Monitoring Report

System: Pineview Reservoir
Target Species: Tiger Muskellunge (*Esox masquinongy* × *E. lucius*)

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Monitoring Objectives:

1. Providing anglers the opportunity to catch trophy Tiger Muskellunge.
2. Increase use of Tiger Muskellunge for biological control needs.
3. Harness the unique qualities of Tiger Muskellunge for management purposes beyond trophy fish management and biological control (*e.g.,* use them as a tool to increase the visibility and public interest in Utah's fishing opportunities by showcasing them at community fisheries).

Sampling Design and Statistical Methods:
A cooperative management plan between members of Muskies Inc. Chapter 65 (hereafter Chapter) and UDWR biologists has been in place since 2015. The first step in the strategic approach to allow population management, after culture and stocking success was established, was to establish a monitoring program. Tiger Muskellunge are difficult to collect using traditional fisheries sampling methods and thus a volunteer angler program has been used to supplement traditional sampling methods. This report uses demographic data (*e.g.*, total length, sex) and pelvic fin rays as aging structures collected through the volunteer angler program via hook and line by members of the Chapter. These data equip UDWR biologists with additional resources and have become a valuable tool for estimating Tiger Muskellunge growth and mortality rates. In addition, since 2017, the Chapter has tagged new Tiger Muskellunge captures and recorded recaptures of tagged individuals. Prior to data collection and tagging, Chapter members were trained by UDWR biologists on proper anchor tagging, fin ray collection, and data recording techniques.

Growth was summarized with the Francis parameterization of the vonBertalanffy growth function (VBGF) with parameters defined by the minimum (two) and maximum (11) age in common between the two sexes and the midpoint of these ages (five). Therefore, the model parameters represented the mean lengths of age-2, age-5, and age-11 fish. Differences in VBGF parameters between males and females were assessed by fitting models where all three parameters, two parameters, and one parameter differed by sex, and then comparing the fit of nested subsets of these models with an extra sum-of-squares test.

Size structure was estimated using three analyses: 1) empirical cumulative length distributions and 2) length frequency with Gabelhouse length cutoffs. An empirical cumulative length distribution shows the proportion of fish that are less than each observed length. A length frequency analysis shows the number (*i.e.*, frequency) of fish within a predefined length interval. Gabelhouse length categories define minimum lengths for stock-, quality-, preferred-, memorable-, and trophy-sized individuals based on a percentage of world-record size for the species. Gabelhouse length categories for Tiger Muskellunge do not exist and thus categories for Muskellunge (*E. masquinongy*) were applied.

Population estimates (N) were calculated using Jolly-Seber and Cormack-Jolly-Seber capture-recapture models. The model descriptions are beyond the scope of this report and are thus not presented here. These models are widely applied in ecology and a plethora of literature exists on each model. Note that estimates of N_1 and N_k, where k is the number of sampling events (*i.e.*, years), cannot be estimated in the analysis below.

Mortality was expressed as a catch curve from catch-at-age data. Curves are commonly used to estimate the instantaneous total mortality rate (Z) and total annual mortality rate (A). “Z” is a measure of how the number of individuals declines in an imperceptibly short period of time. “Z” is estimated as the negative slope of a weighted linear regression model fit to the natural logarithm of catch at each age on the descending limb. “A” is the proportion of fish in a population closed to immigration, recruitment, and emigration that die in one year. “A” is estimated as $A = 1 - e^{Z}$.

Summary:

Growth
Differences in growth was present between female and male Tiger Muskellunge (*i.e.*, sexual dimorphism) but no visible difference was observed in growth over time (Tables 1 & 2; Figures 1 & 2). Comparisons of the Francis parameterization of the VBGF indicated that the mean length-at-age-2 did not differ (F = 0.25, P = 0.615) between sexes, but the mean lengths-at-age-5 (F = 21.5, P < 0.001) and at age-11 (F = 8.6, P = 0.004) parameters were significantly smaller for male than female Tiger Muskellunge (Table 2; Figure 2). Growth was initially fast with half of the maximum size attained by age-4 for female and age-3 for male Tiger Muskellunge (Table 3). Absolute growth rates after age-4 (*i.e.*, change in total length per year) was similar for females and males, which grew 29.6 mm (1.2 in) per year on average (Figure 3).

Size Structure
Analysis of Tiger Muskellunge size structure indicates a shift towards anglers capturing larger individuals within the fishery (Figures 4 & 5). This shift appears to be driven by a strong year-class first observed in 2017. Subsequent year-classes do not appear to have been as successful as the minimum length observed increased from 2017-2020. The total number of individuals observed in 2021 decreased and could be explained by the larger individuals observed in 2017 reaching the end of their lifespan. A possible new year-class may have been recruited to angler gear in 2021 but additional temporal data is required to confirm this observation (Figures 4 & 5). All pairwise comparisons of length distributions between years were significantly different (maximum P = 0.049), except for comparisons between 2017-18 (P = 0.203) and 2020-21 (P = 0.277; Table 4). The dominant age observed has increased from age-2 in 2017 to age-5 in 2021 (Figure 6). Future size structure analyses should examine females and males separately given the growth results.

Population Estimate
Although capture and recapture models can be useful for the development of Tiger Muskellunge population estimates, the recommendation from UDWR biologists is to not interpret the population estimates provided in this report as accurate or viable estimates until additional

analyses can be conducted. Because data are not collected through standardized surveys, variability in the amount of annual angler effort would need to be accounted for to ensure any change in the number of recaptures was not induced from a change in catchability caused through changes in angler effort. Additionally, UDWR biologists need to investigate alternative capture-recapture models to improve population estimates due to the unique characteristics of this fishery (*e.g.*, no natural recruitment, angler-tagging program, variable tagging events, etc.). However, the decline in population size presented here (Table 5 & Figure 7) does align with the results observed in the size structure analysis.

Mortality

Catch rates were highly variable and the descending limb of the catch curve was not able to be fit. Thus, no mortality estimates are provided in this report.

Management Actions:

No changes in management are recommended at this time, assuming the future stocking quota of 20,000 individuals in 2023-24 is achieved.

Tables:

Table 1: vonBertalanffy growth model coefficients of Tiger Muskellunge from Pineview Reservoir in 2017-2021.

Year	Linf	K	t0
2017	43.33	0.39	-0.45
2018	45.94	0.24	-1.83
2019	40.86	0.42	-0.86
2020	45.50	0.35	-0.67
2021	47.37	0.27	-1.34

Table 2: Francis parameterization of the vonBertalanffy growth model coefficients for female and male Tiger Muskellunge from Pineview Reservoir among 2017-2021.

Sex	L1	L2	L3
Female	27.8	41.3	44.2
Male	28.1	38.8	40.5

Term Definitions:

1. L_∞ (Linf): Maximum mean length of the group. L_∞ is not the maximum length an individual can grow to and it is possible that an individual fish is longer than L_∞.
2. K: Relates how quickly the growth function approaches L_∞. K is not a growth rate as the units are inverse time (*i.e.*, $\frac{1}{time}$).
3. t_0: X-intercept. t_0 is needed for model fitting and does not have any biological interpretation as a length of 0 cannot exist.
4. L1-3: Mean total length (in) at the minimum (L1), midpoint (L2), and maximum (L3) common ages between sexes.

Table 3: Frequency of female and male Pineview Reservoir Tiger Muskellunge within each 4-in total length (TL) interval and consensus pelvic fin ray age. Ages were pooled across all years (2017-2022).

		Age									
Sex	TL (in)	2	3	4	5	6	7	8	9	10	11
Female	20-23	2	–	–	–	–	–	–	–	–	–
	24-27	14	1	–	–	–	–	–	–	–	–
	28-31	19	16	2	–	–	–	–	–	–	–
	32-35	–	26	14	4	–	–	1	–	–	–
	36-39	–	5	16	11	7	1	3	–	–	–
	40-43	–	–	4	7	7	2	5	–	4	–
	44-47	–	–	–	–	3	1	4	2	1	1
	48-51	–	–	–	–	–	–	1	–	–	1
Male	20-23	2	–	–	–	–	–	–	–	–	–
	24-27	15	1	–	–	–	–	–	–	–	–
	28-31	20	15	2	–	–	–	–	–	–	–
	32-35	1	18	10	9	–	–	–	–	–	–
	36-39	–	2	10	13	2	3	3	–	1	1
	40-43	–	–	2	5	3	–	1	–	–	–
	44-47	–	1	–	–	–	–	1	1	–	–
	48-51	–	–	–	–	–	–	–	–	–	–

Table 4: P-values from length distribution pairwise comparison between years from the Fisher's Exact test for Pineview Reservoir Tiger Muskellunge. P-values were adjusted to account for the increasing experimentwise error rate due to multiple comparisons. A total length interval of 20-mm (0.79-in) was used.

Pairwise Years	P-value	Test Result
2017-18	0.211	No Significant Difference
2017-19	0.007	Significant Difference
2017-20	0.007	Significant Difference
2017-21	0.005	Significant Difference
2018-19	0.040	Significant Difference
2018-20	0.008	Significant Difference
2018-21	0.007	Significant Difference
2019-20	0.005	Significant Difference
2019-21	0.005	Significant Difference
2020-21	0.252	No Significant Difference

Table 5: Population estimates calculated from Cormack-Jolly-Seber and Jolly-Seber models and capture probabilities (P) for Tiger Muskellunge from Pineview Reservoir angler-derived capture-recapture data. Values in parentheses indicate the lower and upper 95% confidence intervals for population estimates and standard error of capture probabilities.

	Population Size Estimate		
Year	Jolly-Seber	Cormack-Jolly-Seber	P
2018	616.0	688.7	0.13
	(176.7, 1055.3)	(193.06, 1184.33)	(0.05)
2019	695.1	752.17	0.13
	(278, 1112.3)	(298.24, 1206.1)	(0.04)
2020	417.1	438.88	0.22
	(218.9, 615.3)	(228.83, 648.93)	(0.06)
2021	329.8	343.52	0.31
	(187.6, 472)	(194.2, 492.85)	(0.07)

Model Descriptions:

1. The Jolly-Seber model is used to estimate abundance at the time of sample event (*i.e.*, year) when three or more samples of marked fish have been collected from an open population. An open population model was selected because the data span periods of time where the assumption of a closed population is not reasonably assured (*i.e.*, substantial mortality could have occurred).

2. The Cormack-Jolly-Seber model is an extension of the Jolly-Seber model to estimate abundance and the probability of capture in sample from multiple samples of individually marked fish from an open population, possibly with variable capture probabilities.

Model Assumptions:

1. Tags are neither lost nor missed.

2. All fish within a sample have an equal probability of capture.

3. Every marked individual has the same probability of surviving among sampling events. If survival rate estimates are to apply to all, rather than just marked, individuals, then it is also assumed that the probability of survival is the same for both marked and unmarked fish.

4. Sampling time is negligible in relation to intervals between samples.

Figures:

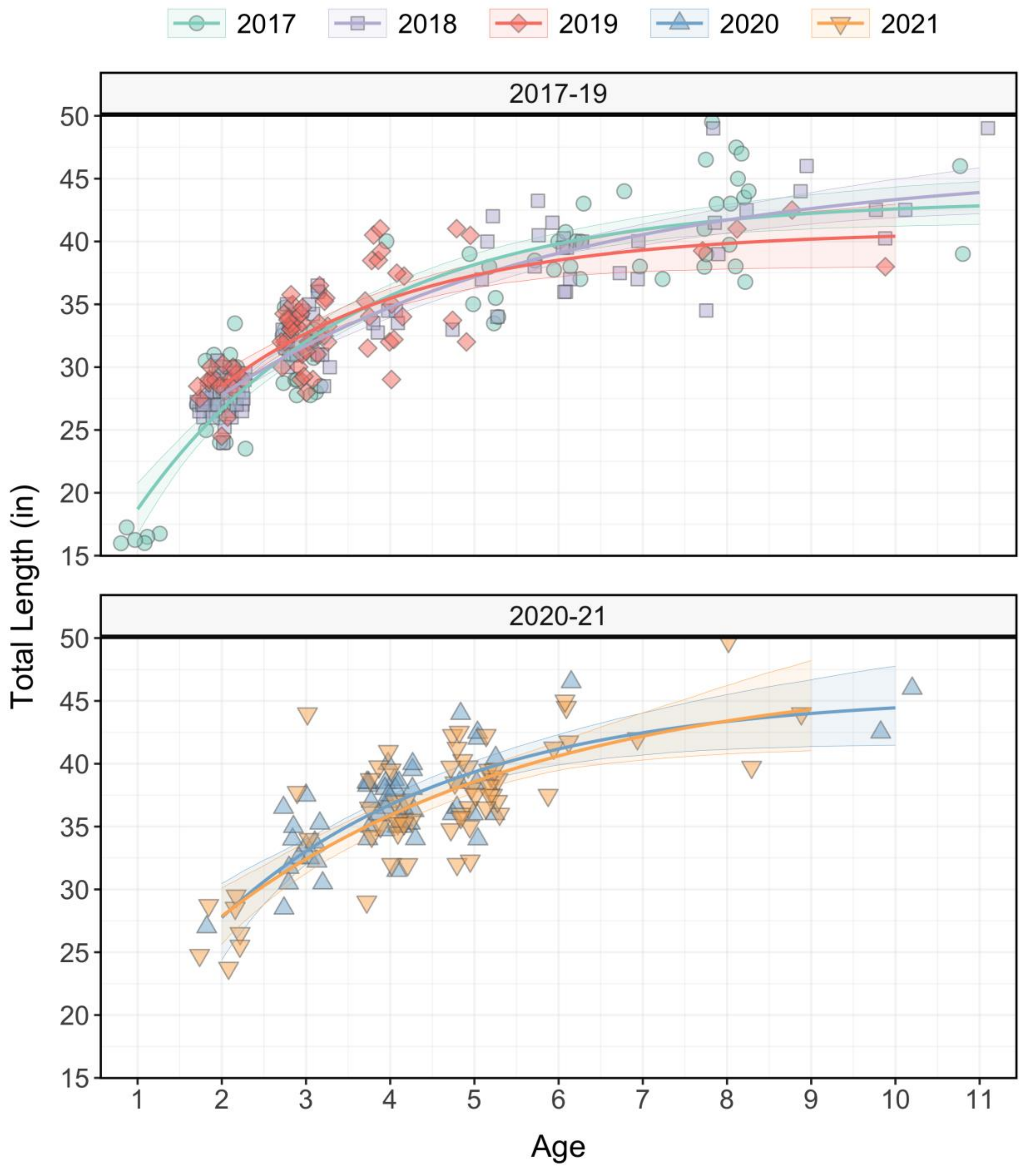

Figure 1: Total length versus age with superimposed best-fit vonBertalanffy growth model for Tiger Muskellunge by year (i.e., 2017-2022) from Pineview Reservoir. Shaded regions represent 95% confidence bands. Individual fish (i.e., points) are jittered to minimize overplotting.

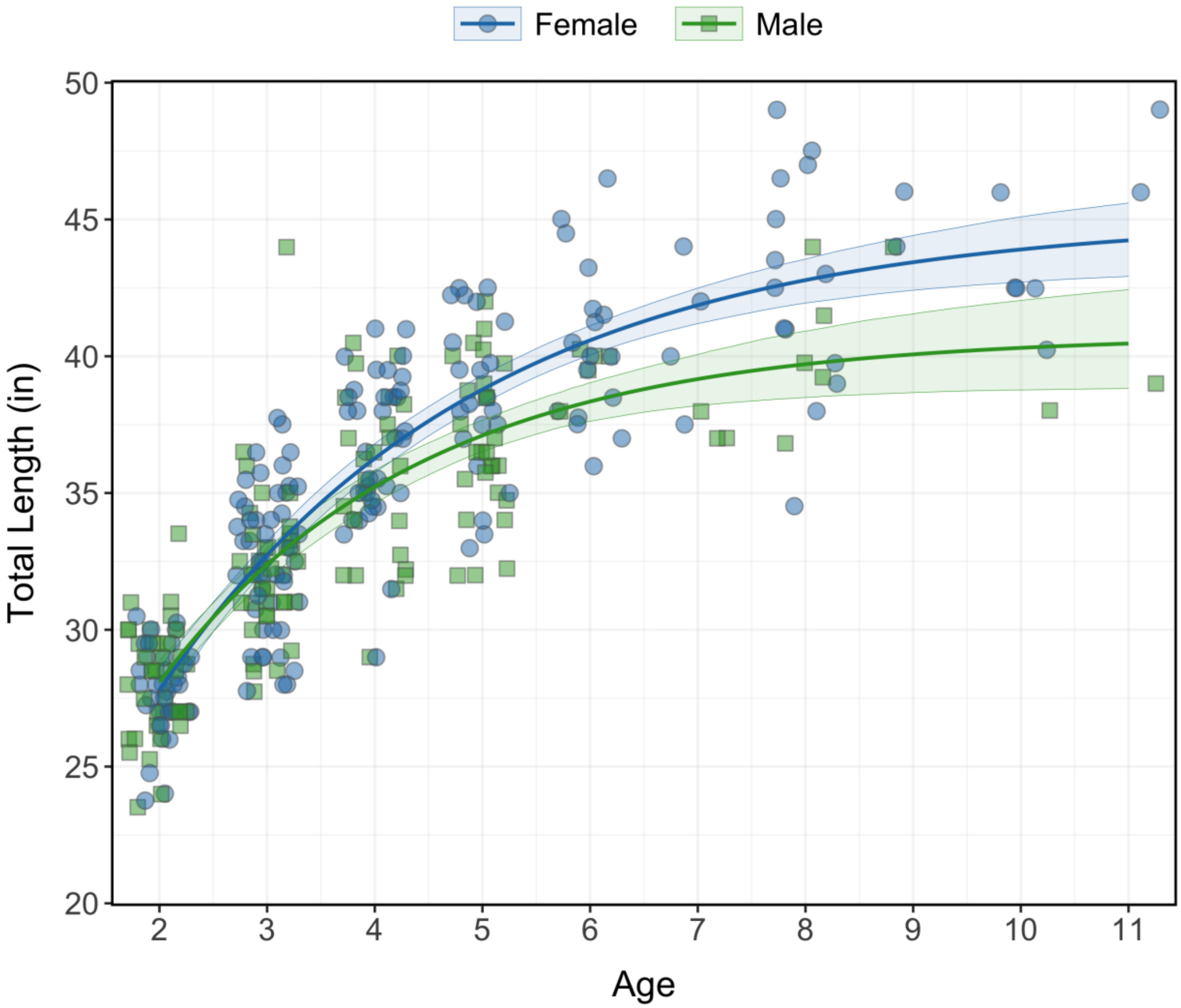

Figure 2: Total length versus age with superimposed best-fit vonBertalanffy growth model for Tiger Muskellunge by sex (i.e., female and male) from Pineview Reservoir. Shaded regions represent 95% confidence bands. Individual fish (i.e., points) are jittered to minimize overplotting.

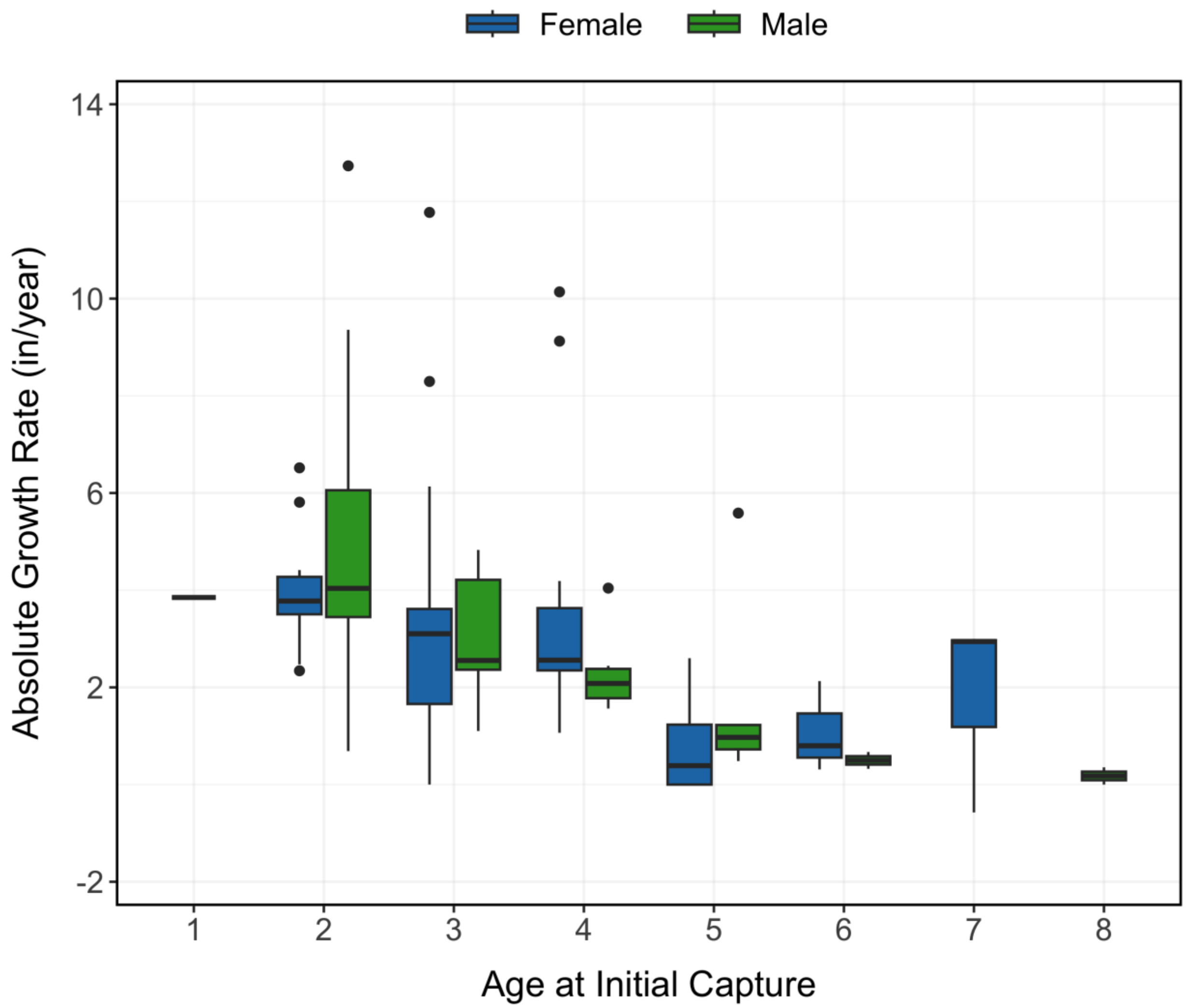

Figure 3: Boxplot expressing the absolute growth rate (inches/day) for Tiger Muskellunge from Pineview Reservoir angler-derived capture-recapture data. Box ends represent the 25th and 75th quantiles, horizontal lines are the median, the upper whisker extends to the largest observation no further than 1.5 * interquartile range (IQR) from the 75th quantile, the lower whisker extends to the smallest observation no further than 1.5 * IQR from the 25th quantile.

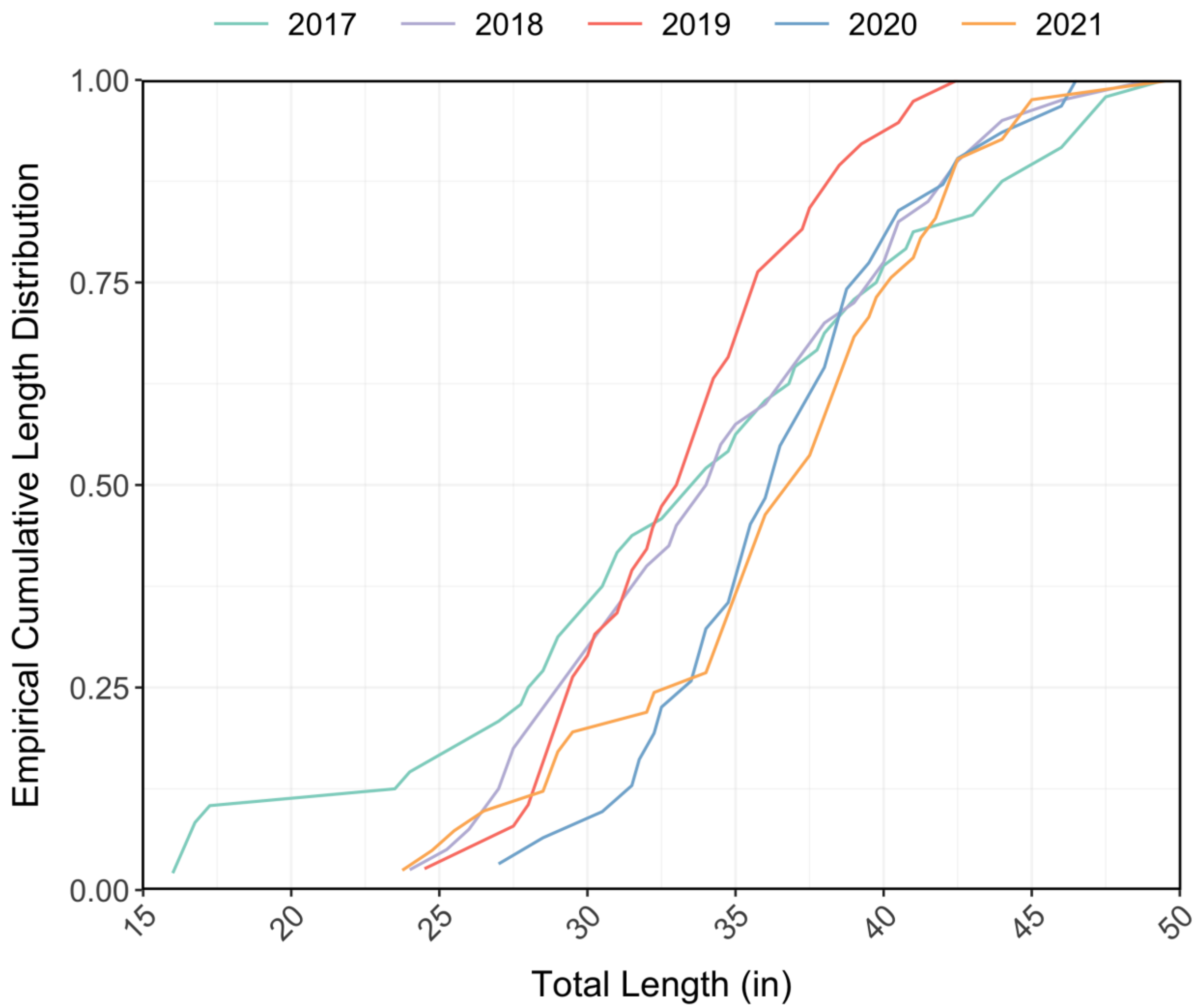

Figure 4: Empirical cumulative total length (in) distribution of Tiger Muskellunge from Pineview Reservoir in 2017-2022.

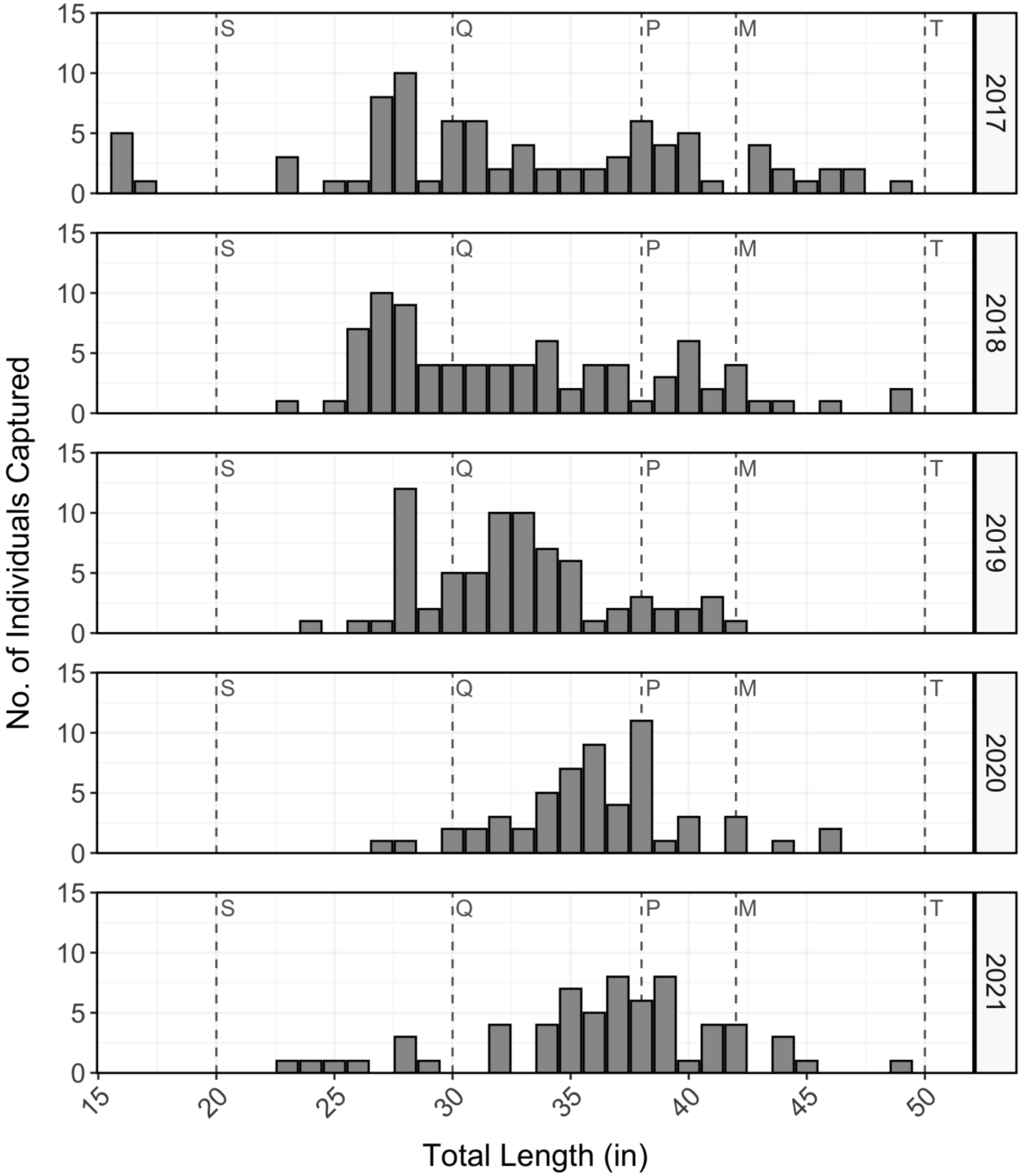

Figure 5: Total length (in) frequency of Tiger Muskellunge from Pineview Reservoir in 2017-2022. The length intervals are left-inclusive and right-exclusive, and the x-axis labels represent the start of the length interval (i.e., left side). The start of each Gablehouse length category is identified by the vertical dashed lines and the category name (i.e., stock, quality, preferred, memorable, and trophy) is indicated by the first letter of each category on the right side of the dashed line.

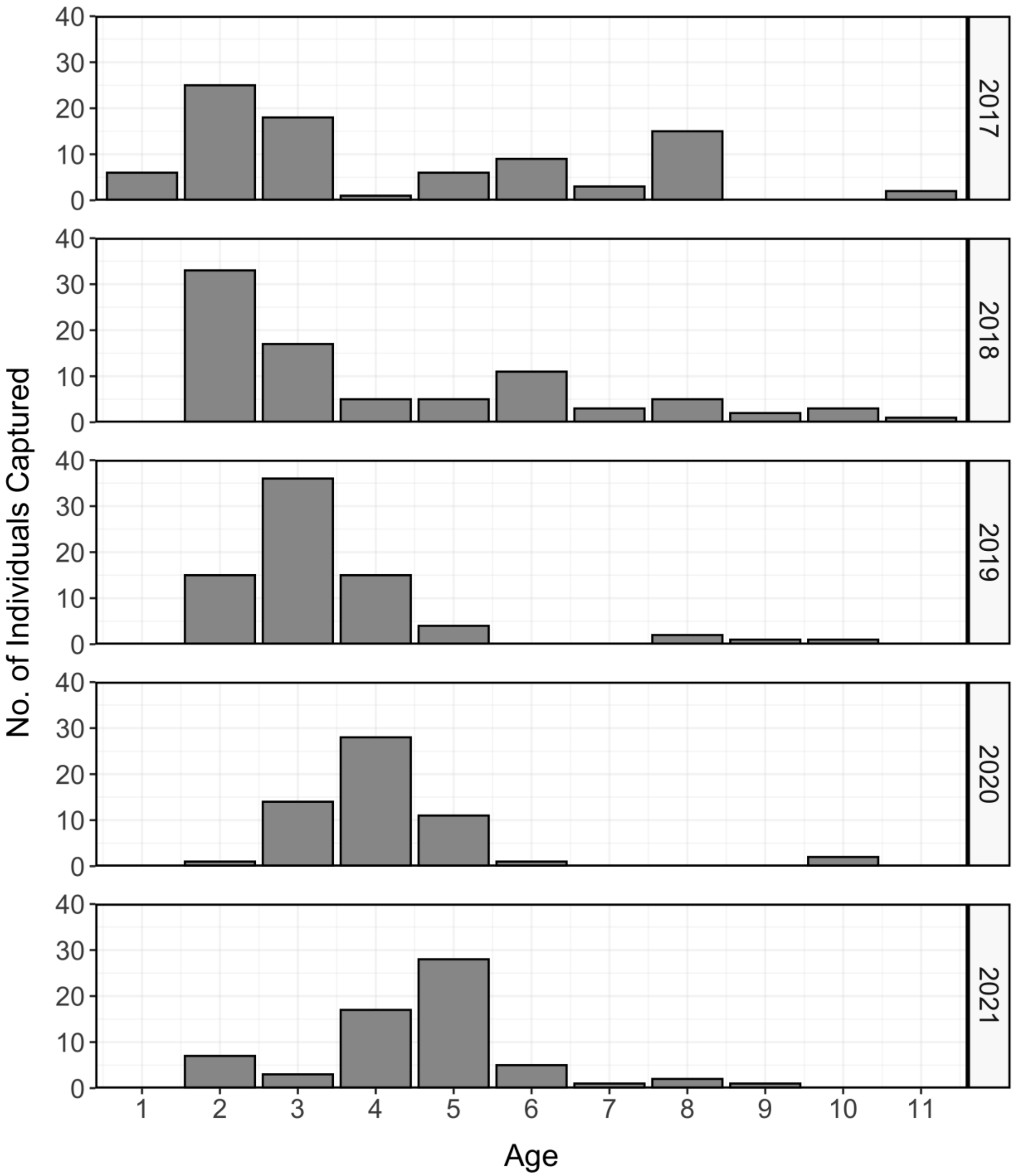

Figure 6: Age frequency of Pineview Reservoir Tiger Muskellunge from 2017-2022. The length intervals are left-inclusive and right-exclusive, and the x-axis labels represent the start of the length interval (i.e., left side).

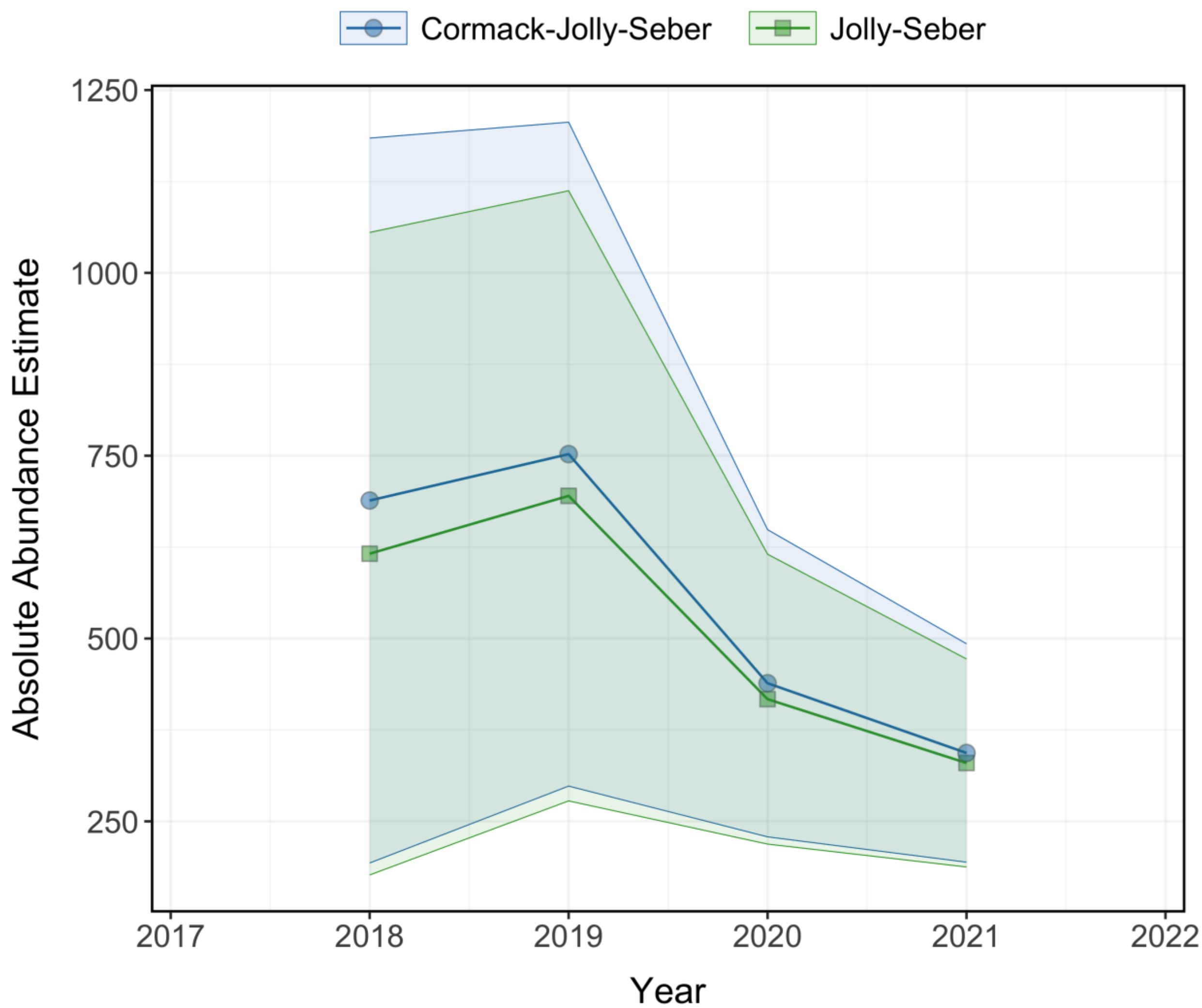

Figure 7: Population estimates calculated from Cormack-Jolly-Seber and Jolly-Seber models for Tiger Muskellunge from Pineview Reservoir angler-derived capture-recapture data. Shaded regions represent 95% confidence bands.

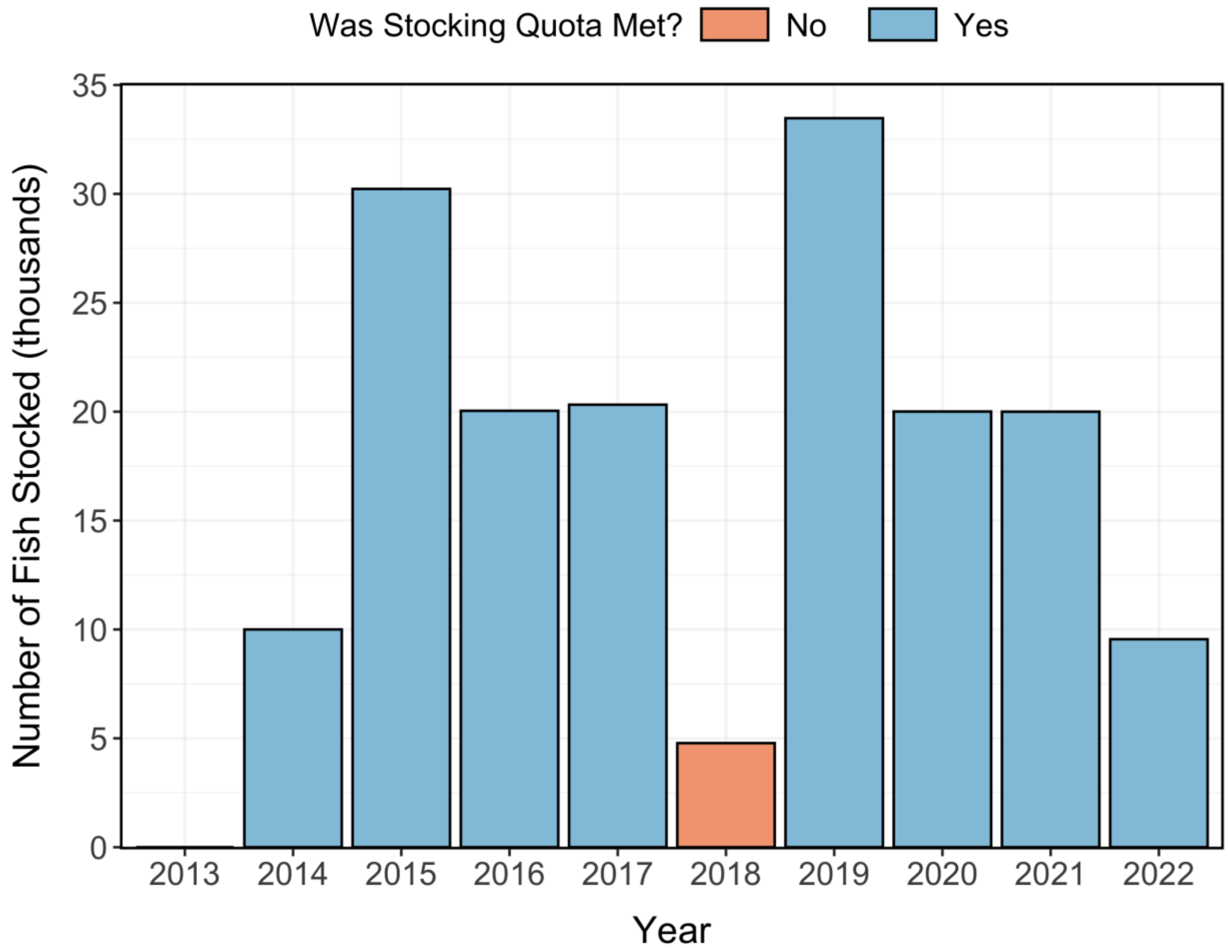

Figure 8: Number of Tiger Muskellunge stocked in Pineview Reservoir from 2013-2022. Length-at-stocking and stocking quota varies among years. A stocking quota was determined to be met if the number of stocked individuals was at least 90% of the stocking quota.