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RESEARCH ARTICLE

Seasonal and Sexual Variation in the Length–Weight Relationship of Narrow–Clawed Crayfish *Pontastacus leptodactylus* (Eschscholtz, 1823) in Eğirdir Lake (Isparta), Türkiye

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Abstract: The length–weight relationship (LWR) is a fundamental aspect of fish biology and fisheries science, providing critical insights into various biological and ecological evolutions, such as growth analysis, stock assessment, health, condition, and feeding habits. Therefore, accurately determining it is extremely important. This study was conducted in Eğirdir Lake in 2015 to determine the length–weight relationship of Türkiye's most important crayfish stock. Seasonal sampling (January, April, July, October) was performed using 200 fyke nets with different mesh sizes. The LWR was determined according to Le Cren (1951), and a t-test following Pauly (1984) was used to assess whether the b value differed from 3. The data were analysed using the R package "ggFishPlots (v 0.3.1)". In the study, 4033 crayfish with a total length ranging from 35.12 to 155.11 mm and a total weight between 1.20 and 130.80 g were evaluated. The sample comprised 56.90% (2295) female and 43.10% (1738) male crayfish, with a F:M ratio of 1:0.76. The evaluations revealed that female crayfish exhibited negative allometric growth in spring, summer, and autumn, while displaying isometric growth in winter. Male crayfish, on the other hand, showed positive allometric growth in spring, autumn, and winter, but isometric growth in summer. As a result, it was determined that the growth characteristics of crayfish varied by sex and season. In studies utilizing LWR parameters, it is believed that sampling during only one period of the year may lead to misleading results. Therefore, monthly or seasonal sampling would provide more accurate assessments.

Anahtar kelimeler:

Allometrik büyüme
İzometrik büyüme
Büyüme tipi
Büyüme deseni
LWR
Sezon dinamikler

Eğirdir Gölü (Isparta-Türkiye) Kerevit *Pontastacus leptodactylus* (Eschscholtz, 1823) Populasyonunda Boy-Ağırlık İlişkisindeki Mevsim ve Eşey Bağlı Değişimler

Öz: Boy-ağırlık ilişkisi (LWR) balık biyolojisi ve balıkçılık biliminin temel bir bileşenidir ve büyüme analizi, stok değerlendirmesi, sağlık ve kondisyon, beslenme alışkanlıkları gibi çeşitli biyolojik ve ekolojik gelişmeler hakkında kritik bilgiler sağlamaktadır. Bu nedenle, doğru bir şekilde belirlenmesi son derece önemlidir. Bu çalışma, Türkiye'nin en önemli kerevit stoğunun boy-ağırlık ilişkisindeki eşey ve sezona bağlı değişikliklerin belirlenmesi amacıyla 2015 yılında Eğirdir Gölü'nde yürütülmüştür. Mevsimsel örnekleme (Ocak, Nisan, Temmuz, Ekim), farklı göz açıklıklarına sahip 200 pinter kullanılarak gerçekleştirilmiştir. LWR, Le Cren'e (1951) göre belirlenmiş ve b değerinin 3'ten farklı olup olmadığını belirlemek için t-testi kullanılmıştır (Pauly, 1984). Veriler "ggFishPlots (v 0.3.1)" R paketi kullanılarak analiz edilmiştir. Çalışmada, toplam boyları 35,12 - 155,11 mm ve toplam ağırlıkları 1,20 - 130,80 g arasında değişen 4033 kerevit değerlendirilmiştir. Örneklemin %56,90'ı (2295) dişi ve %43,10'u (1738) erkek kerevitlerden oluşmuş olup D:E oranı 1:0.76'dır. Değerlendirmeler, dişi kerevitlerin ilkbahar, yaz ve sonbaharda negatif allometrik büyüme sergilediğini, kışın ise izometrik büyüme gösterdiğini ortaya koymuştur. Erkek kerevitler ise ilkbahar, sonbahar ve kış aylarında pozitif allometrik büyüme gösterirken, yaz aylarında izometrik büyüme göstermiştir. Sonuç olarak, kerevitlerin büyüme özelliklerinin cinsiyete ve mevsime göre değiştiği belirlenmiştir. LWR parametrelerinin kullanıldığı çalışmalarda, yılın sadece bir döneminde örnekleme yapılmasının yanıltıcı sonuçlara yol açabileceği düşünülmektedir. Bu nedenle, aylık veya mevsimsel örnekleme daha doğru değerlendirmeler sağlayacaktır.

Introduction

Crayfish are diverse, abundant, and globally distributed omnivorous invertebrates inhabiting both lentic and lotic ecosystems (Momot et al., 1978; Taylor et al., 1996). As keystone species, they play critical ecological roles, serving as bioindicators of water quality and biodiversity,

trophic markers, and ecosystem engineers through bioturbation and habitat modification (Reynolds et al., 2013). Beyond their ecological significance, crayfish hold substantial socio-economic value as a luxury food

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resource, driving aquaculture and commercial fisheries in many regions (Cilbiz et al., 2020).

Length-weight relationship (LWR) studies are crucial in fish biology for several reasons: (I) Assessment of fish health and growth patterns (Heydarnejad, 2009; Mehmood et al., 2021; Mughal et al., 2025); (II) Fishery management and conservation (Karuppiah et al., 2023; Oliveira et al., 2020); (III) Ecological and nutritional insights (Aminisarteshnizi & Moyo, 2022); (IV) Species-specific data for biodiversity conservation (Kamikawa et al., 2015; Manna et al., 2023; Zulkafli et al., 2016); (V) Comparative studies and environmental adaptations (Li et al., 2023); (VI) Support for aquaculture and food security (Jacobs et al., 2018; Monzón and Fernandes, 2021).

Numerous studies have investigated the length-weight relationship (LWR) characteristics of narrow-clawed crayfish *Pontastacus leptodactylus* (Eschscholtz, 1823) across Turkish freshwater ecosystems. Sex-specific analyses have been conducted in populations from Demirköprü Dam Lake (Balık et al., 2006), Manyas Lake (Berber and Balık, 2006), Mamasın Dam Lake (Büyükçapar et al., 2006), Keban Dam Lake (Yüksel and Duman, 2012), Çıldır Lake, Hirfanlı Dam Lake, and Porsuk Dam Lake (Bök et al., 2013), Uluabat Lake (Benzer and Benzer, 2018), and Sapanca Lake (Baltacı et al., 2023). However, these studies focused solely on sex-based differences in LWR parameters, with no investigation of seasonal variations or interactions between sex and season. The current study addresses this critical knowledge gap by analyzing both seasonal and sexual dynamics in the LWR of *P. leptodactylus*.

LWR are critical tools in fisheries science, enabling the conversion of length data to body weight for population surveys and biomass estimation in stock assessments (e.g., Thompson and Bell (1934) yield prediction models). Inaccurate LWR parameters can compromise the accuracy of biomass estimates, leading to erroneous conclusions in resource management strategies. To address this, our study evaluates the influence of seasonal variability and sexual dimorphism on LWR parameter precision in *P. leptodactylus*. By quantifying these dynamics, this work advances efforts to standardize biological sampling protocols for crayfish, ensuring robust data for sustainable stock assessment and ecosystem management.

Material and Methods

Study area

Eğirdir Lake (Figure 1) is a significant freshwater resource located in the Lakes District of Türkiye, specifically at the border of Isparta province. It is the second largest freshwater lake in Türkiye, with a surface area of 482 km² (Şener et al., 2013). The lake is crucial for various uses, including drinking water, irrigation, tourism, fishing, and recreation (Atılğan et al., 2009).

Data collecting process

Seasonal sampling (January, April, July, October) was performed using 200 fyke nets rigged with different mesh sizes (14, 26, 34, 42 mm diamond stretched mesh size) in 2015 three different sampling stations of the lake (Figure 1). Carapace and abdominal lengths were measured using a digital calliper with a precision of 0.01 mm. The total length of each crayfish was calculated by summing the abdominal and carapace lengths. The sex of the captured crayfish was determined macroscopically (males identified by the presence of copulatory swimmerets; females by their absence).

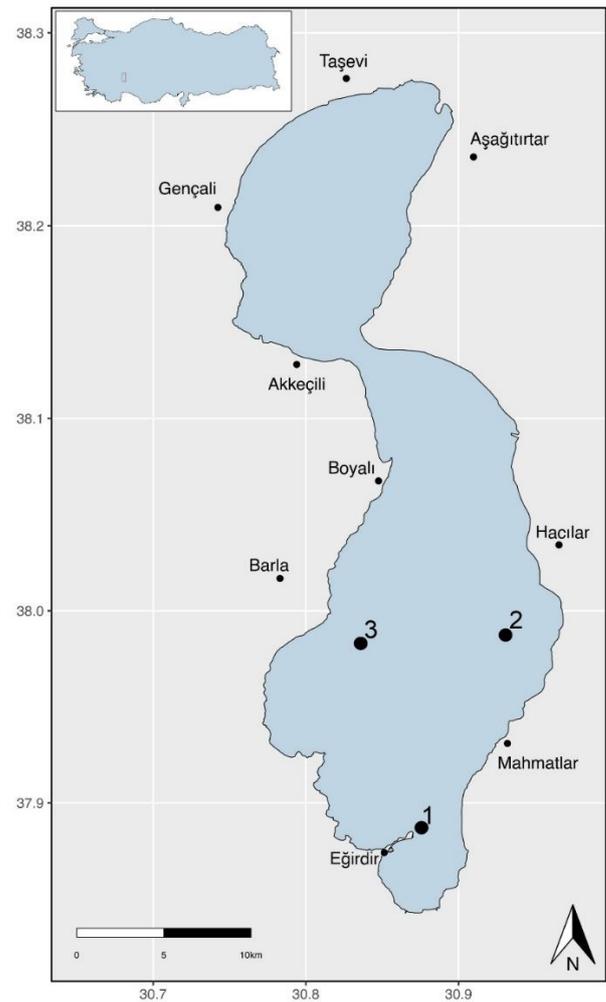


Figure 1. Study area and sampling stations

Modelling of the length-weight relation

Crayfish, similar to fish, exhibit a non-linear relationship between length and weight (Berber and Balık, 2006). This relation described by the equation $W=aL^b$, where W represents total weight (g), L denotes total length (cm), and a and b are species-specific constants (Le Cren, 1951; Froese, 2006). *ggFishPlots* R package (v0.3.0) was utilized for modeling LWR (Vihtakari, 2024). To determine if the b (slope) value of LWR differs from 3, a t -

test was employed (Pauly, 1984). A slope value not statistically different from three indicates that growth is isometric (Ricker, 1958), while a slope value different from three indicates that growth is allometric (Bagenal and Tesch, 1978). Values over three are referred as positive allometry (A+) and values lower than three as negative allometry (A-) (Kondylatos et al., 2024)

Statistical analysis

The Shapiro–Wilk test was employed to assess the normality of the data distribution. For normally distributed data, t-test was used pairwise comparison and one-way ANOVA with Tukey^{HSD} test was used for multiple comparisons. In the evaluation of non-normal disturbed data, Wilcoxon test used pairwise comparison and Kruskal–Wallis with Games-Howell test was used for multiple comparisons. The chi-square test was applied to compare categorical variables. All statistical analyses were performed in RStudio (2024) (v2024.12.1) using the rstatix package (v0.7.2) (Kassambara, 2023) with a significance level set at $p < 0.05$.

Results

As a result of the fishing trials, a total of 4,033 crayfish were captured, with total lengths ranging from 35.12 to 155.11 mm and total weights between 1.20 and 130.80 g.

Of the total catch, 56.90% (2,295 individuals) were females and 43.10% were males. The female-to-male ratio was determined to be 1: 0.76, and the proportional distribution was statistically significant (Chi-square test, $p < 0.001$). Significant seasonal differences were observed in the number of crayfish caught (Table 1), with the variation found to be statistically significant (Chi-square test, $p < 0.001$). Winter was the least productive season for both sexes, whereas the highest catch rates were recorded in summer for females and in winter for males. The mean length and weight values of both male and female crayfish differed significantly in the combined group (ANOVA, $p < 0.05$). A statistically significant difference in mean total length between females and males was observed during the spring season ($p < 0.05$), whereas no significant differences were found in the other seasons (Table 1). When a similar comparison was conducted based on total weight, statistically significant differences were observed in summer and autumn ($p < 0.05$), while no significant differences were found in the other seasons ($p > 0.05$; Table 1). The mean weight of male crayfish was higher than that of females across all seasons. A statistically significant difference was found between the mean total length values of males and females (t-test, $p < 0.05$). Similarly, a significant difference was observed in mean total weight values (t-test, $p < 0.001$).

Table 1. Total length and weight values of *P. leptodactylus* by sex and season caught from Eğirdir Lake

Value	Sex	Parameters	Seasons			
			Spring	Summer	Autumn	Winter
TL (mm)	Female	N	819	856	82	538
		Min-Max	48.14–144.37	47.52–113.75	73.52–139.71	43.48–146.22
		Mean±SE	75.21±0.287 ^b	85.98±0.366 ^c	106.16±1.433 ^a	83.43±0.943 ^c
	Male	N	322	564	78	774
		Min-Max	48.91–133.16	43.07–129.85	79.25–135.34	35.12–155.11
		Mean±SE	73.80±0.627 ^b	85.62±0.505 ^c	108.28±1.411 ^a	83.51±0.669 ^c
	Comb.	N	1,141	1,420	160	1,312
		Min-Max	48.14–144.37	43.07–129.85	73.52–139.71	35.12–155.11
		Mean±SE	74.82±0.272 ^b	85.84±0.298 ^c	107.20±1.007 ^a	83.48±0.552 ^d
TW (g)	Female	Min-Max	3.01–76.32	3.63–33.97	9.32–62.74	1.90–86.20
		Mean±SE	11.86±0.144 ^b	16.66±0.194 ^c	29.66±1.148 ^a	18.52±0.730 ^c
		Male	Min-Max	3.29–71.20	5.02–65.14	12.99–77.83
	Mean±SE		12.31±0.423 ^b	17.81±0.319 ^c	37.81±1.604 ^a	19.07±0.651 ^c
	p*		0.199	0.001	<0.001	0.578
	Comb.	Min-Max	3.01–76.32	3.63–65.14	9.32–77.83	1.20–130.80
		Mean±SE	11.99±0.158 ^b	17.12±0.173 ^c	33.63±1.028 ^a	18.84±0.487 ^d

TL: Total length, TW: Total weight, N: Number of crayfish, Comb.: Combined group with female and male crayfish. There is a statistical difference between means marked with different letters in the same row. p*: Male-female comparison results for the corresponding measurement in the same season, bold values show statistical differences ($p < 0.05$).

The crayfish population in Eğirdir Lake exhibited different growth characteristics based on both sex and season. Female crayfish demonstrated allometric growth during spring, summer, and autumn, while isometric growth was observed in winter. Male crayfish exhibited allometric growth in spring, autumn, and winter, and isometric growth in summer. When the entire population was evaluated by season, growth was found to be allometric only in autumn, while isometric growth was

observed in the other seasons. In the annual data pooled across all seasons, females exhibited isometric growth, whereas males and the combined group showed allometric growth (Table 2). Population size and distribution displayed significant seasonal variation (Figure 2). In both spring and summer, each sex group exhibited a distinct distribution pattern, separate from the main population cluster (Figure 2).

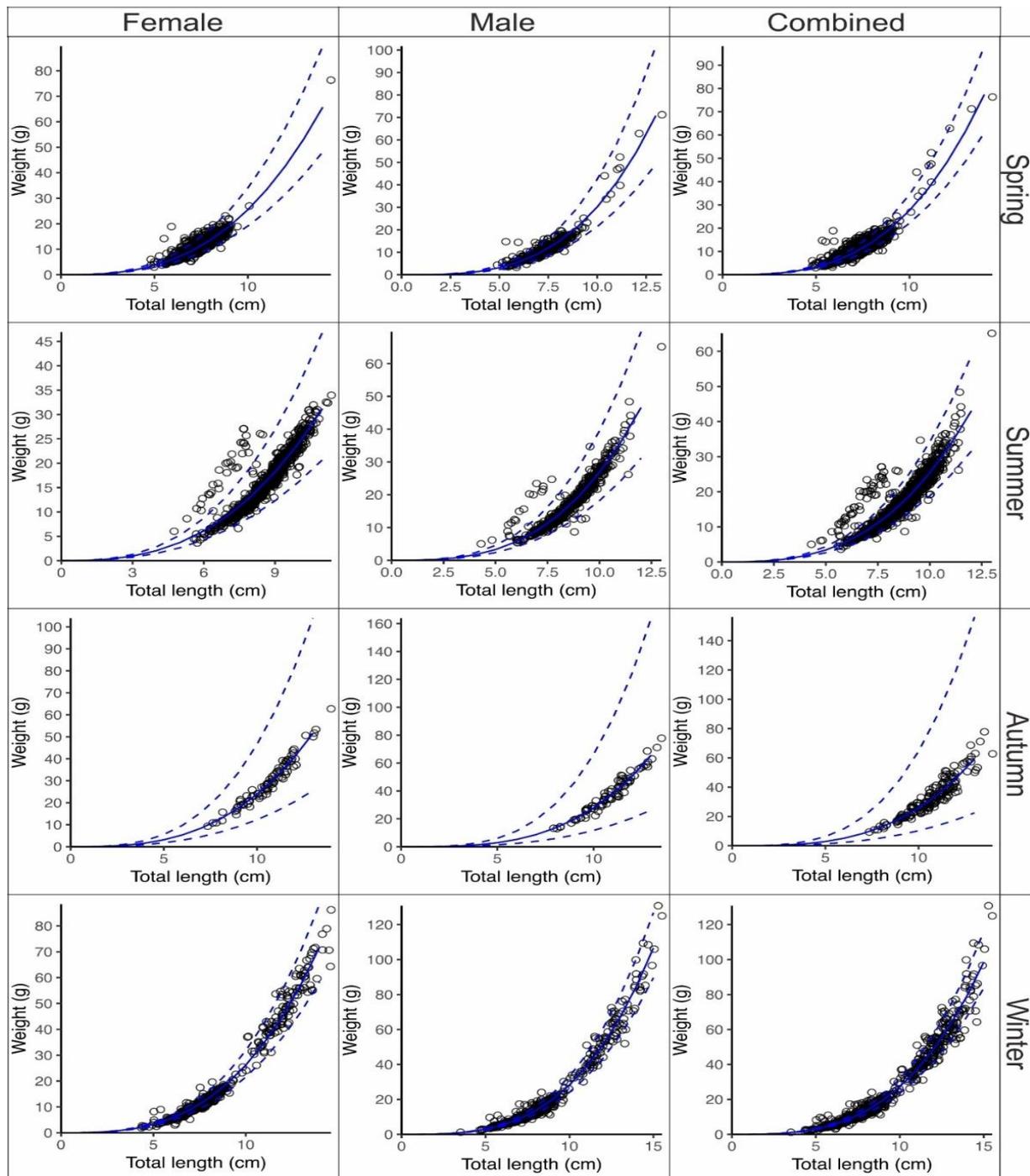


Figure 2. LWR plots of Eğirdir Lake’s *P. leptodactylus* population by sex and season (Dashed blue lines represent 95% CI)

Table 2. LWR model parameters of Eğirdir Lake's *P. leptodactylus* populations by sex and seasons

Season	Sex	n	Length range (TL, cm)	Parameters of the relationship				Growth type	t_s
				a	b	95% CI of b	r ²		
Spring	Female	819	(4.81-14.44)	0.04	2.81	(2.74-2.87)	0.83	A-	4.58 ^a
	Male	322	(4.89-13.32)	0.02	3.26	(3.18-3.33)	0.93	A+	8.85 ^a
	Combined	1141	(4.81-14.44)	0.02	3.06	(3.01-3.11)	0.87	I	1.59 ^b
Summer	Female	856	(4.75-11.38)	0.05	2.69	(2.60-2.78)	0.83	A-	7.74 ^a
	Male	564	(4.31-12.99)	0.02	3.03	(2.95-3.12)	0.90	A+	0.95 ^b
	Combined	1420	(4.31-12.99)	0.03	2.90	(2.84-2.97)	0.86	I	2.64 ^b
Autumn	Female	82	(7.35-13.97)	0.03	2.92	(2.78-3.06)	0.96	A-	3.80 ^a
	Male	78	(7.93-13.53)	0.01	3.28	(3.10-3.46)	0.95	A+	10.79 ^a
	Combined	160	(7.35-13.97)	0.02	3.17	(2.98-3.37)	0.88	A+	4.43 ^a
Winter	Female	538	(4.35-14.62)	0.03	3.00	(2.96-3.04)	0.98	I	0.00 ^b
	Male	774	(3.51-15.51)	0.02	3.27	(3.24-3.31)	0.98	A+	15.55 ^a
	Combined	1312	(3.51-15.51)	0.02	3.17	(3.14-3.20)	0.97	I	8.85 ^b
Annual	Female	2295	(4.35-14.62)	0.03	2.96	(2.94-2.99)	0.95	I	2.70 ^b
	Male	1738	(3.51-15.51)	0.02	3.26	(3.24-3.29)	0.97	A+	19.75 ^a
	Combined	4033	(3.51-15.51)	0.02	3.15	(3.13-3.17)	0.95	A+	14.29 ^a

a: $t_{table} < t_s$ 015–b value different from 3 (allometric growth)–. b: $t_{table} < t_s$ –b value not different from 3 (isometric growth)

Discussion

The present study investigated the effects of sex and seasonal variation on the LWR of the crayfish population in Eğirdir Lake. When compared with other (LWR) studies on the species (Table 3), the present dataset is considered highly successful in terms of both size range and sample size. Sample size is particularly important in LWR studies. According to Cheng et al. (2022), increasing the sample size improves the accuracy of LWR parameter estimation, thereby reducing both relative estimation error and bias. Additionally, the sample length range is a critical factor in LWR studies. Larger sample sizes and broader length ranges generally enhance the accuracy of LWR estimates. This is because different size classes of fish may exhibit varying growth patterns. For instance, *Hilsa (Tenulosa ilisha)* shows isometric growth in larger size classes (TL \geq 25 cm) but negative allometric growth in smaller size classes (TL < 25 cm) (Faruque and Das, 2024). A broader length range ensures that the growth pattern is accurately captured across different life stages. In some studies, presented in Table 3, the minimum sample length was very close to the Minimum Conservation Reference Size (MCRS) of 100 mm total length for the species. This indicates that small individuals were underrepresented, resulting in a size distribution of the population that may not accurately reflect its true structure. The use of these data sets in the calculation of LWR parameters is believed to be the primary reason for the observed differences in results. Undoubtedly, one of the key factors in achieving the desired broad size range is the use of specialized

fishing gear with low size selectivity, rather than commercial fishing gear with high size selectivity. It has been reported that the use of fyke nets with varying mesh sizes for codend nets in crayfish fishing influences the length distribution of the catch (Bolat et al., 2010; Cilbiz et al., 2022).

In our study, when evaluated seasonally, all male crayfish exhibited allometric (+) growth characteristics. Female crayfish showed isometric growth in some seasons, allometric (-) growth in others, and allometric (+) growth when the entire population was considered. This phenomenon is explained by Harlıoğlu (1999), who states: "After reaching reproductive maturity, shell thickness in crayfish varies according to species. Consequently, in some crayfish species, the increase in weight due to shell changes can exceed three times the increase in length. This is also attributed to the increase in pincer weight accompanying progressive shell changes in male individuals. Therefore, negative allometric or isometric growth typically occurs in female crayfish." This observation regarding female crayfish is consistent with the results of our study. To improve the accuracy and precision of LWR parameters, it is crucial to collect samples across different seasons. Growth in crayfish is constrained by the shell, meaning that shell moulting is necessary for growth to occur (Büyükcıpar et al., 2006). Moulting primarily occurs during the spring and summer seasons (Cilbiz, 2021). Consequently, growth during these seasons is significantly faster than in winter (Korkmaz et al., 2023). In our study, distinct distribution patterns were

observed for both sex groups in the spring and summer seasons, separate from the main population cluster (Figure 2). This is believed to be due to individuals that had not yet moulted, as the old shell is heavier than the new one, resulting in individuals of varying weights within the same

size class. Furthermore, growth differences between localities have been attributed to factors such as feeding behaviour, foraging efficiency, and the availability and quality of food resources (Bök et al., 2013).

Table 3. Summary LWR results of previously studied *P. leptodactylus* populations

Location	Sex	N	TL-range (mm)	b value	r	Growth type	Author
Demirköprü Dam Lake (Türkiye)	F	113	54.60-123.90	3.05	0.97	I	(Balık et al., 2006)
	M	233	60.40-123.35	3.26	0.98	A+	
	F+M	346	54,60-123.90	3.16	0.97	A+	
Manyas Lake (Türkiye)	F	387	28.65-141.1	2.83	0.99	A-	(Berber and Balık, 2006)
	M	731	53.7-151.9	3.06	0.99	A+	
	F+M	1118	28.65-151.9	2.88	0.98	A-	
Mamasın Dam Lake (Türkiye)	F	194	63.09-148.01	2.62	0.74	A	(Büyükçapar et al., 2006)
	M	356	66.37-145.06	2.72	0.70	A	
Keban Dam Lake (Türkiye)	F	2412	67-135	271	0.86	A-	(Yüksel and Duman, 2012)
	M	2962	65-144	3.10	0.88	A+	
	F+M	5374	65-144	2.95	0.83	–	
Çıldır Lake (Türkiye)	F	55	96-142	2.80	0.94	I	
	M	46	95-139	3.44	0.91	A+	
	F+M	101	95-142	3.14	0.90	I	
Hirfanlı Dam Lake (Türkiye)	F	79	94-140	2.78	0.88	I	(Bök et al., 2013)
	M	86	91-150	3.21	0.93	A+	
	F+M	165	91-150	3.03	0.81	I	
Porsuk Dam Lake (Türkiye)	F	87	81-124	2.42	074	A-	
	M	99	92-126	3.38	0.83	A+	
	F+M	186	81-126	3.04	0.70	I	
Uluabat Lake (Türkiye)	F	270	95-153	2.78	0.97	–	(Benzer and Benzer, 2018)
	M	270	97-145	2.95	0.96	–	
	F+M	540	95-153	2.85	0.96	–	
Sapanca Lake (Türkiye)	F	146	68.81-132.13	3.29	0.95	A+	(Baltacı et al., 2023)
	M	118	63.70-133.43	3.02	0.96	I	
	F+M	264	63.70-133.43	3.12	0.95	A+	
Eğirdir Lake (Türkiye)	F	2295	43.48-146.22	2.96	0.95	I	Current study
	M	1738	35.12-155.11	3.26	0.97	A+	
	F+M	4033	35.12-155.11	3.15	0.95	A+	

F: Female, M: Male, I: Isometric, A (+): positive allometric, A (-): negative allometric

Conclusion

Seasonal and sex-dependent differences in the total length and weight values of Eğirdir Lake the crayfish population were reflected in the modelled LWR values, resulting in distinct growth characteristics. In this context,

it was determined that individual sampling could lead to misleading evaluations in scientific studies on the species based on LWR. Therefore, conducting sampling at least seasonally, to cover an entire year, would provide a more accurate approach. Developing an internationally recognized standard for biological sampling of crayfish

would be highly beneficial in ensuring methodological consistency.

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Conflict of Interest

The authors declare no competing interests.

Author Contributions

M.C. collected the data. M.C. analysed the data. M.C. and T.A. wrote the first draft of the manuscript. M.C. and T.A. contributed to manuscript revision, and read and approved the submitted version.

Ethics Approval

Since the living material used in this study is not a vertebrate, ethics committee approval was not required under national legislation.

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