor summertime water column conditions which squeeze the available habitat that is tolerable in terms of both dissolved oxygen and temperature (Coutant 2013; Kilpatrick and Ney 2013).

Hybrid Striped Bass stocking success can also depend on the fish community. As aforementioned, Largemouth Bass predation can be significant (Lundgren et al. 2014). Doll et al. (2015) determined that Walleye stocking success, as measured the first fall, was negatively related to moronid stocking density, implying a tradeoff between moronid and Walleye stocking programs. Notably, many of the waterbodies stocked with Hybrid Striped Bass in Iowa may be eligible for Walleye *Sander vitreus* stocking, including Three Mile Lake, Lake Macbride, and Lake Manawa. Hybrid Striped Bass stocking success may also depend on forage availability and species. Stocking has sometimes been predicated on the idea of controlling high-density forage species like Gizzard Shad, although studies have shown that predatory control of such species is unlikely (Dettmers et al. 1998; Michaletz 2014) except in small impoundments (Jahn et al. 1987; Neal et al. 1999). Nevertheless, Gizzard Shad and other clupeids can serve as a stable and abundant food source, providing greater stability in recruitment of *Morone* species (Sutton and Ney 2001; Bauer 2002).

As Hybrid Striped Bass fisheries become more in demand at waterbodies that may not meet some of these ideal criteria, it will be necessary to improve stocking strategies to create fisheries as cost-effectively as possible. The objective of this study was to identify factors contributing to more successful stocking, i.e., establishment of Hybrid Striped Bass year-classes, including stocking practices and environmental variables.

METHODS

Fry versus Fingerling Size at Stocking

Data Collection

A natural experiment of size at stocking occurred at Lake Macbride due to very regular alternating of fish stocking size from 2006 to 2018 (Table 19). Lake Macbride is a 940-acre reservoir in east-central Iowa with stable water levels. Each year except 2015, only one size was stocked into the reservoir, allowing year-class to serve as an indicator of genetic cross. This is the only location in the state in which this scenario occurred regularly.

Table 19. Stocking history for Hybrid Striped Bass in Lake Macbride, Iowa.

Year	Size	Category	Number	Date of stocking
2006	1.5”	Fingerling	12,000	6/21/06
2007	Fry	Fry	1,000,000	5/11/07
2008	1.8”	Fingerling	18,013	6/19/08
2009	3.0”	Fingerling	11,400	7/8/09
2010	Fry	Fry	1,000,000	5/11/10
2011	1.9”	Fingerling	11,800 59,258	6/24/11 6/27/11
2012	Fry	Fry	500,000	4/11/12
2013	2”	Fingerling	10,000 49,476	6/26/13 7/3/13
2014	Fry	Fry	600,000	5/22/14
2015	Fry	Fry	875,000	4/24/15 and 5/6/15
	2”	Fingerling	9,773	6/18/15
2016	Fry	Fry	500,000	5/11/16
2017	2”	Fingerling	21,659	6/28/17 and 6/30/17
2018	Fry	Fry	700,000	5/10/18

Hybrid Striped Bass were sampled at Lake Macbride both haphazardly and at fixed sites between 2009 and 2019. A variety of sampling methods was used over the years, primarily fisheries management standard community sampling (i.e., electrofishing). However, some concerted experimental gill netting was conducted during specific years. All fish offered by recreational and commercial anglers were also accepted, recognizing that commercial angling was not necessarily conducted every year.

A variety of calcified structures were collected from fish over the years: sagittal otoliths, dorsal spines, and scales. Scales were typically removed from the left side behind the pectoral fin, unless the fish had scarring or injury in that spot; in that case the right side was used. Spines were set in epoxy and sectioned using a diamond-edge high-precision saw, whereas both scales and otoliths were read whole. All structures were prepared for reading and digitally imaged under a microscope with power 3-10x. A double-blind reading process was used for each structure, and structures from the same fish were not examined together to avoid bias in age estimation. Disagreements between readers were resolved by reading the saved imagery together, re-assessing age estimates individually without additional metadata, and then coming to an agreement with available metadata (e.g., fish total length). If an agreement could not be reached, the structure was discarded due to poor quality. We assumed sagittal otoliths would provide the least biased age estimates;

if an otolith-based estimate was available, it was preferred. If not, a dorsal spine-based estimate was used, and lastly scale-based estimates.

Data Analysis

Age estimates were used to develop age-length keys by season, recognizing that fish length-at-age would differ between spring and fall. Age-length keys were then applied to catch data regardless of gear, by season. The year-class of each fish caught was assigned by subtracting its age from the year of capture, and its size-at-stocking was joined from stocking records. Fish assigned to the 2015 year-class were excluded from catch curve analysis because it was unknown whether they derived from fry or fingerling stockings.

Because each sampling approach may have size-related bias and different measures of effort (and in the case of convenience sampling, no valid statistical design), catch curves were calculated separately for each sampling approach. Catch per effort was calculated as fish/minute for electrofishing and fish/net-night for gill netting. Because effort was unknown for recreational and commercial fishing, total catch per year was used instead. Catch or catch rate was then natural-log-transformed, and a general linear mixed model was used to fit the catch curve regression. Fixed effects included fish age and size-at-stocking; the catch curve was modeled with either fish age only or with both fixed effects. Random effects included year of capture and year-class. One model also included data from all gears, with gear of capture as a random effect. Models could not be directly compared across gears, but within a single gear type, Akaike's information criterion for small sample sizes (AICC) was used to identify the more effective and parsimonious model.

The effect of size-at-stocking was estimated using the best-fitting model's least-square means of fixed effects. In other words, two catch curves were fitted, one for each size-at-stocking. The difference in intercepts was calculated as a percentage, indicating the relative return of fish from size compared to the other. The typical cost of producing each size was also compared based on historical stocking and culture records.

Fingerling Stocking Rate

Data Collection

A natural experiment of size at stocking occurred at Three Mile Lake due to varying stocking rates of fingerling Hybrid Striped Bass between 2007 and 2012. Three Mile Lake is an 880-acre reservoir in southwest Iowa. Stocking ended in 2013 due to plans for a fishery chemical renovation in 2016. Stocking rates varied from 4.3 fish/acre to 10.0 fish/acre.

Hybrid Striped Bass were sampled at Three Mile Lake both haphazardly and at fixed sites between 2009 and 2016. A variety of sampling methods was used, primarily fisheries management standard community sampling (i.e., electrofishing and experimental gill nets). However, a concerted experimental gill netting effort was conducted during 2016 immediately before chemical renovation of the fishery, and all dead fish observed after renovation were also collected.

A variety of calcified structures were collected from fish over the years: sagittal otoliths, dorsal spines, and scales. Scales were typically removed from the left side behind the pectoral fin, unless the fish had scarring or injury in that spot; in that case the right side was used. Spines were set in epoxy and sectioned using a diamond-edge high-precision saw, whereas both scales and otoliths were read whole. All structures were prepared for reading and digitally imaged under a microscope with power 3-10x. A double-blind reading process was used for each structure, and structures from the same fish were not examined together to avoid bias in age estimation. Disagreements between readers were resolved by reading the saved imagery together, re-assessing age estimates individually without additional metadata, and then coming to an agreement with available metadata (e.g., fish total length). If an agreement could not be reached, the structure was discarded due to poor quality. We assumed sagittal otoliths would provide the least biased age estimates; if an otolith-based estimate was available, it was preferred. If not, a dorsal spine-based estimate was used, and lastly scale-based estimates.

Data Analysis

Age estimates were used to develop an age-length key, which was then applied to catch data regardless of gear. The year-class of each fish caught was assigned by subtracting its age from the year of capture, and its affiliated stocking rate was joined from stocking records.

Because each sampling approach may have size-related bias and different measures of effort, catch curves were calculated separately for each sampling gear. Catch per effort was calculated as fish/minute for electrofishing and fish/net-night for gill netting. Catch or catch rate was then natural-log-transformed, and a general linear mixed model was used to fit the catch curve regression. Fixed effects included fish age and stocking rate; the catch curve was modeled with either fish age only or with both fixed effects. Random effects included year of capture and year-class. Models could not be directly compared across gears, but within a single gear type, Akaike's information criterion for small sample sizes (AICC) was used to identify the more effective and parsimonious model. The effect of stocking rate was demonstrated by presenting the catch curve with a range of possible stocking rates.

Environmental Conditions and Stocking Success

Data Collection

Environmental conditions at the time of fish stocking were studied at the same two reservoirs. Lake Macbride received fry stockings intermittently from 2006 to 2018, allowing assessment of weather conditions at the time of fry stocking. Three Mile Lake received fingerling Hybrid Striped Bass stockings from 2007 to 2012, allowing assessment of weather conditions at the time of fingerling stocking.

Environmental conditions were not recorded at the time of stocking, and weather and water chemistry data were severely limited at the specific locations and times Hybrid Striped Bass were stocked. For instance, although West Lake Osceola (initially considered for this portion of the study) was used as the city water supply for Osceola, water temperature and turbidity records were incomplete. Likewise, the city of Creston only recorded water chemistry from Three Mile Lake during periods of water withdrawal and frequently relied on the adjacent reservoir Twelve Mile Lake instead. Furthermore, the city did not begin recording data until 2012, when Hybrid Striped Bass stocking was halted in preparation for fishery renovation. Thus, on-site water chemistry records were unavailable for a thorough analysis.

As an alternative, air temperature and precipitation records were derived from the National Oceanic and Atmospheric Administration's Global Historical Climatology Network (NOAA 2023). Daily summary data were obtained for each reservoir's nearest available weather station, including amount of precipitation, maximum temperature, and minimum temperature. Daily summary data were used directly, but also used to calculate 24-hour temperature drop and 48-hour temperature drop after the date of stocking. Data for Lake Macbride were obtained from the Iowa City Municipal Airport, located just south of the reservoir. Data for Three Mile Lake were obtained from the city of Creston, located just west of the reservoir.

Data Analysis

Catch per effort was calculated as fish/net-night from gill netting. Catch rate was then natural-log-transformed, and a series of general linear models were fitted. First, a stepwise variable selection process was used to identify the most important variables; however, this process could not properly account for random effects such as year-class and year. General linear mixed models were used to fit the catch curve regression. Fixed effects included fish age, precipitation amount, minimum daily temperature (Tmin), maximum daily temperature (Tmax), 24-hour temperature change post-stocking (△Temp24), 48-hour temperature change post-stocking (△Temp48), and stocking rate. Stocking rate was included based on the previous section's results, which indicated stocking rate of fingerlings was an important factor. The catch curve was modeled with either fish age only or with one or more other fixed effects. Random effects included year of capture and year-class. Models were compared using Akaike's information criterion for small sample sizes (AICC) to identify the most effective and parsimonious model. The effect of significant variables was demonstrated by presenting the catch curve with a range of possible values, while holding other fixed effects at their mean values.

RESULTS AND DISCUSSION

Fry versus Fingerling Size at Stocking

A total of 616 Hybrid Striped Bass were captured from Lake Macbride between 2009 and 2019 (Table 20). Variable amounts of effort were used each year, depending on whether a formal study was ongoing (e.g., 2018), typical management standard sampling, or whether fish were returned by a commercial angler from their bycatch (e.g., 2018). The oldest fish detected was 11 years old. Relatively few age estimation structures were taken from fish captured with electrofishing (*n* = 17). However, a total of 112 and 205 structures were obtained via recreational and commercial fishing, respectively. Finally, experimental gill nettings in 2018 and 2019 yielded 134 age estimates. Thus, catch curves were only developed using the latter three sampling methods. A total of 468 age estimates were available to develop gear-specific age-length keys and subsequent catch curves.

Table 20. Total number of Hybrid Striped Bass captured from Lake Macbride between 2009 and 2019 using a variety of sampling methods.

Year	N	Angling/Convenience	Electrofishing	Gill Netting
2009	29			29
2010	37	37		
2013	4		4	
2014	87	27	60	
2015	112		112	
2016	30		30	
2017	1		1	
2018	223	68		155
2019	93	31	4	58
Total	**616**	**168**	**211**	**242**

For all but one gear/method of fish collection, inclusion of size-at-stocking in the catch curve yielded a better model than age alone (Table 21). The final catch curve was derived from experimental gill net data because 1) it had the greatest number of fish with age estimate data, 2) sampling effort was most accurately measured, and 3) it was most comparable to fisheries management sampling data. Mean catch rate at Lake Macbride was 12.45 fish per net-night (95% confidence interval 8.61-16.28 fish/net-night).

Table 21. Akaike's Information Criterion, adjusted for small sample sizes (AICC), ΔAICC, model weight (W_i), and number of parameters (K) of general linear models predicting Hybrid Striped Bass catch (fish/minute or total fish) using fish age and size-at-stocking.

Gear	Model	AICC	ΔAICC	W_i	K
Combined	Age + Size-at-stocking	**153.02**	0.00	1.00	2
	Age	164.47	11.45	0.00	1
Experimental gill nets	Age + Size-at-stocking	**25.47**	0.00	0.96	2
	Age	31.85	6.38	0.04	1
Commercial seines	Age + Size-at-stocking	**34.30**	0.00	0.98	2
	Age	42.61	8.31	0.02	1
Recreational angling	Age + Size-at-stocking	43.92	6.55	0.04	2
	Age	**37.37**	0.00	0.96	1

According to the best fitted model, stocking fry rather than fingerling Hybrid Striped Bass at Lake Macbride **reduced return to gill nets by 19.3%** (Figure 13). In terms of year-class strength, fingerlings were also slightly more reliable in establishing year-classes of fish (Figure 14). Out of five year-classes of fingerlings, two were strong. Out of five year-classes of fry, one was strong and one was average. The 2015 year-class was strong, but it was unknown whether fish derived from fry or fingerling stocking (Table 22).

A typical fry stocking rate is 3,000 fish/acre, costing approximately $14,100 to stock Lake Macbride with purchased fish ($0.005/fish from Keo Fish Farms; Table 23). However, fish could be obtained via trade, thereby reducing the cost. A typical fingerling stocking rate is 10 fish/acre, costing approximately $400.63 to stock Lake Macbride. Given the cost of purchased fry was greater than the cost of fingerlings, we recommend stocking fingerling-size Hybrid Striped Bass into Lake Macbride when fry are not available via fish trades for better return to the adult population. Our finding differed from that of Seidensticker and Byrne (1991), who found through cost-benefit analysis that fry stocking yielded more age-2 Hybrid Striped Bass than fingerling stocking in Lake Sam Rayburn, Texas. They also found that fry-stocked fish achieved a greater total length at age-2. In their study, fry were stocked at 22-32 fish/ha, whereas fingerlings were stocked at 10-12 fish/ha. This fry stocking rate differs drastically from the typical fry stocking rate in Iowa and is likely the reason their cost-benefit analysis yielded a different outcome.

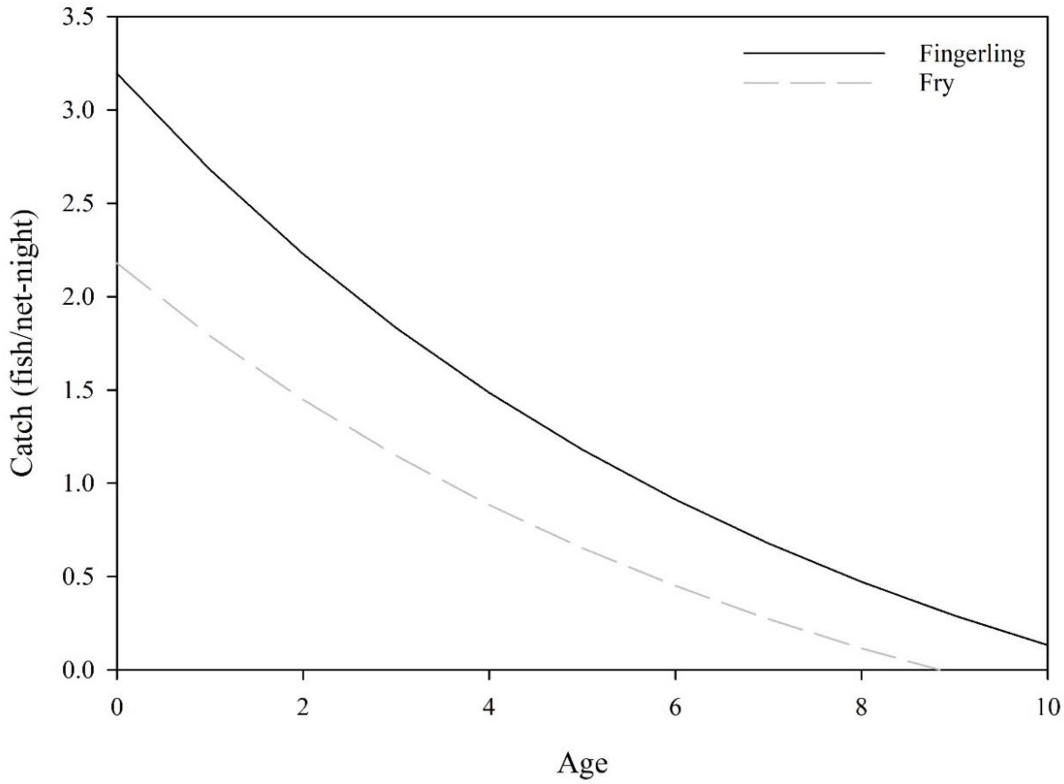

Figure 13. Catch curve for Hybrid Striped Bass in Lake Macbride, Iowa, based on size at stocking (fry or fingerling).

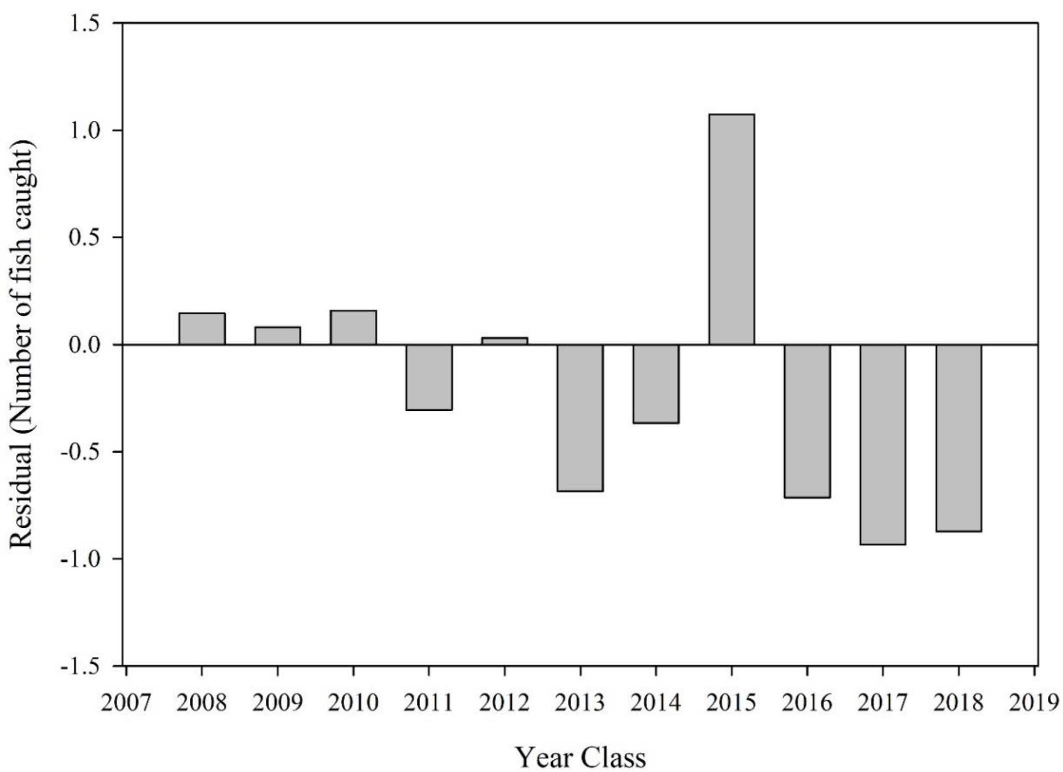

Figure 14. Residual from catch curve prediction of number of Hybrid Striped Bass captured per net-night at Lake Macbride, Iowa, by year-class.

Table 22. Year-class strength of Hybrid Striped Bass stocked into Lake Macbride, Iowa, from 2006-2016.

Year	Category	Year-class Strength
2006	Fingerling	
2007	Fry	
2008	Fingerling	Strong
2009	Fingerling	Strong
2010	Fry	Strong
2011	Fingerling	Weak
2012	Fry	Strong/Neutral
2013	Fingerling	Weak
2014	Fry	Weak
2015	*Both*	*Strong*
2016	Fry	Weak
2017	Fingerling	Weak
2018	Fry	Weak

Table 23. Cost per 1,000 fish produced of each size of Hybrid Striped Bass by Iowa Department of Natural Resources from 2013-2021.

Year	Fingerling	Fry
2021	$45.27	
2019	$38.60	
2018	$17.85	
2017	$23.20	
2016	$19.06	
2015	$122.35	
2014	$14.95	
2013	$59.65	
Average	**$42.62**	**$5.00**

Fingerling Stocking Rate

A total of 100 age estimates were available from Three Mile Lake, most of them deriving from the chemical renovation in 2016. However, younger fish were not captured due to the halt in stocking prior to renovation. Thus, the age-length key provided guidance only for fish Age 4 to Age 9. A total of 710 Hybrid Striped Bass were captured during sampling efforts across gears/methods and did not have age structures removed; unfortunately, 657 of them were likely younger than Age 4. The key was thus applied to only 11 fish, resulting in a total of 317 fish used in catch curve analysis. Catch curves were developed for fish captured after chemical renovation (n =37) and fish captured by experimental gill net (n = 280).

Resulting catch curve models did not clearly indicate an effect of stocking rate (Table 24). The post-renovation collection of fish yielded a catch curve that did not improve with addition of stocking rate as a fixed effect. Experimental gill nets deployed in fall over several different years yielded a catch curve that was improved by addition of stocking rate (Figure 15), although its Type III test of fixed effect was not statistically significant (F = 1.87, p-value = 0.1768). We present the result of the gill net-based catch curve because it was based on multiple years' data collection and more individual fish.

Table 24. Akaike's Information Criterion, adjusted for small sample sizes (AICC), ΔAICC, model weight (*W*ᵢ), and number of parameters (K) of general linear models predicting Hybrid Striped Bass catch (fish/net-night or total fish) using fingerling stocking rate.

Gear	Model	AICC	ΔAICC	W_i	K
Chemical renovation	Age + Stocking Rate	49.25	19.87	0.00	2
	Age	**29.38**	0.00	1.00	1
Experimental gill nets	Age + Stocking Rate	**213.79**	0.00	1.00	2
	Age	290.57	76.78	0.00	1

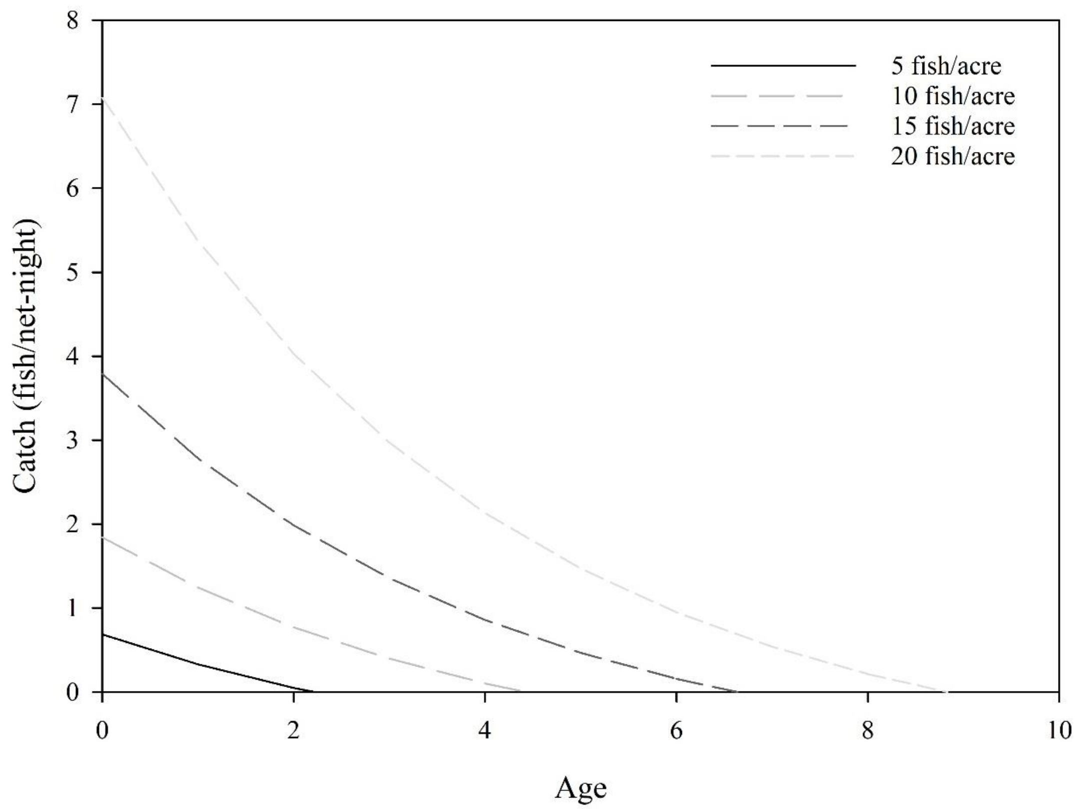

Figure 15. Catch curve by stocking rate of fingerling Hybrid Striped Bass in Three Mile Lake, Iowa.

We suggest that a stocking rate of 5 fish/acre may not yield adequate returns to gill net catch, but 10 fish/acre might be acceptable and 15 fish/acre may yield a desirable total catch per net-night in Three Mile Lake. This is very similar to guidance provided by Moore et al. (1991) for Smith Mountain Lake, Virginia, where a stocking rate of 9.7 to 12.1 fish/acre (24-30 fish/ha) yielded the optimal number of Striped Bass recruits to Age-1. Increasing the stocking rate above a lower threshold (e.g., from 20 fish/ha [8 fish/acre] to 50 fish/ha [20 fish/acre]) not only yielded increased gill net catches in Texas, but was also associated with an increase in fishing effort and harvest of Hybrid Striped Bass (Moczygemba et al. 1991). Odenkirk et al. (2021) suggested rate should be adjusted based on predator growth rates and forage abundance estimates, emphasizing that overstocking could be detrimental to multiple desirable species in the fishery. Generally, fingerling rates used in other states are similar or higher than Iowa's historical stocking rates (Figure 16).

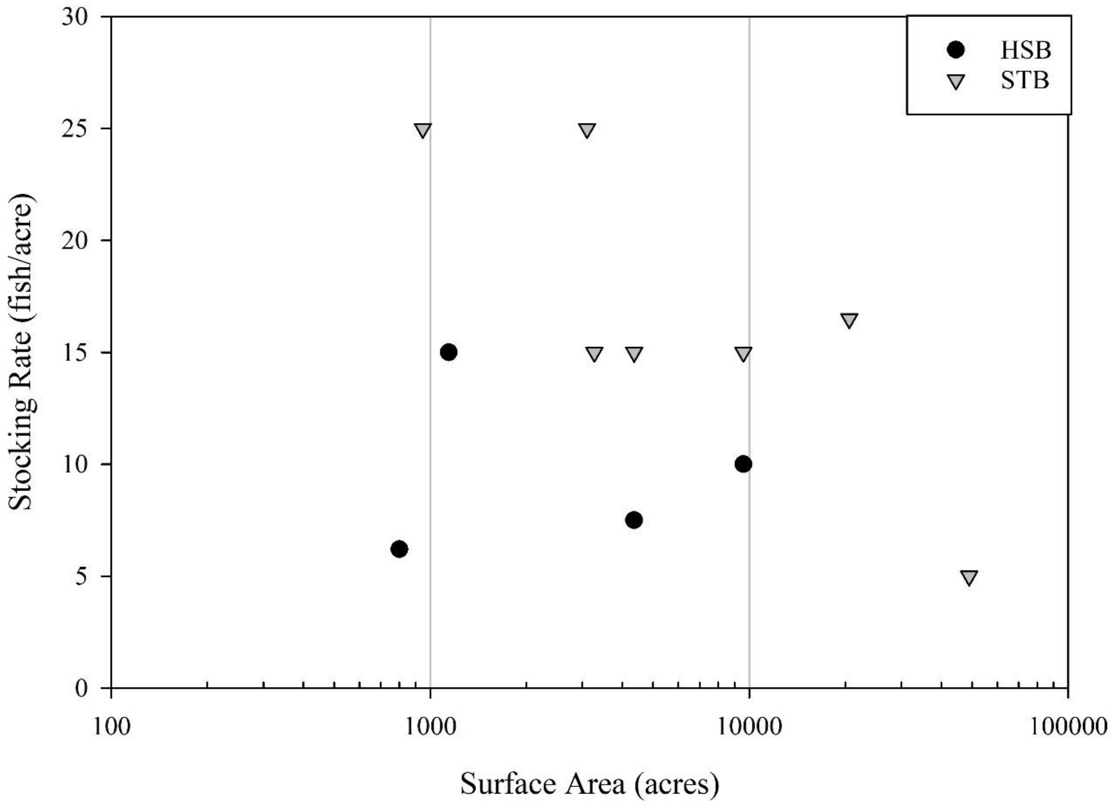

Figure 16. Fingerling stocking rate used for *Morone* species (STB = Striped Bass, HSB = Hybrid Striped Bass) in Virginia, by lake surface area (Odenkirk et al. 2021). Rates of 1-10 fish/acre are used in Kansas regardless of surface area (Nelson et al. 2008).

Environmental Conditions and Stocking Success

Fingerlings

Air temperature and precipitation data were available for Three Mile Lake for 2007 to 2012. The stepwise procedure identified maximum daily temperature on the date of stocking as the only variable to retain in a model of catch, even excluding fish age (and thereby not a catch curve); this variable alone explained 84% of the variance in the data. Based on Akaike's information criterion, numerous models performed similarly, indicating poor performance overall of individual explanatory variables (Table 25). Top models consistently included stocking rate, precipitation, some measure of daily temperature, and some measure of temperature change. That said, those models did perform substantially better than a simple age-only or age-and-stocking-rate-only catch curve, so it seemed that environmental variables at the time of stocking were somewhat important. Daily temperature had a positive effect, whereas the amount of temperature change immediately post-stocking had a negative effect. Precipitation and stocking rate effects were unclear. It is likely the data were overfitted.

Given the likelihood of overfitting and a desire for parsimony, the model including only maximum daily temperature was retained, as had been indicated by the stepwise selection procedure. This model had a marginally higher AICC than the top models, and is far simpler. Essentially, warmer temperatures at the time of stocking were beneficial to fingerling Hybrid Striped Bass return to catch in experimental gill nets later on (Figure 17). Typical maximum daily temperatures from 2007 to 2012 at Three Mile Lake ranged from 64 to 96°F, with a mean of 83.3°F.

It is possible maximum daily temperature at the time of stocking was reflective of broader weather patterns, in which a warmer spring was conducive to better growth in general, thereby resulting in greater survival (Quist et al. 2004). However, Perrion et al. (2020) did not find mean seasonal water temperatures to be important factors influencing Hybrid Striped Bass abundance in Branched Oak Reservoir, Nebraska. Although spring temperature was the strongest correlation they observed, it explained little variance in the data. That said, Perrion et al. (2020) examined this question over a number of decades with varying stocking rates and sizes, rather than a single scenario such as fingerling stocking in the spring, and their study location was invaded by White Perch during the study. Sutton and Ney (2001) determined that fingerling size moderated the diet shift to clupeids, resulting in greater lipid storage and overwintering survival for

Age-0 Striped Bass in a Virginia reservoir; they suggested that both size and earlier stocking would support stocking success (Sutton et al. 2013), an outcome that is more likely in a warm spring than a cold one. Sutton et al. (2013) suggested that stocking 2-3 weeks after clupeid spawning begins would be adequate.

Table 25. Akaike's Information Criterion, adjusted for small sample sizes (AICC), ΔAICC, model weight (*W_i*), and number of parameters (K) of general linear models predicting Hybrid Striped Bass catch (fish/net-night or total fish) using fingerling stocking rate and weather on the date of stocking.

Model	AICC	ΔAICC	W_i	K
Age + StockingRate + Precipitation + △Temp24 + Tmin	203.96	0	0.13	5
Age + Precipitation + △Temp24 + △Temp48 + Tmax	204.14	0.18	0.12	5
Age + StockingRate + Precipitation + △Temp48 + Tmin	204.23	0.27	0.12	5
Age + Precipitation + △Temp24 + △Temp48 + Tmin	204.45	0.49	0.11	5
Age + StockingRate + Precipitation + △Temp24 + Tmax	205.02	1.06	0.08	5
Age + StockingRate + Precipitation + △Temp48 + Tmax	205.21	1.25	0.07	5
Age + StockingRate + Precipitation + △Temp24 + △Temp48 + Tmin	205.31	1.35	0.07	6
Age + StockingRate + Precipitation + △Temp24 + △Temp48 + Tmax	206.11	2.15	0.05	6
Age + StockingRate + Precipitation + △Temp24 + △Temp48	206.37	2.41	0.04	5
Age + StockingRate + Precipitation + △Temp24 + △Temp48 + Tmin + Tmax	206.76	2.8	0.03	7
Age + Precipitation + △Temp24 + △Temp48 + Tmin + Tmax	207.18	3.22	0.03	6
Age + StockingRate + Precipitation + △Temp48 + Tmin + Tmax	207.49	3.53	0.02	6
Age + Tmax	**207.8**	**3.84**	**0.02**	**2**
Age + StockingRate + Precipitation	208.04	4.08	0.02	3
Age + Precipitation + △Temp48 + Tmin	208.29	4.33	0.02	4
Age + StockingRate + Precipitation + △Temp24 + Tmin + Tmax	208.31	4.35	0.02	6
Age + StockingRate + Precipitation + △Temp24	208.71	4.75	0.01	4
Age + Precipitation	208.55	4.59	0.01	2
Age + Precipitation + △Temp24 + Tmin	209.15	5.19	0.01	4
Age + StockingRate + Precipitation + △Temp48	209.98	6.02	0.01	4
Age + Precipitation + △Temp24 + △Temp48	210.18	6.22	0.01	4
Age + Precipitation + △Temp48	210.65	6.69	0.00	3
Age + StockingRate + △Temp24 + △Temp48 + Tmin	211.20	7.24	0.00	5
Age + △Temp48 + Tmin	212.92	8.96	0.00	3
Age + StockingRate	213.79	9.83	0.00	2
Age + StockingRate + △Temp48	216.23	12.27	0.00	3
Age + StockingRate + △Temp24 + △Temp48	216.45	12.49	0.00	4
Age + △Temp48	216.93	12.97	0.00	2

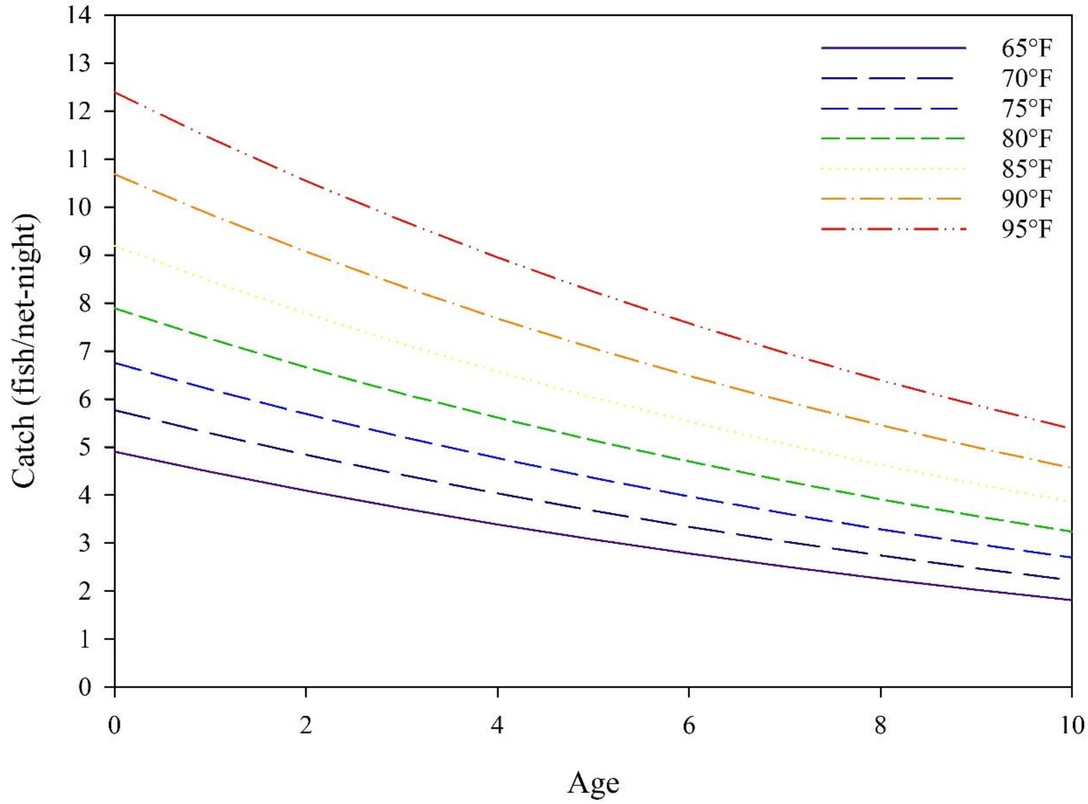

Figure 17. Catch curve by maximum air temperature on the date of stocking of fingerling Hybrid Striped Bass in Three Mile Lake, Iowa.

Fry

Air temperature and precipitation data were available for Lake Macbride from 2006 to 2018. The stepwise procedure identified maximum daily temperature on the date of stocking and 48-hour temperature change post-stocking as important variables to retain in a model of catch rate, even excluding fish age (and thereby not a catch curve); these variables explained 66.6% of the variance in the data. Based on Akaike's information criterion, however, the most important variable in a catch curve appeared to be precipitation on the day of fry stocking, such that greater rainfall was associated with greater catch in gill nets later on (Table 26). This could be spurious, as the data were quite limited, but it could also indicate lower light conditions for newly stocked fry, which could result in reduced predation. Predation by species such as Largemouth Bass (Michaelson et al. 2001; Lundgren et al. 2014) has been shown to be significant even for advanced fingerling size fish, particularly within the first few days after stocking (Lundgren et al. 2014). Predation seemed to be lesser when an alternative species like Alewife were available (Michaelson et al. 2001). Mean rainfall at Lake Macbride during mid-June was 0.23 inches (range 0 - 5.65 inches) between 2006 and 2018. The regular appearance of 48-hour temperature change post-stocking could also indicate that fry stocking success is somewhat affected by immediate temperature changes.

Pitman and Gutreuter (1993) found that, in the absence of predation, stocked Hybrid Striped Bass fry survival depended on dissolved oxygen at the stocking location and cumulative differences in pH and conductivity during transport process. Hybrid Striped Bass prefer dissolved oxygen levels over 2 mg/L and water temperatures below 25°C during summer and can be subject to temperature-oxygen squeeze (Douglas and Jahn 1987; Phalen et al. 1988). We did not have any of these water chemistry metrics available for analysis, but the practice of tempering based on pH and water temperature is becoming more common (B. Dodd, personal communication). Tempering, especially based on any variable besides temperature, was not historically consistent across states (Yow et al. 2013). We recommend any Hybrid Striped Bass fry stocking does incorporate tempering into the standard stocking protocol, and that these chemistry parameters are recorded in future stocking events. We also recommend waterbodies be assessed for potential habitat squeezes during summertime prior to initiation of stocking (Coutant 2013).

Due to limitations in the dataset (i.e., specific environmental conditions and plankton samples were not taken in conjunction with stocking), we were unable to assess certain variables which could also have been important. Specifically, we were unable to assess zooplankton or ichthyoplankton availability, but that has been shown to be important for Striped Bass (Sutton and Ney 2001) and other species (Walleye *Sander vitreus*: Donovan et al. 1997). The timing of Walleye fry stocking was important in Ohio reservoirs primarily due to alignment or misalignment with the availability of Gizzard Shad larvae (Donovan et al. 1997). In terms of Hybrid Striped Bass stocking, some states don't even consider stocking fish into locations without a clupeid forage base (Odenkirk et al. 2021).

Table 26. Akaike's Information Criterion, adjusted for small sample sizes (AICC), ΔAICC, model weight (W_i), and number of parameters (K) of general linear models predicting Hybrid Striped Bass catch (fish/net-night or total fish) using fingerling stocking rate and weather on the date of stocking.

Model	AICC	ΔAICC	W_i	K
Age + Precipitation	23.74	0.00	0.63	2
Age + Precipitation + △Temp48	27.12	3.38	0.12	3
Age + △Temp48	28.09	4.35	0.07	2
Age + Precipitation + Tmax	29.23	5.49	0.04	3
Age + Tmax	29.53	5.79	0.03	2
Age + △Temp24	29.54	5.8	0.03	2
Age + Precipitation + △Temp24 + △Temp48 + Tmin	29.89	6.15	0.03	5
Age + Precipitation + △Temp24 + △Temp48 + Tmax	30.53	6.79	0.02	5
Age + Precipitation + △Temp24 + △Temp48	31.97	8.23	0.01	4
Age + StockingRate + Precipitation	32.84	9.1	0.01	3
Age + Precipitation + △Temp24 + Tmin	34.59	10.85	0.00	4
Age + △Temp48 + Tmax	35.38	11.64	0.00	3
Age + △Temp48 + Tmin	35.38	11.64	0.00	3
Age + Precipitation + △Temp48 + Tmin	35.65	11.91	0.00	4
Age + StockingRate + Precipitation + △Temp24 + △Temp48	35.79	12.05	0.00	5
Age + StockingRate + △Temp24 + △Temp48	37.79	14.05	0.00	4
Age + StockingRate + Precipitation + △Temp24	38.49	14.75	0.00	4
Age + StockingRate + △Temp24	39.54	15.8	0.00	3
Age + StockingRate + Precipitation + △Temp48	39.92	16.18	0.00	4
Age + StockingRate + △Temp48	40.85	17.11	0.00	3
Age + StockingRate + Precipitation + △Temp24 + △Temp48 + Tmin	42.17	18.43	0.00	6
Age + StockingRate + Precipitation + △Temp24 + △Temp48 + Tmin + Tmax	42.17	18.43	0.00	7
Age + StockingRate	42.25	18.51	0.00	2
Age + StockingRate + Precipitation + △Temp24 + Tmin + Tmax	42.73	18.99	0.00	6
Age + StockingRate + Precipitation + △Temp24 + △Temp48 + Tmax	42.81	19.07	0.00	6
Age + StockingRate + Precipitation + △Temp48 + Tmin + Tmax	43.00	19.26	0.00	6
Age + StockingRate + △Temp24 + △Temp48 + Tmin	45.28	21.54	0.00	5
Age + StockingRate + Precipitation + △Temp24 + Tmin	50.78	27.04	0.00	5
Age + StockingRate + Precipitation + △Temp24 + Tmax	50.94	27.2	0.00	5
Age + StockingRate + Precipitation + △Temp48 + Tmin	52.01	28.27	0.00	5
Age + StockingRate + Precipitation + △Temp48 + Tmax	52.37	28.63	0.00	5
Age + Precipitation + △Temp24 + △Temp48 + Tmin + Tmax	54.28	30.54	0.00	6

Recommendations and Future Work

We were unable to relate Hybrid Striped Bass sampling to return to the creel during this study, and we know relatively little regarding angler catch and harvest rates or satisfaction with the various Hybrid Striped Bass fisheries around the state. Furthermore, we have little information regarding the effectiveness or acceptability of any kind of protective length-based regulation. In Iowa, *Morone* species have traditionally be grouped in regulations, and with both White Bass and Yellow Bass *Morone mississippiensis* present in many waterbodies, no length limit exists. Other states manage Hybrid Striped Bass fisheries with length-based regulation, bag limits, and catch-and-release requirements to protect larger individuals (e.g., Nelson et al. 2008, Chizinski et al. 2010). A concerted effort should be made to coordinate creel surveys with Hybrid Striped Bass sampling in order to 1) establish a connection between management sampling and return to creel, and 2) establish harvest behaviors and attitudes toward trophy-oriented regulation. Such data can further clarify the true cost and benefit of Hybrid Striped Bass stocking to the anglers of Iowa (Moss and Lawson 1982).

We were also limited in our conclusions regarding Hybrid Striped Bass in flood control reservoirs, where their stocking history in Iowa is the longest. Due to the particular stocking histories at different large reservoirs, the best locations to study the questions posed in this study were Lake Macbride and Three Mile Lake. Lake Macbride has a centrarchid forage base, whereas Three Mile Lake had a moronid and centrarchid forage base. However, we know that Hybrid Striped Bass typically grow larger and faster in large flood control reservoirs like Saylorville and Red Rock Reservoirs, where Gizzard Shad or other clupeids provide a forage base and openwater habitat covers a large area. Unfortunately, we did not have clear stocking histories in these locations to answer size-at-stocking, rate, or environmental condition question. That said, Hybrid Striped Bass have been consistently sampled including age structures at Rathbun Reservoir, and we recommend analysis of this dataset to better examine Hybrid Striped Bass growth in the flood control reservoirs. Such work should be integrated with the growth information from this study to test the effectiveness of special regulations to protect Hybrid Striped Bass fisheries, if found to be appropriate and needful.

We also recommend waterbodies be evaluated for various environmental, flow, and structural characteristics prior to Hybrid Striped Bass stocking. Specifically, waterbodies should be assessed for potential habitat squeezes during summertime prior to initiation of stocking, examined for flow characteristics such as residence time and outflow and spillway design, and fish community composition. Hybrid Striped Bass are known to have a tendency to emigrate, making reservoir fishery management more challenging (Axon and Whitehurst 1985). Hybrid Striped Bass will readily emigrate waterbodies with higher flushing rates and no barrier to emigration (Jahn et al. 1987; Prophet et al. 1991). For instance, flows during and immediately after stocking of fingerling Hybrid Striped Bass were related to catch rates later that fall in the Ohio River impoundments, with mean June flow being an important factor (Henley 2006). As a troubling aside, the fish tagged during Approach 1 of this study were later stocked into a reservoir with a physical barrier with 2” bar spacing, and over one-third of the advanced fingerling Hybrid Striped Bass still emigrated from the reservoir within a few months (B. Dodd, unpublished data). Consideration of appropriate waterbodies in which to stock Hybrid Striped Bass was outside the scope of the current study, but would be a logical step prior to expanding the Hybrid Striped Bass stocking program in Iowa.

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