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Length–Weight Relationships for 22 Mid-Atlantic Species Show Variability in Slopes Spatially, Temporally, and With Published Regressions

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ABSTRACT

Despite their importance in understanding stream food webs and community dynamics, small-bodied and nongame fish remain relatively understudied. This is also true of the basic ecology for these taxa, such as calculating length–weight relationships (LWRs). Here we present LWRs for 22 species including nongame and small-bodied taxa from eastern North America in the Susquehanna River watershed in > 30 small watersheds across four years, seven families, and > 7500 individuals. To contextualize these LWRs, we compared the slopes (b) of our relationships for abundant species across broad-scale watersheds, over time, and to published slopes in eastern North America. We found significant variability in b for our four most abundant species: *Rhinichthys atratulus* (blacknose dace), *Semotilus atromaculatus* (creek chub), *R. cataractae* (longnose dace), and *Etheostoma olmstedi* (tessellated darter) across both watershed and year of sampling yet inconsistent changes across species. We also found published values for b to be > 0.1 different from our LWRs for 36% of species, indicating wide variability across their geographic range as well. Collectively, these results highlight variability in LWRs, and while they may caution against the generalized use for management, they also identify opportunities for LWR use as a tool for comparing populations. The addition of these equations to the literature fills an important gap in our understanding of LWRs for eastern North American fishes, while also providing regional, temporal, and taxonomic context for consistency of LWRs across these species.

1 | Introduction

Small-bodied and nongame fish species are understudied across ecological and socioeconomic contexts [1, 2], despite their importance for understanding food web interactions (e.g., [3, 4]), ecosystem function [5], management and policy decisions [6], and emerging recreational importance [7]. In particular, understanding length–weight relationships (LWRs) and individual body condition can be valuable for assessing differences in community dynamics that are not visible with biomass or count data alone [8, 9]. While there have been recent calls to expand management focus and data collection for nongame species in light of their importance [10], there is still a relative dearth of information on these relationships in North America.

Research to understand LWRs has expanded globally in recent years, particularly in Asia [11–13] and Africa [14–16]. Yet, in eastern North America, there are very few published LWRs for nongame species, with only four studies we could identify including any nongame stream fishes [17–20]. LWRs may also vary across a species' geographic range, environmental conditions, and taxonomic groups [21, 22]. Therefore, replication and comparative studies of LWRs across species ranges can help to identify plasticity of these relationships within and across taxonomic groups. In addition, genus- and form-based data on

LWRs may help inform biomass estimates when only lengths or photos are available (e.g., citizen science projects or historic imagery [23]).

Our purpose in this study is three-fold: (1) to document LWRs for 22 mid-Atlantic species from the Susquehanna River watershed, (2) to compare consistency of LWR patterns across years, watersheds, and taxonomic groups to better understand the local context for statistical confidence in estimating biomass from length data, and (3) to compare our LWR coefficients to those published in eastern North America to identify relative variability in LWRs across species' geographic ranges. These LWRs allow improved understanding of species variability in body condition across a range, aiding management of fisheries and improving the utility of historic data in future research for taxa in eastern North America.

2 | Methods

We sampled 77 sites from 34 hydrologic unit code 12 (HUC; a United States hierarchical coding system with larger numbers referring to smaller watershed scales) watersheds across two HUC 6 watersheds (9700 to 18,000 km^2 in size) in the Susquehanna River basin (Figure 1) from 2022 to 2025 during May–July each summer via backpack electrofishing (Smith-Root LR-24 units). These stream sites ranged in average wetted width from 0.5 to 10.2 m, included a range of land use from primarily forested to agricultural and cross six ecoregions: Unglaciated High Allegheny Plateau, Glaciated High Allegheny Plateau, Northern Dissected Ridges and Knobs, Northern Limestone/Dolomite Valleys, Northern Sandstone Ridges, and Northern Shale Valleys. For each sampling event, we sampled a 100 m reach with upstream and downstream block nets and used dip nets for fish capture with 3-mm mesh for all nets. We measured total length to the nearest millimeter and weight to the nearest 0.1 or 0.01 g when feasible depending on field conditions (e.g., wind affected higher precision balances), on the first 30 individuals of each species captured at the site. All fish were measured in the field and either released into the reach where they were captured or vouchered in formalin after euthanasia with tricaine mesylate (MS-222). All field sampling was completed under Pennsylvania Fish and Boat Commission permits and Susquehanna University IACUC approval.

We included species for analysis if we collected more than 10 individuals; regression intercept (a) and slope (b) were both significant, and multiple age classes were sampled, leaving us with 7631 individuals across 22 species. For the taxa that could not be differentiated in the field (*Cottus cognatus* and *C. bairdii*; sculpin spp.), we have included genus-level LWRs and listed the contributing species. We $\log_{10}$-transformed all length (millimeters) and weight (grams) data to follow the standard LWR formula of $\log_{10}(\text{weight}) = \log_{10}(a) + b\log_{10}(\text{length})$ to calculate the intercept and slope of the equation for each species [24].

To compare LWR slopes across years and HUCs for our data and published LWRs we used nonoverlapping 95% confidence intervals as a conservative estimate of significance. We used this estimate as we did not have more than a maximum of four groups for any comparison, for which a 95% interval approximates a Bonferroni-corrected p value of 0.05 and is a more conservative

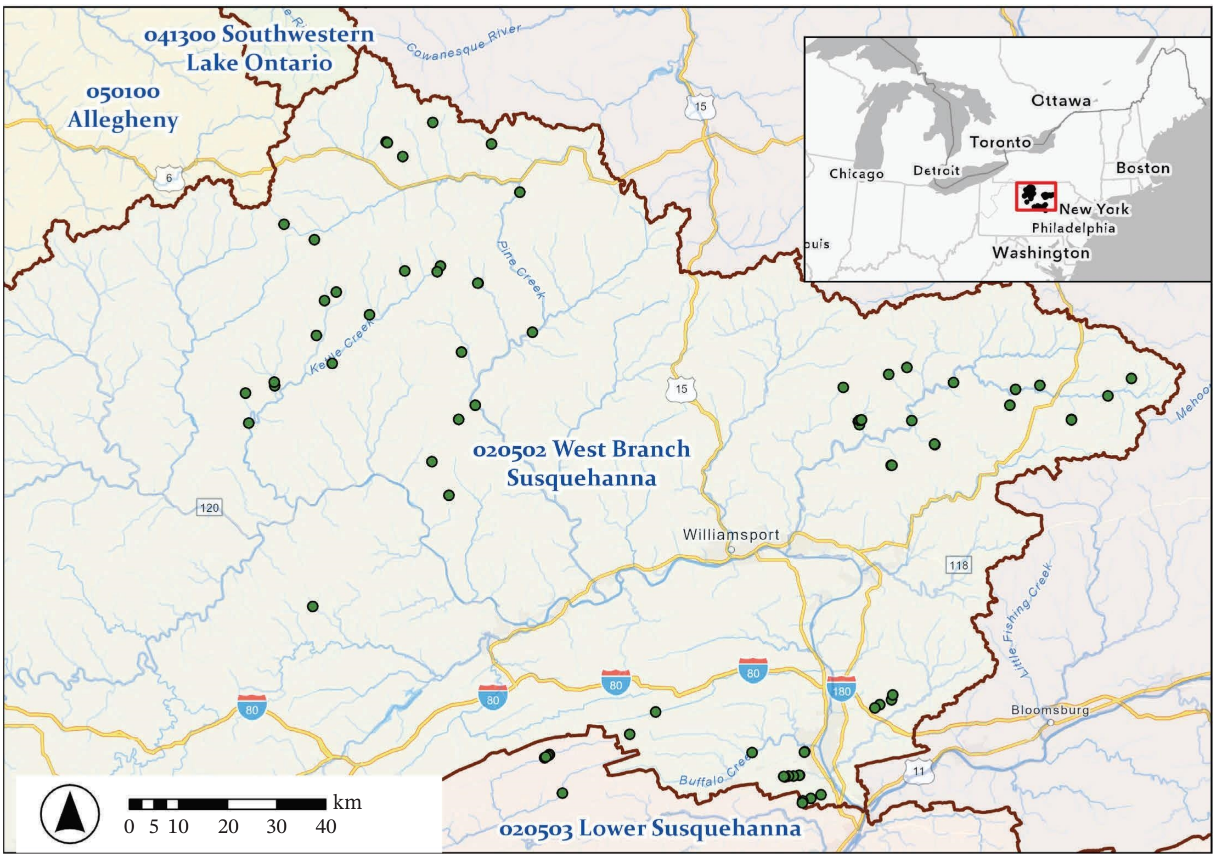

FIGURE 1 | Northcentral Pennsylvania sampling locations (in green) overlayed on HUC 6 watersheds.

TABLE 1 | Length–weight relationships for 22 mid-Atlantic species.

Family	Genus/species	Common name	Count	Mean length mm (min–max)	Mean weight g (min–max)	$a10^5$ (95% CI)	b (95% CI)	Adj R^2
Catostomidae	*Catostomus commersonii*	White sucker	385	133.01 (43–370)	47.66 (0.5–525.4)	0.867 (0.681–1.10)*****	3.035 (2.984–3.085)*****	0.973
Centrarchidae	*Ambloplites rupestris*	Rock bass	10	77.40 (38–116)	14.13 (1–38.5)	0.924 (0.430–1.98)****	3.183 (3.005–3.361)****	0.995
	Lepomis cyanellus	Green sunfish	99	83.09 (39–167)	16.90 (0.71–87.9)	1.16 (0.732–1.84)****	3.108 (3.002–3.214)****	0.972
	Lepomis macrochirus	Bluegill	121	83.79 (42–159)	15.16 (1.01–86.8)	0.557 (0.442–0.702)*****	3.240 (3.187–3.293)*****	0.992
	Micropterus nigricans	Largemouth bass	49	92.10 (31–217)	19.79 (0.4–135.7)	1.12 (0.727–1.72)****	3.008 (2.910–3.105)****	0.988
Cottidae	*Cottus cognatus & C. bairdii*	Sculpin spp.	1701	71.33 (12–131)	4.66 (0.01–28.8)	0.762 (0.675–0.862)*****	3.089 (3.060–3.118)*****	0.963
Fundulidae	*Fundulus diaphanus*	Banded killifish	140	63.12 (35–96)	2.85 (0.49–9.3)	0.786 (0.416–1.48)****	3.057 (2.903–3.210)****	0.917
Ictaluridae	*Noturus insignis*	Margined madtom	28	98.39 (47–136)	12.72 (1–38.9)	1.57 (0.266–9.29)****	2.926 (2.536–3.315)****	0.898
Leuciscidae	*Campostoma anomalum*	Central stoneroller	309	79.55 (48–161)	5.85 (0.8–46.62)	0.566 (0.400–0.800)*****	3.110 (3.030–3.189)*****	0.950
	Clinostomus funduloides	Rosyside dace	79	46.28 (31–70)	0.95 (0.3–3.1)	3.19 (1.03–9.94)****	2.667 (2.371–2.964)****	0.804
	Exoglossum maxillingua	Cutlip minnow	234	70.84 (35–187)	5.41 (0.44–31.7)	1.07 (0.636–1.81)*****	3.011 (2.888–3.135)*****	0.908
	Luxilus cornutus	Common shiner	177	79.68 (32–155)	6.65 (0.3–45.9)	0.451 (0.340–0.599)*****	3.167 (3.102–3.232)*****	0.981
	Margariscus margarita	Allegheny pearl dace	29	83.34 (58–100)	5.87 (1.9–9.1)	0.759 (0.187–3.08)****	3.054 (2.736–3.371)****	0.933
	Miniellus procne	Swallowtail shiner	25	70.76 (42–96)	3.47 (0.73–7.7)	1.30 (0.317–5.33)****	2.911 (2.579–3.243)****	0.932
	Pimephales notatus	Bluntnose minnow	116	60.02 (34–90)	2.55 (0.3–7.6)	0.891 (0.386–2.06)****	3.027 (2.822–3.233)****	0.881
	Pimephales promelas	Fathead minnow	38	64.29 (48–74)	2.91 (1.42–4.69)	0.962 (0.0741–12.5)****	3.021 (2.405–3.638)****	0.726
	Rhinichthys atratulus	Blacknose dace	1700	56.88 (23–92)	1.90 (0.12–7.5)	0.759 (0.661–0.871)*****	3.046 (3.011–3.080)*****	0.947
	Rhinichthys cataractae	Longnose dace	859	73.46 (33–154)	4.44 (0.2–38)	0.474 (0.406–0.553)*****	3.150 (3.114–3.186)*****	0.971
	Semotilus atromaculatus	Creek chub	1039	76.21 (30–228)	7.70 (0.1–146.8)	0.849 (0.730–0.986)*****	3.055 (3.020–3.090)*****	0.966
	Semotilus corporalis	Fallfish	79	96.52 (44–236)	12.33 (0.7–114.3)	0.898 (0.685–1.18)****	3.002 (2.942–3.062)****	0.992
Percidae	*Etheostoma flabellare*	Fantail darter	16	66.38 (53–75)	2.54 (1.25–3.8)	11.3 (0.217–592)***	2.382 (1.438–3.326)***	0.654
	Etheostoma olmstedi	Tessellated darter	398	57.32 (30–85)	1.94 (0.3–5.41)	1.42 (0.963–2.10)*****	2.899 (2.802–2.996)*****	0.897

Note: Lengths are in millimeters and weights in grams with ranges in parentheses. 95% confidence intervals are included in parenthesis for a and b with regression adjusted R-squared. p values are represented as $^{***}< 0.0001$, $^{****}< 1 \times 10^{-10}$, and $^{*****}< 1 \times 10^{-100}$. Intercept ($a$) values are all presented in scientific notation of 10^5 for clarity.

TABLE 2 | Difference in values for *b* between our results and published values for all species (negative values represent a lower value in the published comparison).

Family	Genus/species	Common name	FishBase	Miller et al. 2015	Parker et al. 2018	Driehaus et al. 2023	Beckman 1948
Catostomidae	*Catostomus commersonii*	White sucker	−0.045	.	.	−0.095	.
Centrarchidae	*Ambloplites rupestris*	Rock bass	−0.093	.	.	−0.143	−0.214
	Lepomis cyanellus	Green sunfish	0.002	.	.	0.082	.
	Lepomis macrochirus	Bluegill	**−0.110***	**−0.428***	.	−0.080	−0.130
	Micropterus nigricans	Largemouth bass	0.072	−0.055	.	0.032	−0.015
Cottidae	*Cottus cognatus* and *C. bairdii*	Sculpin spp.	0.061	.	.	−0.059	.
Fundulidae	*Fundulus diaphanus*	Banded killifish	0.043	.	.	.	.
Ictaluridae	*Noturus insignis*	Margined madtom	0.144	.	.	.	.
Leuciscidae	*Campostoma anomalum*	Central stoneroller	−0.050	.	.	−0.090	.
	Clinostomus funduloides	Rosyside dace	0.443	.	.	.	.
	Exoglossum maxillingua	Cutlip minnow	0.049	.	.	.	.
	Luxilus cornutus	Common shiner	−0.077	.	.	.	.
	Margariscus margarita	Allegheny pearl dace	−0.004	.	.	.	.
	Miniellus procne	Swallowtail shiner	0.199	.	.	.	.
	Pimephales notatus	Bluntnose minnow	0.193	.	**0.364***	**0.253***	.
	Pimephales promelas	Fathead minnow	0.049	.	.	.	.
	Rhinichthys atratulus	Blacknose dace	0.024	.	.	0.024	.
	Rhinichthys cataractae	Longnose dace	0.010	.	.	−0.020	.
	Semotilus atromaculatus	Creek chub	−0.005	.	.	**−0.115***	.
	Semotilus corporalis	Fallfish	0.008	.	.	.	.
Percidae	*Etheostoma flabellare*	Fantail darter	0.698	.	.	0.508	.
	Etheostoma olmstedi	Tessellated darter	0.221	.	.	.	.

Note: FishBase values are Bayesian estimates, and all others are calculated from field measures. Beckman (1948) did not include confidence intervals to make statistical comparisons. Values with 95% confidence intervals that do not overlap are bolded with an asterisk. Comparison LWRs for sculpin are *C. bairdii*.

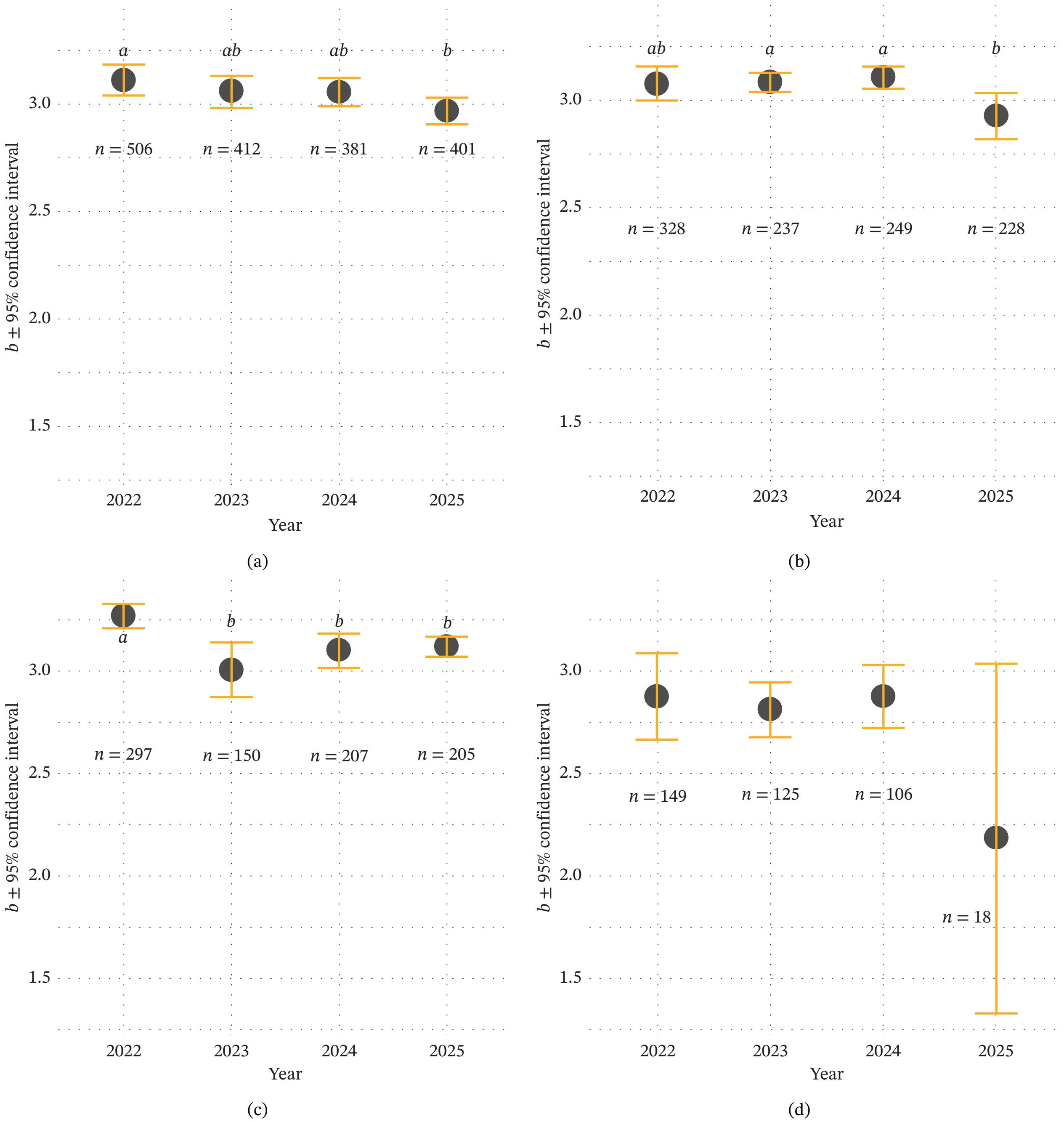

FIGURE 2 | Interannual variability in b between 2022 and 2025 for the four most common species sampled: (a) blacknose dace, (b) creek chub, (c) longnose dace, and (d) tessellated darter. Points represent mean values for b with error bars for 95% confidence intervals. The n used to calculate each length–weight regression is plotted by the point and letters indicate non-overlapping 95% confidence intervals.

estimate of significance for fewer comparison groups [25]. Published LWRs for comparison of a and b used both frequentist estimates from sampled fish [17–20] and a Bayesian hierarchical approach depending on the quality and quantity of available data and species body shape [26] to generate slopes. While Bayesian credible intervals and frequentist confidence intervals are generated from distinct underlying statistical frameworks, they become numerically equivalent, or Bayesian estimates become more precise, with $n > 75$ and an absence of strongly skewed distributions or bias priors [27], allowing for direct comparison here between our results and FishBase estimates. Similar to all published studies we used for comparison, we did not control for gut contents or sex for individual inclusion in LWRs. All analyses and figures were completed with R and the ggplot2 package [28, 29].

3 | Results and Discussion

We calculated LWRs for 22 species from seven families and 17 genera (Table 1). In addition, 10 of these species did not have published LWRs that we could find based on field measurements, though other species have been sampled from the Mississippi and eastern drainages (e.g., [30]), and all species included modelled equations from FishBase. In comparing our LWR slopes to those

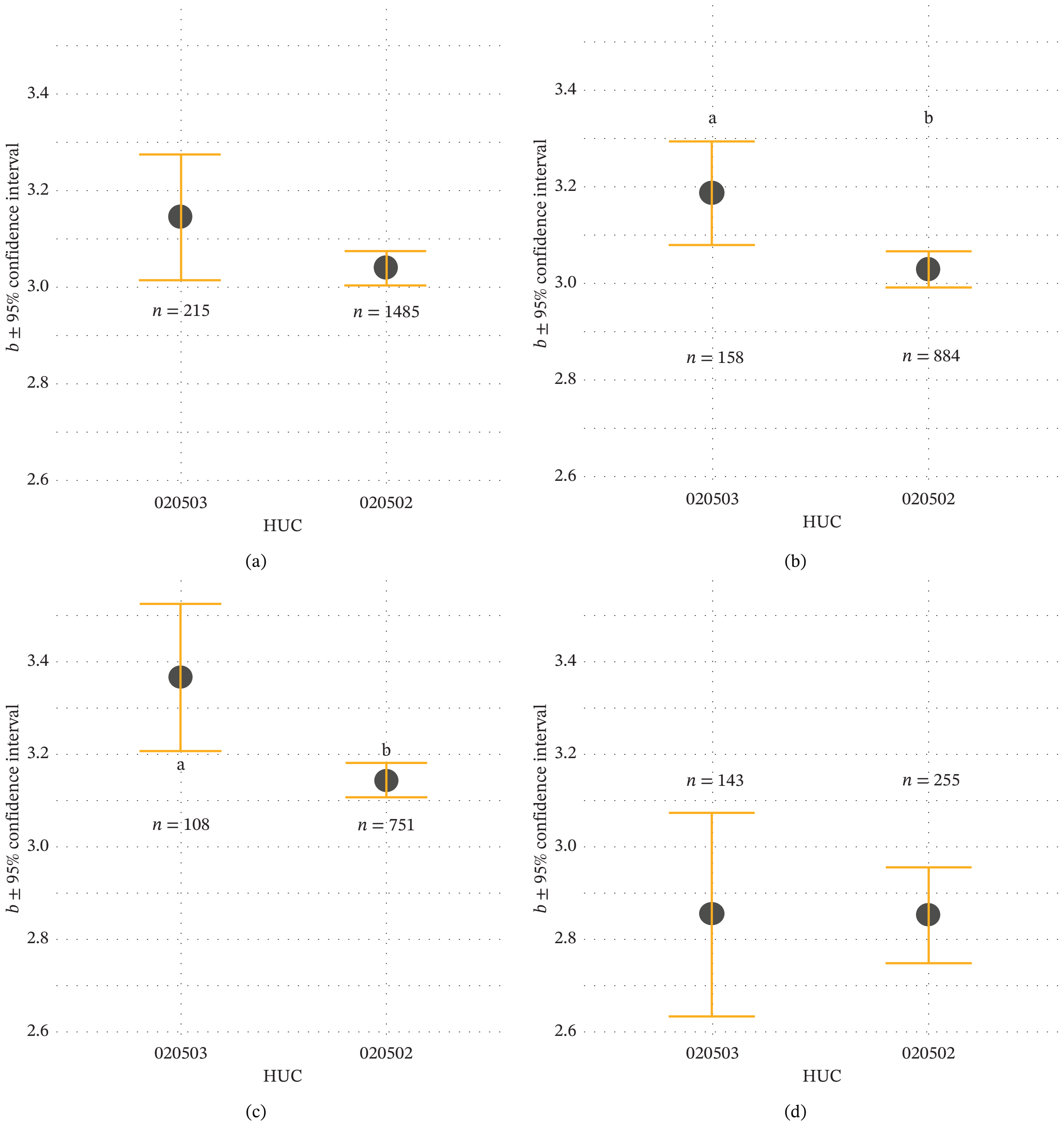

FIGURE 3 | Spatial variability in *b* for the two HUC6 watersheds and the four most common species sampled: (a) blacknose dace, (b) creek chub, (c) longnose dace, and (d) tessellated darter. HUC 020502 represents the West Branch Susquehanna River and 020503 is the lower Susquehanna River. Points represent mean values for *b* with error bars for 95% confidence intervals. The *n* used to calculate each length–weight regression is plotted by the point and letters indicate non-overlapping 95% confidence intervals.

published for these species, we identified significant differences in *b* for three species: *Lepomis macrochirus* (bluegill), *Pimephales notatus* (bluntnose minnow), and *Semotilus atromaculatus* (creek chub; Table 2). *Micropterus nigricans* (largemouth bass) and bluegill also had significantly different *b* between existing published values.

In addition to these significant differences in slope, we identified high variability in *b* for some species that has the potential to create very different biomass interpretations from length data, depending on the slope coefficient used and size of the individuals in question (even if 95% confidence intervals overlap). For 15 species (68%), values for *b* varied by > 0.05 and by > 0.1 for eight species (36%). To create context, a decrease of 0.05 in *b* for a 100-mm *Catostomus commersonii* (white sucker) in our LWR equation would decrease the calculated weight by 21%; and a decrease of 0.10 in *b* for the same fish would decrease the estimated weight by 37% if *a* is held constant. While this might not be realistic in all cases, slope variability also increases in importance for larger fish relative to intercept. For example, a 150-mm bluegill would be estimated to weigh 16% less if using the equation calculated by[19], a 200-mm bluegill would be 26% less, and a 300-mm bluegill would be 37% less.

These differences could create compounding impacts on ecological inference or management decisions.

Within our own data, we identified significant and differing variability in *b* for our four most abundant species: *Rhinichthys atratulus* (blacknose dace), creek chub, *R. cataractae* (longnose dace), and *Etheostoma olmstedi* (tessellated darter) across both time (Figure 2) and HUC6 watersheds (Figure 3). For three of these species, *b* was significantly different between at least 2 years of sampling. However, the pattern over time was inconsistent across species, with blacknose dace and creek chub showing similar patterns to each other but not longnose dace. In addition, the range in confidence intervals varied widely across species, likely driven by *n* for each group (e.g., tessellated darter count in 2025). Comparing large HUC6 watersheds, creek chub and longnose dace had significantly lower *b* values for the West Branch Susquehanna than for the Lower Susquehanna watershed. Blacknose dace showed a similar pattern (though not significant), and tessellated darter had nearly identical *b* for these watersheds (difference of 0.002). Within genera, slopes also varied inconsistently. Blacknose and longnose dace had significantly different slopes while *P. promelas* (fathead minnow) and bluntnose minnow were nearly identical (mean difference in *b* of 0.006), despite these species having similar body types within both genera.

Our results and comparisons to published LWRs indicate that some species might be more or less likely to have variable LWRs within a region or dependent on local conditions (e.g., drought or flooding years [31]). Regional patterns may also be a result of local stress for some species by altering the timing of spawning or size at maturity [32], which can alter the ratio or developmental state of gravid individuals potentially sampled. Species interactions can also affect competitiveness based on local conditions [33], contributing to variable stress across a range while staying more consistent within each individual stream. In addition, variability in sampling methods used across studies may influence sampled individuals and have the potential to impact body condition as a result, which is an unexplored methodological question with ecological implications. While these results highlight the potential variability in LWRs and may caution against generalized use for management, we suggest that this strengthens the opportunity for their use as a tool for comparing populations and points to future directions for identifying when LWRs are likely to be translatable across a species range or stream conditions. In addition, it points to opportunities for identifying the number of individuals and sampling locations that may be needed to generate a more robust and generalized LWR, within a watershed and across a species range.

4 | Conclusions

The addition of these equations to the literature can help inform management and future research, while also providing regional, temporal, and taxonomic context for the consistency of LWRs across these species. These results also fill an important gap in our understanding of LWRs for eastern North American fishes and identify future directions for research into the application of LWRs in fish ecology.

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Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

All data that support the findings of this study and code to replicate results are openly available in the “FRI_LWReg” GitHub repository at https://github.com/Team-FRI/FRI_LWReg/.

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