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Do the length-weight relationships and condition factors of farmed rainbow trout, brook, and brown trout differ from their wild counterparts?

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ABSTRACT

This study examines the length-weight relationships (LWR) and condition factors (CF) of three farmed fish species: rainbow trout (*Oncorhynchus mykiss*), brook trout (*Salvelinus fontinalis*), and brown trout (*Salmo trutta*). It then compares these findings with existing literature data for their wild counterparts to gain insights into the influence of aquaculture on their growth patterns. Using a simple power function, $W = \alpha L_T^{\beta}$ where W represents the fish's weight, and L_T represents the fish's total length, the LWR is determined. The estimated β values indicate positive allometric growth for rainbow and brook trout, whereas brown trout exhibit an isometric growth pattern. The estimated condition factors ranged from 0.992 to 1.442 for rainbow trout, 0.665 to 1.731 for brook trout, and 0.841 to 1.321 for brown trout, with significant differences observed among them (Kruskal-Wallis test, $p < 0.05$). Compared with literature data from their wild counterparts, notable variations in growth patterns emerge, particularly evident in rainbow and brook trout, possibly illustrating the contrasting effects of aquaculture.

Keywords: Aquaculture, Freshwater, Length-weight relationship, Wild-caught fish, Salmonidae

Introduction

Aquaculture significantly contributes to the global food supply, with 90.86 million tonnes of aquatic animals valued at USD ~275.54 billion in 2021, marking a ~57.31% increase from 2010 (FAO, 2022; FishStatJ, 2023). Ultimately, this industry plays a crucial role in reducing overfishing of wild fish by providing a sustainable alternative source of seafood, meeting the rising demand for protein and essential nutrients inherent to aquatic animals (Ye & Beddington, 1996; Lem et al., 2014; Kobayashi et al., 2015; Babu & Joshi, 2019).

Farm-raised fish, which are cultivated in controlled pens within lakes, oceans, or rivers, as well as fish raised in large tanks, can exhibit notable differences in characteristics compared with their wild counterparts caught from their natural habitats (Johnston et al., 2006; Gaviglio & Demartini, 2009; Molversmyr et al., 2022). These differences include various characteristics such as carcass composition, taste profile, texture, and overall quality. Generally, these differences arise from the prevailing trend in fish farming, centred on cost reduction and enhanced productivity through genetic advancements and the formulation of specialised diets (Gjedrem, 1997; Quinton et al., 2005; Johnston et al., 2006). Consequently, farmed fish typically tend to have a more significant proportion of muscle mass and fat content in their carcasses, resulting from controlled feeding practices and optimised growth conditions in aquaculture settings (Laird, 1997; Johnston et al., 2006; Başçinar et al., 2007; Deng et al., 2016). In addition to these, significant morphological differences have been identified between wild and farmed fish across various fish species (Von Cramon-Taubadel et al., 2005; Jawad et al., 2020). Their length-weight relationships (LWR) have shown considerable variation, enabling the distinction between wild and farmed fish (Naeem et al., 2011; Hassan, 2021).

Escapees from farmed fish have significant implications, affecting the aquaculture industry and the surrounding wild populations (Arechavala-Lopez et al., 2013). These escapees can have detrimental effects on the wild ecosystem. For example, they can prey on native species, compete for vital resources such as food availability, territorial space, and suitable breeding habitats, potentially spread parasites and diseases, and even interbreed with wild fish (Jonsson & Jonsson, 2006; Grigorakis & Rigos, 2011; Atalah & Sanchez-Jerez, 2020). Apart from the several negative consequences of farmed escapees, a significant issue arises when farm-aggregated wild fish are occasionally caught from the wild and fraudulently mislabelled as genuine "wild fish" (Bell et al., 2003; Morrison et al., 2007). This deceptive practice directly impacts the assurance of fish quality for consumers, eroding their trust in the market (Arechavala-Lopez et al., 2013). Several methods, such as genetics, chemical analysis, fatty acid composition, trace elements, stable isotopes, pollutants, morphology, and sensory characteristics, have been used to identify and distinguish escapees of farmed fish from their wild counterparts (Arechavala-Lopez et al., 2013). There is an obvious necessity to prioritise the development of cost-effective tools, such as morphometric methods, for effectively detecting farmed individuals within the wild population (Arechavala-Lopez et al., 2013; Dürrani et al., 2023).

The objective of this study was to examine the LWR and condition factors (CF) of farmed rainbow trout (Oncorhynchus mykiss), brook trout (Salvelinus fontinalis), and brown trout (Salmo trutta). These measurements were then compared with the existing literature data of their wild counterparts. This study should provide essential baseline data that can aid in identifying and distinguishing escapees of farmed fish from their wild counterparts in the natural environment.

Materials and Methods

Fishes Acquisition

The trout hatchery at the Sürmene Faculty of Marine Sciences, KTÜ, Çamburnu, provided the farmed specimens of rainbow trout, brook trout, and brown trout. In the hatchery, these fish were fed commercial diets acquired from Skretting Aquaculture, a subsidiary of Nutreco based in Türkiye. The commercial feed contained ~44% crude protein and ~21% crude fat for larger fish, whereas smaller fish were fed diets comprising approximately ~55% crude protein and ~12% crude fat. The hatchery receives freshwater from a nearby brook and continuous aeration in each fish tank to maintain optimal oxygen levels. The annual water temperature fluctuates between 7° C and 22° C throughout the year.

Length-Weight Relationship

The fish's total lengths (LT) were measured to the nearest 0.1 cm, and their body weight (W) was measured to 0.01 g for each species. The length-weight relationships were determined by the simple power function (Basusta & Dürrani, 2021):

$$W = \alpha {L_T}^{\beta} \quad (1)$$

Where α represents the intercept and β represents the slope.

An estimated value of β equal to 3 signifies the isometric growth of fish. If β is less than 3, fish exhibit negative allometric growth, becoming slimmer as their length increases. If β is greater than 3, fish display positive allometric growth, becoming heavier and reflecting optimal growth conditions (Mazlum & Turan, 2018). The statistical deviation of β from the hypothetical value of 3.0 (within the isometric range) was tested using Student's t-test to evaluate isometry.

Condition Factor

The condition factor (CF) was calculated using the following function (Bal, 2021):

$$C_{\mathrm{F}} = \frac{W \cdot 100}{L_{\mathrm{T}}^{3}} \quad (2)$$

The non-parametric Kruskal-Wallis test was used to assess significant differences in CF of different farmed fishes due to the non-normal distribution of Cf data. Significant differences were considered when $P < 0.05$.

Results and Discussion

Length-Weight Relationship

The minimum and maximum lengths of rainbow trout ranged from 15.2 to 33.2 cm, brook trout ranged from 13.4 to 32.4 cm, and brown trout ranged from 14.0 to 33.0 cm (Table 1).

The estimated values with 95% confidence intervals (CI) for β were 3.10 ±0.10 for rainbow trout, 3.55 ±0.15 for brook trout, and 3.10 ±0.16 for brown trout (Table 2). The Student's t-test analysis revealed significant deviations in the β values of rainbow trout and brook trout from the isometric range of 3.0, indicating a positive allometric growth pattern in these fish species. Conversely, the estimated β value of brown trout exhibited no significant deviation from the isometric range, suggesting an isometric growth pattern for this fish.

Table 1. Body measurements of three farmed fish species acquired from a local fish hatchery in Trabzon, Türkiye

Fish species	*n*	Estimated ± 95% CI	
		Total length (cm)	Total weight (g)
Rainbow trout	157	23.777 ±0.759	182.505 ±15.788
Brook trout	160	23.036 ±0.892	185.46 ±20.725
Brown trout	93	22.902 ±1.468	169.304 ±26.474

The parameterised simple power function $W = \alpha L_{\mathrm{T}}^{\beta}$ for each fish species was used to provide the curve lines in Figure 1, which illustrate the relationship between LT and W for rainbow trout, brook trout and brown trout.

Condition Factor

The estimated minimum and maximum CF for rainbow trout was 0.992–1.442, for brook trout 0.665–1.731, and brown trout 0.841–1.321. No differences in CF were found between rainbow trout and brook trout, but both differed significantly from brown trout (Figure 2).

Table 2. Summary statistics of the length-weight relationships $W = \alpha L_{\mathrm{T}}^{\beta *}$, along with the Student's t-test to evaluate the deviation of the estimated β value from the isometric range

Fish species	Length-weight relationships			Student's *t-test* for *β*		Growth pattern
	α	*β*	Adj. R^2	*t*	*p*-value	
Rainbow trout	0.009 ±0.003	3.101 ±0.096	0.979	2.055	0.041	Positive allometric
Brook trout	0.002 ±0.001	3.554 ±0.146	0.969	7.445	0.000	Positive allometric
Brown trout	0.008 ±0.005	3.095 ±0.164	0.984	1.135	0.258	Isometrics

*W, total weight of fish (g), LT, total length (cm)

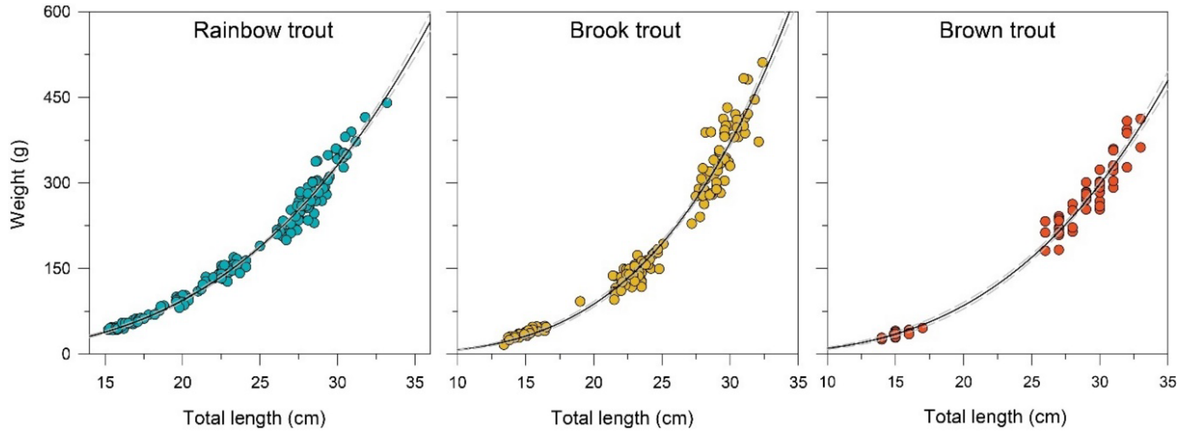

Figure 1. Length-weight relationships for three farmed fish species as determined by $W = \alpha L_T{}^{\beta}$, where W represents the total weight of the fish (g) and L_T represents the total length (cm). The solid lines represent the fitted model, and the dashed lines represent the 95% confidence interval. The coefficients for each species were as follows: rainbow trout: $\alpha = 0.009$, $\beta = 3.101$, brook trout: $\alpha = 0.002$, $\beta = 3.554$, and brown trout: $\alpha = 0.008$, $\beta = 3.095$.

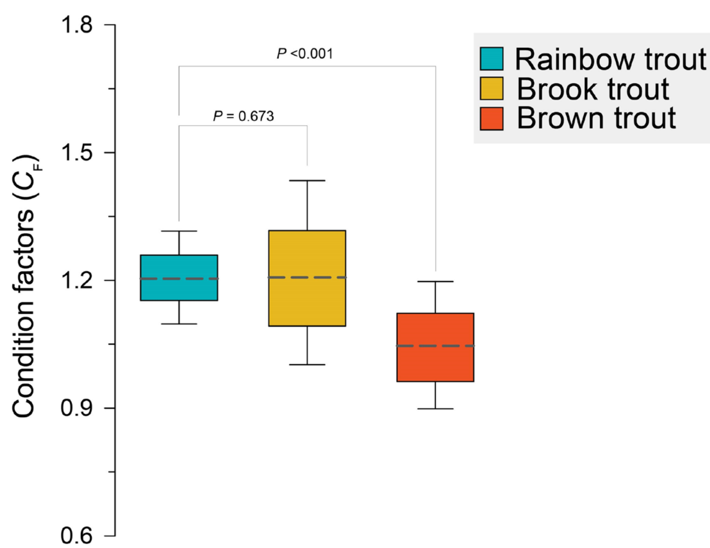

Figure 2. Boxplots of condition factor (C_F) for farmed fish species acquired from a local fish hatchery in Trabzon, Türkiye. Dashed lines indicate the mean values. Significant differences in C_f were checked with the Kruskal-Wallis test, followed by Dunn's post hoc test.

This study demonstrated positive allometric growth of rainbow trout, which aligns with the findings of Ahmad and Ahmed (2019), who determined β of 3.393 in October and 3.384 in December. On the other hand, Wali et al. (2019) determined β = 3.028, suggesting the isometric growth rate of farmed rainbow trout. Furthermore, this study also demonstrated positive allometric growth in brook trout, which is inconsistent with the results of Onder and Khan (2016). Their study determined isometric growth in monoculture but observed negative allometric growth in duoculture. For brown trout, they reported isometric growth in both culture conditions, which is consistent with the findings of this study. The wild brown trout also showed isometric growth determined by Arslan et al. (2004) and Verreycken et al. (2011). In contrast to the present study, rainbow trout and brook trout in the wild had negative allometric growth patterns with β ranging between 2.604 and 2.843 (McAfee, 1966; Ruiz-Campos et al., 1997; Adams et al., 2008; Verreycken et al., 2011; Wali et al., 2019; Rios & Teixeira de Mello, 2020).

The condition factor CF is a commonly employed measure for assessing the overall health of fish: a condition factor CF of 1 generally indicates good condition, while <1 suggests slimness in fish, and more than 1 indicates fatness of fish (Piper, 1972; Joergensen, 2017). In this study, the CF of brown trout was 1.038, significantly smaller than that of rainbow trout and brook trout. In the wild, all these fishes have relatively lower CF, e.g., 0.97 for rainbow trout and 1.05 for brook trout, as Bravo et al. (2021) reported. Likewise, LWR, the farmed and wild brown trout tend to have similar values of CF (1.04), as reported by Bravo et al. (2021). According to Piper (1972), the CF of salmonids typically remains constant as long as there is consistency in water temperature and the feeding rate. Thus, the variation in CF among fish can be attributed to various factors, including food availability and environmental conditions, which significantly impact the overall health of the fish (Luther, 1963). The seasonal CF differences result from varying feeding intensity and reproductive changes (Ahmad & Ahmed, 2019).

Conclusion

Providing appropriate feeding and water conditions in aquaculture promotes positive allometric growth in farmed rainbow and brook trout. As a result, farmed fish exhibit an immense body depth compared with their wild counterparts. In contrast, the negative allometric growth observed in wild populations of these species may indicate challenges related to food availability and environmental conditions. However, unlike rainbow trout and brook trout, the LWR and CF of brown trout in aquaculture are similar to their wild counterparts. Further studies are needed to investigate the impact of different feeding regimes and environmental conditions on the LWR and CF of farmed fishes, which will help identify the primary factors influencing fish allometry. The results of such studies can provide valuable baseline data for distinguishing escaped farmed fish from their wild counterparts in the natural environment.

Compliance with Ethical Standards

Conflict of interest: The author declares that they have no actual, potential, or perceived conflict of interest for this article.

Ethics committee approval: The numerical data used in this study were collected from harvested fish without any welfare concerns, thereby preventing the need for Ethics Committee Permission since no laboratory experiments were involved.

Data availability: Data will be made available on request.

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