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RESEARCH PAPER

Length-based Stock Assessment for the Data-poor Crayfish Fishery from the Eğirdir Lake, Turkiye

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Abstract

In this study, a stock assessment of the *Pontastacus leptodactylus* (Eschscholtz, 1823) population in Egirdir Lake where Turkey's most important crayfish production center, was made. The study was carried out between June 2021 and May 2022 in the concept of length-based data-poor fisheries management. *TropFishR* R package was used in study due to pretty effective in analysing of the length-frequency (LFQ) data. As a result of monthly fishing trials, 14,919 crayfish were caught between 29.92 and 163.38 mm in total length (14.83 – 80.95 mm carapace length). The female-male ratio of the population was found to be 1:1.21. It was determined that growth occurred (+) allometrically in all sexual groups (female, male, female+male). The growth parameters L_∞, K and Φ of the *P. leptodactylus* stock were found to be 86.06-mm, 0.59/year, and 3.64, respectively. The annual rate of total (*Z),* natural (*M*) and fishing mortality (*F*) were estimated to be 3.02, 0.64, and 2.38/ year, respectively. The exploitation rate (*E*) of the crayfish stock was estimated to be 0.78, F_{curr}/F_{max} ratio 1.79 and *SPR* ratio 0.13. In this context, Egirdir Lake *P. leptodactylus* stock was evaluated as overfished. To ensure the sustainability of the stock of the species in the lake, it is necessary to reduce the mortality rate caused by fishing.

Introduction

Inland fisheries are of vital importance for especially low-income developing countries in the world, as it supports the livelihood of 60 million people and is a source of food for hundreds of millions more (Smith et al., 2005; The World Bank, 2012; Moutopoulos et al., 2022). Despite this important function, inland fisheries have generally been seen as undervalued and ignored on a national or regional scale (Cooke et al., 2016; Moutopoulos et al., 2022)), and have never been part of any high-profile global fisheries assessment due to a lack of reliable data (Cooke et al., 2016). In this context, a significant majority of the stock evaluation studies in inland waters were carried out under the concept of low-budget, non-permanent data-poor fisheries management (Abobi et al., 2019; Tesfaye et al., 2021; Veroli et al., 2021). However, fish stocks in inland water environments, which are much more fragile than marine ecosystems, are now under serious threat due to human-induced interventions such as wetland reclamation for the expansion of agricultural land, hydropower generation, water abstraction, chemical pollution, invasive species, and illegal or unregulated fishing activities in both developing and developed countries (Closs et al., 2016; Moutopoulos et al., 2022).

Crayfish, an indispensable element of lentic and lotic ecosystems, are globally distributed omnivorous invertebrates (Momot et al., 1978; Taylor et al., 1996). Crayfish, defined as ecosystem engineers, have received

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this title with their movement and nutritional activities and their ability to affect sediment circulation in waters (Albertson & Daniels, 2018; Jones, 1984; Statzner et al., 2003). In addition to its ecological importance, the fact that it is a commercial product and a luxury nutrient has increased the importance of crayfish once again, and the demand for crayfish for humanity worldwide has increased day by day due to its ecological and economic value.

Turkey's crayfish production is completely based on fishing, and all of the product produced is exported abroad, especially to European countries. Consumption of the species within the borders of the country is not very common. Crayfish became a good source of income for our inland fishermen in Turkey after World War II, especially after 1968, with its increasing export potential until the 1990s (Alpbaz, 2005; Harlioglu, 2008; Köksal, 1988). Annual production peaked at 7,937 tons in 1984 and decreased to 320 tons in the early 1990s (FAO, 2022). Plague disease (*Aphanomyces astaci*) was responsible for this reduction, in addition to unsuccessful stock management. Serious fluctuations in production continued to be observed in the post-disease period.

Egirdir Lake is the most important center of crayfish production in Turkey. 891 tons (72.2%) of the production, which was realized as 1,233 tons throughout the country in 2020, was obtained from Egirdir Lake (Turkstat, 2022). Crayfish is still the most important source of livelihood for 656 fishermen, who are members of ten cooperatives that make a living by fishing in the lake, and it is extremely important to maintain a healthy stock.

Within the framework of the communique regulating commercial fisheries in Turkey (2016/35), (*I*) minimum landing size application in crayfish fishing (catching of individuals under 10 cm in total length is prohibited); (*II*) closed season (fishing is prohibited in the period November 01-June 30); (*III*) closed areas (fishing of crayfish in forest waters is prohibited); (*IV*) prohibitions on fishing technique (using of the baited trap is prohibited); (*V*) regulations on catch composition (female male discrimination is prohibited). In addition, within the framework of other special legislations, there is an obligation to determine a quota by the administration for the maximum amount of products that can be caught during the season. In the quota application, which is a very effective instrument in terms of sustainable fisheries management, there are some problems in determining the maximum amount of products that can be caught and ensuring that the determined amount is not exceeded. The current study has the potential to be an important reference in determining the quota in crayfish fishing and ensuring a country-wide method of cooperation.

Because it is not possible to determine the age of crayfish from osteoid body parts, as it is with fish, age-based packages (such as *fishmethods* (Nelson 2023), *FSA* (Ogle 2023), or *FLR* (Kell, Mosqueira & Grosjean 2007)) cannot be used to modelling of the growth. Therefore, the growth analysis of crayfish has to conducted on length-based. In this context, Electronical LEngth Frequency ANalysis (*ELEFAN*) is the most efficient method for analysing of the length data. Until recent years, FiSAT II (Gayanilo et al., 2005) program has been widely preferred in *ELEFAN* analysis, but nowadays *TropFishR* is preferred by stock assessors (Alam et al., 2022; Aydın & Tıraşın, 2023; Kindong et al., 2022). Because *TropFishR* is used in growth parameter estimation, with new two optimisation techniques (simulated annealing and genetic algorithms), Millar's nonlinear selectivity models (Millar & Holst 1997), and a complete set of methods for fisheries analysis with length-frequency (*LFQ*) data (Mildenberger et al., 2017).

In studies conducted to date regarding the natural populations of the species, some growth characteristics, reproductive characteristics, genetic characteristics of populations, population size research, disease research, length-weight and size-length relationship, morphological characteristics, fyke net selectivity, mortality rates, and recruitment properties have been studied (Akhan et al., 2014; Alekhnovich & Kulesh, 1996; Bolat, 2001; Bolat et al., 2010; Bök et al., 2010; Cilbiz, 2020; Demirol et al., 2017; Deval et al., 2007; Kokko et al., 2012; Vasileva et al., 2006; Yilmaz et al., 2011; Yuksel et al., 2013); however, no studies have been conducted to date to evaluate the stock of the most important population of the species in Turkey. In this study, it was aimed to fill in this gap.

Material and Methods

Study Area

The Study was carried out in Eğirdir Lake which is the most important crayfish harvest centre in Turkey. A total of ten sampling stations were used each of them representing the fishing area of different fisheries cooperatives (Figure 1). As the second largest fresh water resource of Turkey, Eğirdir Lake has a 457 km^2 surface area and is located at latitude 37º 50′ 41″–38º 16′ 55″ N and longitude 30° 57′ 43″–30° 44′ 39″ E in the southwest of Turkey (Figure 1) (Özseven et al., 2020; Şener et al., 2019). The average depth of the lake is 9 meters and the altitude above sea level is 918 meters (Özseven et al., 2020).

Data Collection

All the biological data were gained with survey fishing. Fishing trials were carried out from June – 2021 to May – 2022 with monthly based operations. A total of 600 fyke nets were used in crayfish sampling, 400 specially rigged non-selective fyke nets with 18 mm mesh size (stretched mesh size) and 200 commercial fyke nets with 34 mm (40 fyke net experimental and 20 fyke net commercial for each station). Fyke nets were harvested in two days unless occurred any negative

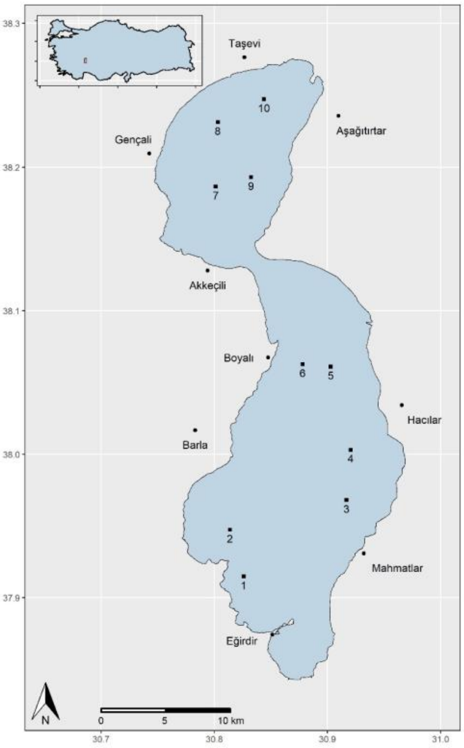

Figure 1. Eğirdir Lake and sampling stations

situation, so the mean soak time was 48 hours. Caught crayfish were classified by stations and carapace length (*CL*) and abdomen length (*AL*) measured by using a digital calliper with 0.01 mm sensitivity. The total lengths (*TL*) of individuals were determined by summing the carapace and abdomen lengths. The total weight (*TW*) of the crayfish was balanced by using digital scales with 0.01 g sensitivity. The sex of the crayfish was determined as macroscopically.

Data Analyses

There is a non-linear relationship between the length and weight of crayfish like fishes [*I*]. The equation (*L*) is represented total or carapace length and (*W*) total weight, besides *a* and *b* values are expressed as constant parameters of the equation (Harlioglu, 1999; Romaire et al., 1977). *t-test* was used for determining the *b* value from 3 whether different, or not (Pauly, 1984). Computed *a* and *b* values for both sexes were used as input parameters for Yield per Recruit analysis in *TropFishR*. Estimating of the growth parameters Electronic LEngth Frequency ANalysis (*ELEFAN*) method was used (Pauly & David, 1981). Analysing of data's *TropFishR v.1.6.3* R package was used (Taylor & Mildenberger, 2017). In the modelling of the crayfish growth "seasonally oscillating growth function *(soVBGP)*" was utilized which was developed by Somers (1988) [*II*] Optimisation of the growth parameters *ELEFAN* with simulated annealing (*ELEFAN_SA*) function was used (Xiang et al., 2013). The growth performance index (φ) [*III*] was estimated by Pauly and Munro (1984). The maximum age (T_{max}) was estimated using Pauly (1980)'s equation [*IV*]. The optimum size (L_{opt}) [*V*] was determined by Froese (2004). Natural mortality is estimated using the length-based updated Pauly estimator recommended by Then et al. (2015) [*VI*]. The linearized length-converted catch curve method [*VII]* was used for estimating of the instantaneous rate of total mortality (*Z*) (Pauly, 1990; Pauly et al., 1995). The fishing mortality rate (*F*) was computed based on the relationship (*VIII*). The exploitation rate (*E*) was determined by the formula [*IX*]. Jones's (1984) length-based virtual population analysis (*VPA*) was used for stock size estimates. The model of Thompson and Bell (1934) was used for estimating of the relative yield per recruit (*Y'/R*) and reference points. The length-based spawning potential ratio (*SPR*) was estimated based on Goodyear (1993) [*X*]. In this study, carapace length (in mm) was used in the length frequency analysis due to a more rigid structure than the total length. The optimal bin size (*OBS*) was computed to be ~3 mm by Wang et al. (2020) equation [*XI*].

$$W = a.L^b \qquad (I)$$

$$L_t = L_\infty(1 - e^{-(K(t-t_o)+S(t)-S(t_o))}) \qquad (II)$$

$$\Phi = \log_{10}(K) + 2\log_{10}(L_\infty) \qquad (III)$$

$$T_{max} = 3/K \qquad (IV)$$

$$L_{opt} = L_\infty [3/(3+M/K)] \qquad (V)$$

$$M=4.118K^{0.73}L_{\infty}^{-0.33} \quad (VI)$$

$$\log\left(\frac{N_i}{dt_i}\right) = a + b_t \quad (VII)$$

$$F=Z-M \quad (VIII)$$

$$E = \frac{F}{Z} \quad (IX)$$

$$SPR = \frac{SSPR_{fished}}{SSPR_{unfished}} \quad (X)$$

$$OBS = 0.23 \times L_{max}^{0.6} \quad (XI)$$

In the spawning potential ratio analysis, input parameters L_{mat} and W_{mat} were applied as 43.43 mm carapace length and 17.33 g respectively. L_{50} maturation length of female *P. leptodactylus* reported as 9.04 cm total length by Cilbiz (2020), this value converted to carapace length by using linear regression equation which gained this study for female crayfish as "$CL = 0.479TL + 0.997$". Comparing of the mean *CL* and *TW* values by sampling months *ANOVA* with $Tukey^{HSD}$ test was used. *agricolae* v1.3-5 (de Mendiburu, 2021) and *rstatix* v0.7.0 (Kassambara, 2021) R packages and Rstudio v2022.02.3 (RStudioTeam, 2022) software were used evaluating of the data.

Results

Monthly Length Distributions and Catch Composition of *P. leptodactylus*

14919 crayfish were caught, total length range 29.92 – 163.38 mm and a total weight range 0.55 – 113.06 g, at the end of the research fishing. The mean carapace length and the total weight of crayfish were shown statistical differences by catching months ($p<0.05$) (Table 1). While minimum mean carapace and total weight values were observed in September, the maximum was in April. Monthly catch numbers show differences between 63 – 2458. While the most productive month was December, most unproductive was January. The total catch consisted of 6739 (45.2%) female and 8180 (54.8%) of male crayfish. In this scope, the ratio of female-male was computed as 1:1.21 and it is observed that natural balance was destroyed for females against.

Length-weight Relationship

The length-weight parameters, *a* and *b*, were obtained from total length (*TL*) and weight (*W*) data using Equation (*I*), and the relationship was computed as $TW = 0.022TL^{3.041}$, $TW = 0.012TL^{3.347}$ and $TW = 0.016TL^{3.215}$ for female, male and both sexes respectively (Figure 2). All sex groups were shown an allomeric (+) growth type. Model parameters of length-weight relationship are given in Table 1.

Length-weight relationship graph of *P. leptodactylus* is given in Figure 2 for different sex groups. In general, different sexes show similar growth types up to 7-8 cm total length (by overlapped regression lines). It can be seen that after 9-10 cm, males of the same length class gain more weight compared to females.

Growth Parameters

The length-frequency data of *P. leptodactylus* was used for the determination of growth parameters. Both *ELEFAN_SA* and *ELEFAN_GA* algorithms were applied to length-frequency data. *ELEFAN_SA* results were

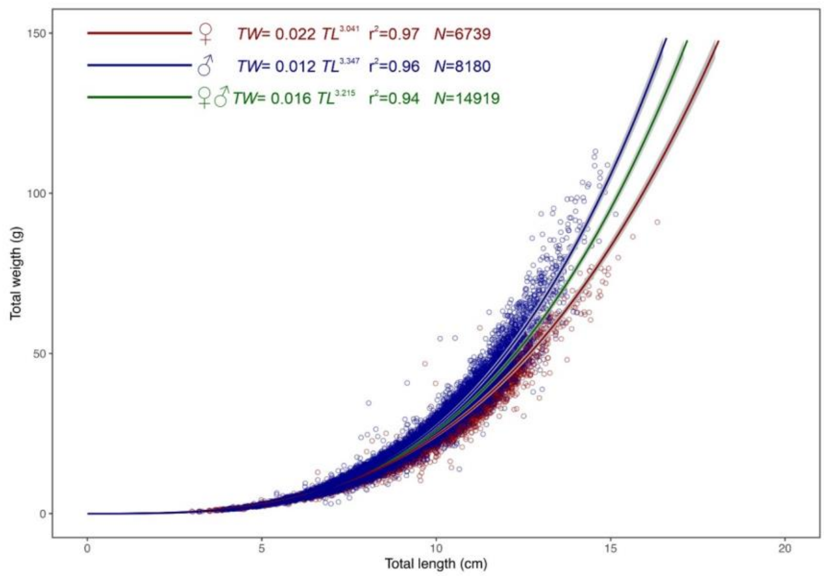

Figure 2. Length-weight relationship graph of *P. leptodactylus* (blue open circles represent males and red ones females; blue, red and green lines show regression line of male, female and both sexes respectively; grey areas describe the 95% *CIs* of regression lines)

evaluated as more suitable for the data set than *ELEFAN_GA* in terms of higher *Rn* (goodness of fit index) value. Accordingly, L_∞ was estimated as 89.07 mm, 87.02 mm, and 86.06 mm carapace length for female, male, and both sexes respectively; *K* values were estimated as 0.54 $year^{-1}$, 0.57 $year^{-1}$ and 0.59 $year^{-1}$ for female, male and both sexes respectively. Estimated other growth parameters based on *ELEFAN_SA* are given in Table 2.

The seasonally oscillating growth curve was computed for both sexes by using growth parameters given in Table 2 (Figure 3). Mainly, the stock has been composed of four age class. Attendance of juveniles on the stock occurred in July when arrived at 15-16 mm carapace length; thereafter, they showed rapid growth performance to December. The growth of crayfish almost stopped from December to April.

Mortality and Exploitation Rates

Based on a linearized length-converted catch curve (Figure, 4), the estimated total mortality rate (Z) by '*TropFishR*' is 3.02 $year^{-1}$. The natural mortality *(M)* was then estimated as 0.64 $year^{-1}$ using the method described by Then et al. (2015). Finally, fishing mortality (F_{curr}) was calculated as 2.38 $year^{-1}$ by subtracting *M* from *Z*. The present exploitation rate (E_{curr}) was computed as 0.78 (Table 3).

Evaluating of Stock Status

The length at first capture (L_c) was 46.65 mm (carapace length), corresponding to *P. leptodactylus* of about 1.33 years. The optimum length (L_{opt}) and t_{max} were calculated as 63.21 mm and 5.11 years respectively. Length-based cohort analysis results are given in Figure 5. Most of the death was caused from catching in over the optimum length, in addition fishing mortality was increased by increasing the length class.

Estimated biological reference points (yield per recruit (*YPR*), biomass per recruit (*BPR*), spawning potential ratio (*SPR*)) of *P. leptodactylus* are given in Table 3. The current *E* value (0.78) is higher than Gulland (1969)'s optimal level (F_{opt} = *M* or *E* = 0.5). In this case, it can say that stock is overfished according to the higher E_{curr} value than 0.5. *SPR* is a measure of the impact that fishing has on the ability of each recruit to contribute to spawning. In this study annual *SPR* is computed as 0.13 lower than *SPR* at F_{max} (0.19) which showed the overexploited condition. The estimated present fishing mortality (F_{curr}) is much higher than the optimum biological fishing mortality F_{max} (1.33 year−1) and $F_{0.1}$ (0.65 year−1). The ratio of F_{curr}/F_{max} is computed as 1.79 which is very higher than the optimum level 1 which is another indicator result for over fishing. Figure 6 shows the graphical outputs of the catch curve and *YPR* model.

Discussion

As a result of fishing trials, a total of 14,919 crayfish were caught between 29.92 and 163.38 mm in total length (14.83 – 80.95 mm *CL*). When compared with other studies on the species (Berber et al., 2012; Bök et al., 2013; Büyükçapar et al., 2006; Deval et al., 2007), it can be stated that the number of samples is quite high, and the length range is relatively wider. The main reason

Table 1. Length–weight relationship model parameters of *P. leptodactylus*

Sex	n	Length range (*TL*, cm)	Parameters of the relationship					t_s
			a	*b*	*95% CI of b*	r^2	*p*	
Female	6739	2.992 – 16.338	0.022	3.041	3.025 – 3.058	0.97	<0.001	9.11[a]
Male	8180	3.200 – 15.417	0.012	3.347	3.033 – 3364	0.96	<0.001	66.11[b]
Both sexes	14919	2.992 – 16.338	0.016	3.215	3.200 – 3.230	0.94	<0.001	34.21[c]

[a]($t>t_{0.05}$, 6739=1.64); [b]($t>t_{0.05}$, 8180=1.64)); [c]($t>t_{0.05}$, 14919=1.64)

Table 2. Estimated growth parameters gained with *ELEFAN_SA* algorithm

Sex group	L_∞ *(mm)*	*K* *(year⁻¹)*	t_0 *(year⁻¹)*	t_{anchor}	t_s	*C*	ϕ
Female	89.07	0.54	-0.223	0.98	0.55	0.96	3.63
Male	87.02	0.57	-0.212	0.97	0.58	0.89	3.44
Both sexes	86.06	0.59	-0.206	0.97	0.57	0.99	3.64

t_{anchor}: Fraction of the year, t_s: Summer point, *C*: Intensity of seasonality

Table 3. Effect of fishing mortality changes on biological reference points of *P. leptodactylus* in habiting Eğirdir Lake

Level of *F*	Parameters				
	F	*E*	*YPR*	*BPR*	*SPR*
01	0.65	0.22	221.46	437.14	0.35
04	0.55	0.18	211.95	482.15	0.3
05	0.45	0.15	198.30	537.73	0.45
max	1.33	0.44	239.32	273.76	0.19
current	2.38	0.78	244.14	206.90	0.13

for this situation is that in addition to the commercial traps with 34-mm mesh size used by the fishermen in the sampling, low selective fyke nets with 18-mm mesh size, which were specially equipped for this study, were used. However, it is believed that the fish caught by nonselective fishing tools represent the distribution of the length of the population (de Graaf & Dekker, 2006). The use of commercial catch or highly selective fishing tools for Length-frequency data (*LFQ*) may lead to misleading results in estimating growth parameters correctly and predicting the length & period of stock participation, as it will lead to the removal of small individuals from the data pool. In this study, if commercial fishing data were used for *LFQ* data, the number of samples below10 cm *TL* would be extremely limited due to the application of minimum landing size (*MLS*), whereas 54.7% of the current data consisted of individuals below *MLS*. Veroli et al. (2021) reported that the majority of the crayfish analyzed in their length-based population dynamic study conducted with another crayfish species, *Procambarus clarkii* were adults, and in this case, it was only due to fishing gear selectivity that enabled larger individuals to be caught. Mildenberger et al. (2021) state that the sample, the

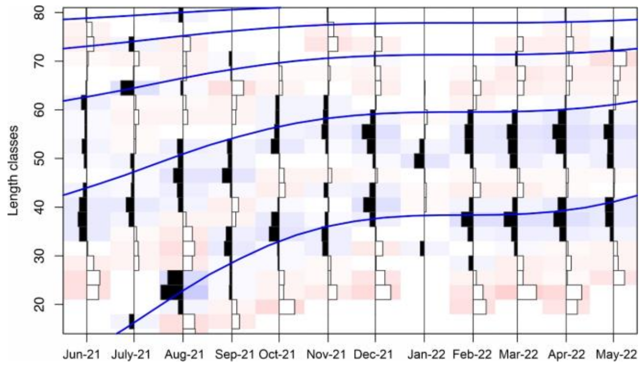

Figure 3. Length-frequency histograms with the growth curves (blue lines) obtained through the bootstrapped *ELEFAN* with *SA* analysis superimposed for *P. leptodactylus*

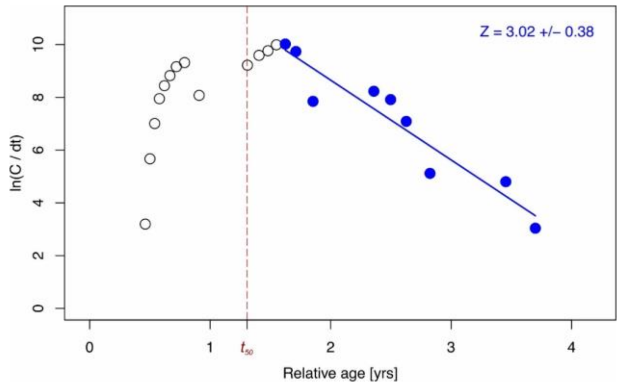

Figure 4. Length-converted catch curve of *P. leptodactylus* (marked with solid dots points were used in calculating using least squares linear regression)

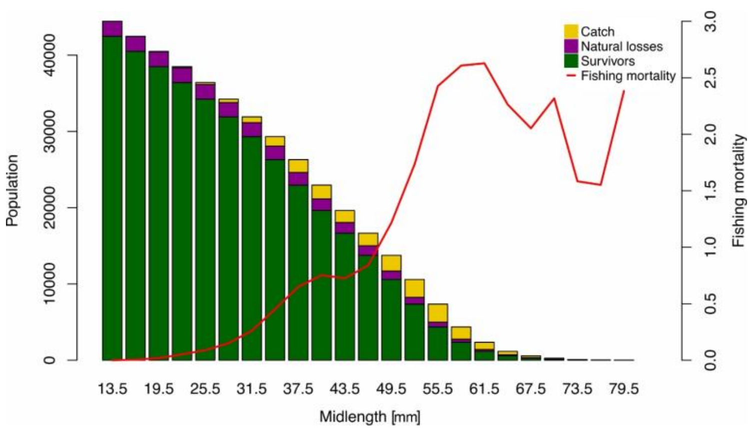

Figure 5. Results of Jones' cohort analysis for *P. leptodactylus* inhabit Eğirdir Lake

source of the *LFQ*, should be representative of the whole stock under investigation and for all seasons of the year.

It can be seen that the number of monthly samples given in Table 4 varies between 63 and 2,458. This is due to the biological characteristics of the species (reproduction period, moulting period), environmental factors (water temperature, vegetation) and operational problems (freezing of the lake surface, and loss of traps). The difference in monthly average lengths is thought to be due to growth, attendance on stock and fishing.

Another important parameter for natural crayfish populations is the female/male ratio. Since they are cannibalistic creatures, keeping the ratio of dominant male individuals at a certain level will reduce the predation effect, especially on young crayfish. In the present study, it was found that the female/male ratio in the Egirdir Lake crayfish population deteriorated from the natural ratio (1/1) to 1/1.21 against the females. A similar situation was observed in other natural stocks of the species. Cilbiz (2020) reported the female/male ratio of crayfish as 1/1.28 for Hirfanli Dam Lake, Berber and Balik (2006) 1/1.88 for Manyas Lake, Deval et al. (2007) 1/1.77 for some northern Marmara's reservoirs, and Yüksel and Duman (2012) 1/1.22 for Keban Dam Lake. The main reason for this situation is thought to be sex-selective fishing. Since the abdominal meat yield of female crayfish is higher than that of male crayfish, although it is prohibited by law, fishermen can occasionally only catch female crayfish in line with the trader and market demands. This situation may cause a decrease in the rate of spawner individuals and thus in the participation in stock in the following years.

The *b* value of Eğirdir Lake crayfish in the length-weight relationship was found to be 3.041 in females, 3.347 in males, and 3.215 in the female-male sex group. All sex groups showed (+) allometry. Bök et al. (2013), in their study examining the length-weight relationships of crayfish populations in Alasehir Lake, Çildir Lake, Hirfanli Dam Lake, Keban Dam Lake, Porsuk Dam Lake and Watermelon Pond, reported that male individuals in all locations showed (+) allometry similar to our study, but either isometric or (-) allometry was displayed in the female and female+male combined group. The difference between the findings is generally thought to be due to the length range of the individuals constituting the sample and the sampling methodology. While the abdomen of the females tends to grow especially after the reproductive period, it is seen that the carapace is larger in males than in females. Since the denser carapace weighs more than the abdomen, males in the same length group are heavier. The effect of this situation is seen in the length-weight relationship graph given in Figure 2.

In the population studies conducted so far regarding the *P. leptodactylus* species, biomass has generally been dealt with, but no comprehensive evaluations have been made regarding the status of the stock being operated. Bolat et al. (2011) investigated the population size of crayfish in Egirdir Lake by marking method, and the population density in the sampling area was reported as 32,590 (*min*: August 27) and 73,503 (*max*: September 28). Yuksel and Duman (2011) investigated the size of the crayfish population in Keban Dam Lake with the Schnabel Method, and the total stock for Agin, Keban, and Cemisgezek regions was estimated to be 204,601 kg. (Yuksel et al., 2013), in their study using the Leslie regression model (Leslie and Davis, 1939), estimated the size of the Keban Dam Lake crayfish population consisting of individuals above the

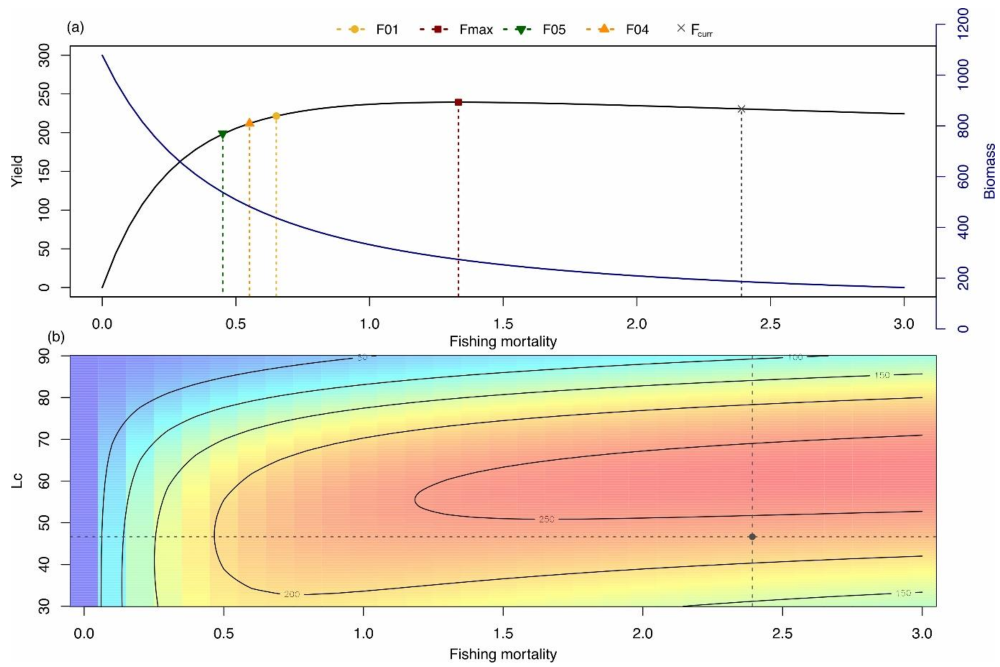

Figure 6. Results of the Thompson and Bell model for *P. leptodactylus* in Eğirdir Lake. (A) Curves of yield and biomass per recruit and (*B*) exploration of impact of different exploitation rates and *Lc* values on the relative yield per recruit.

legal length at the beginning of the season as 28,450 kg with the regression model they created using the changes in the *CPUE* values corresponding to the fishing effort applied from the beginning to the end of the season. To determine the growth and mortality rates of the species, two different studies were conducted using the *FiSAT II* (Gayanilo et al., 2005) software, and the summary findings are given in Table 5. Until now the preferred software for single species stock assessment with length-frequency data has been the windows-based program *FiSAT II* due to its user-friendly, click-based interface. The software is, however, limited in its ability to import data and perform automated analyses (Mildenberger et al. 2017)

When Table 5 is examined, it is observed that the L_∞ values in our study were slightly higher than the other studies. The main reason for this situation may be the maximum lengths of the individuals sampled. The maximum carapace length was 73.7 mm in the study of Berber et al. (2012), and 78.00 mm in the study of Deval et al. (2007), while it was found to be 80.95 mm in our study. Another reason may be the techniques used in the optimization of parameters. While optimization may differ from user to user in other studies conducted with *Fisat II*, *TropFishR* eliminates user-induced errors thanks to its advanced algorithms and allows standard results to be obtained for the same data. The *K* values reported for the species varied between 0.40 and 0.68 in previous studies, and it is believed that the difference is caused by the sex distribution and habitat-related nutritional conditions. The estimated exploitation rate (*E*) 0.78 is quite high compared to other fishing areas in the country. Another remarkable point in Table 5 is that the fishing mortality (*F*) rates applied to male and female individuals are different. This may be an indication that sex-selective fishing is taking place. The deterioration of the female-male ratio in natural environments can also be explained in this way.

SoVBGP (Figure 3), which was drawn using growth parameters determined by using *TropFishR*, has very successfully modelled the growth of the species in the natural environment. Unlike fish, crayfish are creatures that can only grow by changing their shells, and moulting is essential for growth (Cilbiz, 2021; McLay & van den Brink, 2016). In this context, the period of moulting and the period in which growth takes place corresponds to approximately the same months. Growth should not be observed in crayfish that do not change almost any shell in the winter season. When Figure 3 is carefully examined, it can be seen that there is no length increase in January, February, March, and April, whereas when the water starts to heat up,

Table 4. The number of samples and monthly carapace length and total weight distributions

Month	*N*	Carapace length (mm)			Total weight (g)		
		Min-Max	*Mean±SE*	*CI (95%)*	*Min-Max*	*Mean±SE*	*CI (95%)*
Jun-2021	1144	21.54-80.62	44.42±0.28[c]	0.557	3.02-97.53	19.50±0.42[cd]	0.82
Jul-2021	732	16.82-75.26	44.18±0.26[c]	0.682	0.7-88.84	17.40±0.37[de]	0.735
Aug-2021	871	14.83-80.07	44.80±0.36[c]	0.704	0.55-93.45	19.83±0.41[c]	0.798
Sep-2021	1045	15.83-71.42	41.03±0.34[e]	0.673	0.6-76.82	16.01±0.37[e]	0.722
Oct-2021	760	19.24-71.80	42.47±0.41[d]	0.803	1.31-89.49	18.76±0.56[cd]	1.106
Nov-2021	891	21.70-80.95	49.74±0.39[b]	0.771	1.83-108.81	30.65±0.68[a]	1.341
Dec-2021	2393	23.63-77.50	49.60±0.18[b]	0.351	2.4-113.06	27.93±0.30[d]	0.579
Jan-2022	63	31.88-68.95	50.82±0.73[ab]	1.467	6.67-70.98	28.71±1.36[ab]	2.711
Feb-2022	919	19.45-70.81	45.48±0.35[c]	0.691	1.04-78.97	22.95±0.50[b]	0.974
Mar-2022	2051	21.41-75.22	48.75±0.22[b]	0.422	1.35-90.35	26.51±0.33[b]	0.643
Apr-2022	2458	20.49-79.38	50.61±0.19[a]	0.368	1.35-106.54	29.95±0.31[a]	0.604
May-2022	1592	25.36-77.79	48.60±0.23[b]	0.445	2.71-111.31	27.56±0.38[b]	0.749

Table 5. Summary result of some population dynamics studies carried on *P. leptodactylus*

Author	Locality	Sex	L_∞	*K*	*Z*	*F*	*M*	*E*
Deval et al. (2007)	Some northern Marmara reservoirs	♀♀+♂♂	80.8	0.40	2.11	1.53	0.578	0.72
Berber et al. (2012)	Manyas Lake	♀♀	73.45	0.61	1.87	1.06	0.81	0.57
		♂♂	81.90	0.55	1.52	0.82	0.70	0.54
	Uluabat Lake	♀♀	74.96	0.46	1.78	1.13	0.65	0.63
		♂♂	76.81	0.51	1.69	0.91	0.68	0.57
	İznik Lake	♀♀	71.47	0.41	1.79	1.19	0.60	0.66
		♂♂	69.97	0.68	1.78	0.03	0.85	0.53
Current study	Eğirdir Lake	♀♀	89.07	0.54	-	-	-	-
		♂♂	87.02	0.57	-	-	-	-
		♀♀+♂♂	86.06	0.59	3.02	2.38	0.64	0.78

significant growth occurs especially in the 1-year-old group in the May-October period when the shell changes start. In support of this idea, Cilbiz (2021) reported in his study conducted at Hirfanli Dam Lake that he did not sample soft-shelled crayfish in November, December, January, February, and March, but observed soft-shelled crayfish in other periods, especially in May.

In our study, the length-based Thompson and Bell (1934) method was preferred for future product and biomass estimation. In the study conducted by Chong et al. (2019) evaluating the performances of 4 different data-limited, length-based stock assessment methods (length-based Thompson and Bell (*TB*), length-based spawning potential ratio (LBSPR), length-based integrated mixed effects (*lime*), and length-based risk analysis (LBRA)), it was stated: "In the absence or uncertainty of such knowledge on life history, recruitment, and exploitation, *LBSPR* and *TB* can be expected to perform more consistently than *LIME* and *LBRA* in the rapid assessment of limited data of a single year".

Conclusions

In the concept of data-limited, length-based stock assessment, *TropFishR* is very successful in the effective evaluation of limited data. It has filled an important gap in the evaluation of stocks, especially crayfish, where age determination is almost impossible. In this context, the widespread use of natural resources will contribute positively to the sustainable use of natural resources. Within the framework of the estimated biological reference points, considering (*I*) the *E* value predicted as 0.78 at a level higher than 0.5, (*II*) the F_{curr} / F_{max} ratio predicted as 1.79 at a level higher than 1, and finally (*III*) the *SPR* ratio as 0.13, which is considerably below 0.40, which is acceptable for many stocks, it can be said that the crayfish stock of Eğirdir Lake is overfished. If the limit *SPR* ratio is predicted to be 0.20 and 0.40 at the target *SPR* rate, fishing-related death should be reduced to F_{05} levels. In this case, the current fishing pressure needs to be reduced by approximately 82%. In this context, it is recommended that the fishing quota determined by the administration as 1,000 tons for 2022 be reduced to 180 tons. In addition, fishing activities should be closely monitored so as not to exceed the determined quota.

Ethical Statement

Not applicable duo to research live material as a crustacean.

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Author Contribution

Bayram Korkmaz collected the data. Mehmet CİLBİZ analysed the data. Mehmet CİLBİZ and Yıldız Bolat wrote the first draft of the manuscript. Mehmet CİLBİZ, Bayram Korkmaz and Yıldız Bolat contributed to manuscript revision, and read and approved the submitted version.

Conflict of Interest

The authors certify that they have NO affiliations with or involvement in any organization or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript.

References

Abobi, S. M., Mildenberger, T. K., Kolding, J., & Wolff, M. (2019). Assessing the exploitation status of main fisheries resources in Ghana's reservoirs based on reconstructed catches and a length-based bootstrapping stock assessment method. *Lake and Reservoir Management*, *35*(4), 415-434. https://doi.org/10.1080/10402381.2019.1616340

Akhan, S., Bektas, Y., Berber, S., & Kalayci, G. (2014). Population structure and genetic analysis of narrow-clawed crayfish (*Astacus leptodactylus*) populations in Turkey. *Genetica*, *142*(5), 381-395. https://doi.org/10.1007/s10709-014-9782-5

Alam, M. S., Liu, Q., Schneider, P., Mozumder, M. M. H., Chowdhury, M. Z. R., Uddin, M. M., Monwar, M. M., Hoque, M. E., & Barua, S. (2022). Length-Based Stock Assessment for the Data-Poor Bombay Duck Fishery from the Northern Bay of Bengal Coast, Bangladesh. Journal of Marine Science and Engineering, 10(2), 213. https://www.mdpi.com/2077-1312/10/2/213

Albertson, L. K., & Daniels, M. D. (2018). Crayfish ecosystem engineering effects on riverbed disturbance and topography are mediated by size and behavior. *Freshwater Science*, *37*(4), 836-844. https://doi.org/10.1086/700884

Alekhnovich, A., & Kulesh, V. (1996). Comparative analysis of reproduction of narrow-clawed crayfish, Astacus leptodactylus in its eastern area. *Freshwater crayfish*, *11*, 339-347.

Alpbaz, A. (2005). Su Ürünleri Yetiştiriciliği. Alp Yayınları. İzmir. 549p.

Aydın, C. M., & Tıraşın, E. M. (2023). Information on the deep-water giant red shrimp *Aristaeomorpha foliacea* (Risso, 1827) (Crustacea, Decapoda, Aristeidae) population in Antalya Bay (Eastern Mediterranean Sea, South of Turkey) based on the MEDITS protocol. Regional Studies in Marine Science, 60, 102885. https://doi.org/https://doi.org/10.1016/j.rsma.2023.102885

Berber, S., & Balık, S. (2006). Determination of traits some growth and morphometric of crayfish (*Astacus leptodactylus* Eschscholtz, 1823) at Manyas Lake (Balıkesir)[in Turkish]. *E.U. Journal of Fisheries & Aquatic Sciences*, *23*(1-2), 83–91.

Berber, S., Mazlum, Y., Demirci, A., & Türel, S. (2012). Structure, growth, mortality and size at sexual maturity of various populations *Astacus leptodactylus* Eschscholtz, 1823 (Cructecea: Decopada) in Turkey. *Marine Science and Technology Bullettin*, *1*, 21-27.

Bök, T. D., Harlioğlu, M. M., & Deval, M. C. (2010). A study on the morphometric characteristics of *Astacus leptodactylus* inhabiting the Thrace region of Turkey. *Knowledge and Management of Aquatic Ecosystems*(397), Article kmae100011. https://doi.org/10.1051/kmae/2010021

Bök, T., Aydın, H., & Ateş, C. (2013). A study on some morphological characteristics of *Astacus leptodactylu*s (Eschscholtz 1823) in seven different inland waters in Turkey. *J. Black Sea/Mediterranean Environment*, *19*(2), 190-205.

Bolat, Y. (2001). *The Estimation of population size of freshwater crayfish (Astacus leptodactylus salimus Nordmann,1842)in Hoyran Part of Lake Eğirdir* [in Turkish]. Süleyman Demirel Üniversitesi, Fen Bilimleri Enstitüsü. PhD Thesis. 117p.

Bolat, Y., Demirci, A., & Mazlum, Y. (2010). Size Selectivity of Traps (Fyke-Nets) of Different Mesh Size on The Narrow-Clawed Crayfish, *Astacus leptodactylus* (ESCHSCHOLTZ, 1823) (Decapoda, Astacidae) İn Eğirdir Lake, Turkey. *Crustaceana*, *8*(11), 1349-1361. https://doi.org/https://doi.org/10.1163/001121610X536969

Bolat, Y., Mazlum, Y., Demirci, A., & Koca, H. U. (2011). Estimating the population size of *Astacus leptodactylus* (Decapoda: Astacidae) by mark-recapture technique in Eğirdir lake, Turkey. *African Journal of Biotechnology*, *10*(55), 11778-11783. http://www.scopus.com/inward/record.url?eid=2-s2.0-80053072155&partnerID=40&md5=3e2fa85381def36b789e4f60e725230f

Büyükçapar, H. M., Alp, A., Kaya, M., & Çiçek, Y. (2006). The length-weight relationships, and meat yield of crayfish (*Astacus leptodactylus* Eschscholtz, 1823) in the Mamasın Reservoir (Aksaray, Turkey) [in Turkish]. *E.U. Journal of Fisheries & Aquatic Sciences*, *23*(1-2), 21–25.

Cilbiz, M. (2020). Pleopodal fecundity of narrow-clawed crayfish (Pontastacus leptodactylus Eschscholtz, 1823). *Invertebrate Reproduction & Development*, *64*(3), 208–218. https://doi.org/10.1080/07924259.2020.1762771

Cilbiz, M. (2021). Effect of some Biotic and Abiotic Factors on Hard and Soft-shell of Crayfish (*Pontastacus leptodactylu*s Eschscholtz, 1823): A Case Study from Hirfanlı Dam Lake. *Acta Aquatica Turcica*, *17*(4), 548 - 555. https://doi.org/https://doi.org/10.22392/actaquatr.915080

Closs, G.P., Krkosek, M. & Olden, J.D. (Eds.). (2016) Conservation of freshwater fishes, Vol. No. 20. Cambridge: Cambridge University Press.

Cooke, S. J., Allison, E. H., Beard, T. D., Jr., Arlinghaus, R., Arthington, A. H., Bartley, D. M., Cowx, I. G., Fuentevilla, C., Leonard, N. J., Lorenzen, K., Lynch, A. J., Nguyen, V. M., Youn, S. J., Taylor, W. W., & Welcomme, R. L. (2016). On the sustainability of inland fisheries: Finding a future for the forgotten. *Ambio*, *45*(7), 753-764. https://doi.org/10.1007/s13280-016-0787-4

de Graaf, G. J., & Dekker, P. (2006). A simple spreadsheet model to incorporate seasonal growth into length-based stock assessment methods. http://hdl.handle.net/1834/25761

de Mendiburu, F. (2021). agricolae: Statistical Procedures for Agricultural Research_. R package version 1.3-5, https://CRAN.R-project.org/package=agricolae.

Demirol, F., Yuksel, F., Gunduz, F., Beri, A., Guler, M., Yildirim, T., Coban, M. Z., & Sciences, A. (2017). The Stock Assessment of Crayfish (*Astacus leptodactylus* Eschscholtz, 1823) in the Keban Dam Lake. *Turkish Journal of Fisheries*, *17*(7), 1373-1380. https://doi.org/10.4194/1303-2712-v17_6_30

Deval, M. C., Bök, T., Ateş, C., & Tosunoğlu, Z. (2007). Length-based estimates of growth parameters, mortality rates, and recruitment of *Astacus leptodactylus* (Eschscholtz, 1823) (Decapoda, Astacidae) in unexploited inland waters of the northern Marmara region, European Turkey). *Crustaceana*, *80*(6), 655-665. https://doi.org/10.1163/156854007781360649

FAO. 2022. Fishery and Aquaculture Statistics. Global capture production 1950-2020 (FishStatJ). In: FAO Fisheries and Aquaculture Division [online]. Rome. Updated 2022. www.fao.org/fishery/statistics/software/fishstatj/en

Froese, R. (2004). Keep it simple: three indicators to deal with overfishing. *Fish and Fisheries*, *5*(1), 86-91. https://doi.org/10.1111/j.1467-2979.2004.00144.x

Gayanilo, F. C., Sparre, P., & Pauly, D. e. (2005). *The FAO-ICLARM Stock Assessment Tools (FISAT II) program package*.

Gulland, J. A. (1969). *Manual of Methods for Fish Stock Assessment. Part 1. Fish population analysis, Fishery Resources and Exploitation Division*.

Harlioglu, M. M. (1999). The relationships between length-weight, and meat yield of freshwater crayfish, *Astacus leptodactylus* eschscholtz, in the Agin Region of Keban Dam Lake. *Turkish Journal of Zoology*, *23*(3), 949-957. http://www.scopus.com/inward/record.url?eid=2-s2.0-0033390853&partnerID=40&md5=e3ae65bd3383665fbd9d8514a4080396

Harlioğlu, M. M. (2008). The harvest of the freshwater crayfish *Astacus leptodactylus* Eschscholtz in Turkey: Harvest history, impact of crayfish plague, and present distribution of harvested populations. *Aquaculture International*, *16*(4), 351-360. https://doi.org/10.1007/s10499-007-9145-7

Jones, R. (1984). *Assessing the effects of changes in exploitation pattern using length composition data (with notes on VPA and cohort analysis)*. FAO Fish.Tech.Pap., (No:256): 118p.

Kassambara, A. (2021). rstatix: Pipe-Friendly Framework for Basic Statistical Tests_. R package version 0.7.0, https://CRAN.R-project.org/package=rstatix.

Kell, L., Mosqueira, I., Grosjean, P.et al. (2007) FLR: an open-source framework for the evaluation and development of management strategies. *ICES Journal of Marine Science*, 64, 640–646. https://doi.org/10.1093/icesjms/fsm012

Kindong, R., Sarr, O., Wu, F., & Tian, S. (2022). Length-Based Assessment Methods for the Conservation of a Pelagic Shark, *Carcharhinus falciformis* from the Tropical Pacific Ocean. Fishes, 7(4), 184. https://www.mdpi.com/2410-3888/7/4/184

Kokko, H., Koistinen, L., Harlioğlu, M. M., Makkonen, J., Aydin, H., & Jussila, J. (2012). Recovering Turkish narrow clawed crayfish (Astacus leptodactylus) populations carry Aphanomyces astaci. *Knowledge and Management of Aquatic Ecosystems*(404), 12(17p). https://doi.org/10.1051/kmae/2012006

Köksal, G.A. (1988). *Astacus leptodactylus in Europe. In: Freshwater Crayfish: Biology, Management, and Exploitation (D. M. Holdich and R. S. Lowery, Eds., pp. 365–400)*.

McLay, C. L., & van den Brink, A. M. (2016). Crayfish growth and reproduction. In S. P. Longshaw M (Ed.), *Biology and ecology of crayfish*. CRC Press, Boca Raton, FL, USA.

Mildenberger, T. K., Taylor, M. H., & Wolff, M. (2017). TropFishR: an R package for fisheries analysis with length-frequency data. *Methods in Ecology and Evolution*, 8(11), 1520-1527. https://doi.org/10.1111/2041-210x.12791

Mildenberger, T.K., Taylor, M.H., & Wolff, M. (2021). vignettes of *TropFishR*. Access: https://cran.r-project.org/web/packages/TropFishR/vignettes/lfqData.html. Access date: Jully 20, 2022.

Millar, R. B., & Holst, R. (1997). Estimation of gillnet and hook selectivity using log-linear models. *ICES Journal of Marine Science*, 54(3), 471-477. https://doi.org/10.1006/jmsc.1996.0196

Momot, W. T., Gowing, H., & Jones, P. D. (1978). The Dynamics of Crayfish and Their Role in Ecosystems. *The American Midland Naturalist*, *99*(1), 10-35. https://doi.org/10.2307/2424930

Moutopoulos, D. K., Koutsikos, N., Vardakas, L., & Perdikaris, C. (2022). A history of Greek inland fishery development during 1928–2019. *Fisheries Management and Ecology*. https://doi.org/10.1111/fme.12558

Nelson, G.A.N. (2023) fishmethods: Fishery Science Methods and Models. R package version 1.12-0. Available at: https://CRAN.R-project.org/package=fishmethods (accessed 15 March 2023)

Ogle, D. (2023) FSA: Simple Fisheries Stock Assessment Methods. R package version 0.9.4. Available at: https://cran.r-project.org/web/packages/FSA (accessed 15 March 2017)

Özseven, A., Akkurt, I., & Günoğlu, K. (2020). Determination of some dosimetric parameters in Eğirdir Lake, Isparta, Turkey. *International Journal of Environmental Science and Technology*, *17*(3), 1503-1510. https://doi.org/10.1007/s13762-019-02569-z

Pauly, D. (1980). On the interrelationships between natural mortality, growth parameters, and mean environmental temperature in 175 fish stocks. *ICES Journal of Marine Science*, *39*(2), 175-192. https://doi.org/10.1093/icesjms/39.2.175

Pauly, D. (1984). Fish population dynamics in tropical water: a manual for use with programmable calculators. *ICLARM Studies and Reviews 8, 325 p. International Center for Living Aquatic Resources Management, Manila, Philippines.*, 325.

Pauly, D. (1990). Length-converted catch curves and the seasonal growth of fishes. *Fishbyte*, *8*(3), 33-38.

Pauly, D., & David, N. (1981). ELEFAN I, a BASIC program for the objective extraction of growth parameters from length-frequency data. *Meeresforschung*, *28*(4), 205-211.

Pauly, D., & Munro, J. L. (1984). Once more on the comparison of growth in fish and invertebrates. *ICLARM Fishbyte,*, *2*(1), 21.

Pauly, D., Moreau, J., & Abad, N. (1995). Comparison of age-structured and length-converted catch curves of brown trout Salmo trutta in two French rivers. *Fisheries Research*, *22*(3-4), 197-204.

Romaire, R., Forester, J., & Avault, J. (1977). Length–weight relationships of two commercially important crayfishes of the genus Procambarus. *Freshwater Crayfish*(3), 463–470.

RStudioTeam. (2022). RStudio: Integrated Development for R. RStudio, PBC, Boston, MA Retrieved from http://www.rstudio.com/.

Şener, E., Varol, S., Şener, Ş., & Davraz, A. (2019). Assessment of the stream network pollution in the Eğirdir Lake Basin (Turkey) using water quality index and multivariate analysis. *Mühendislik Bilimleri ve Tasarım Dergisi*, *7*(2), 352-368.

Smith, L.E.D., Khoa, S.N., & Lorenzen, K. (2005). Livelihood functions of inland fisheries: policy implications in developing countries. Water Policy 7: 359–383.

Somers, I. F. (1988). On a seasonally oscillating growth function. *ICLARM Fishbyte*, *6*(1), 8-11.

Statzner, B., Peltret, O., & Tomanova, S. (2003). Crayfish as geomorphic agents and ecosystem engineers: effect of a biomass gradient on baseflow and flood-induced transport of gravel and sand in experimental streams. *48*(1), 147-163. https://doi.org/10.1046/j.1365-2427.2003.00984.x

Taylor, C. A., Warren, M. L., Fitzpatrick, J. F., Hobbs, H. H., Jezerinac, R. F., Pflieger, W. L., & Robison, H. W. (1996). Conservation Status of Crayfishes of the United States and Canada. *Fisheries*, *21*(4), 25-38. https://doi.org/10.1577/1548-8446(1996)021<0025:CSOCOT>2.0.CO;2

Taylor, M. H., & Mildenberger, T. K. (2017). Extending electronic length frequency analysis in R. *Fisheries Management and Ecology*, *24*(4), 330-338. https://doi.org/10.1111/fme.12232

Tesfaye, M., Tesfaye, G., & Getahun, A. (2021). Growth and status of Nile tilapia (Oreochromis niloticus L.) stock in Lake Chamo, Ethiopia. *Lakes & Reservoirs: Science, Policy and Management for Sustainable Use*, *26*(3). https://doi.org/10.1111/lre.12375

The World Bank. 2012. Hidden harvest: the global contribution of capture fisheries. The World Bank, Report 66469-GLB, Washington, DC.

Then, A. Y., Hoenig, J. M., Hall, N. G., & Hewitt, D. A. (2015). Evaluating the predictive performance of empirical estimators of natural mortality rate using information on over 200 fish species. *ICES Journal of Marine Science*, *72*(1), 82-92. https://doi.org/10.1093/icesjms/fsu136

Turkstat, (2022). Fishery Statistics, Available from: https://biruni.tuik.gov.tr/medas/?kn=97&locale=tr, Access date: July 20, 2022

Vasileva, P., Zaikov, A., & Hubenova, T. (2006). Investigation on Fecundity and Egg Size in Cultured and Natural Crayfish Population of *Astacus leptodactylus* Esch. in Bulgaria. *Bulgarian Journal of Agricultural Science*, *12*(2), 208.

Veroli, M., Martinoli, M., Caprioli, R., Angelici, C., Pulcini, D., & Capoccioni, F. (2021). Population structure and dynamics of the invasive Procambarus clarkii (Girard, 1852) in a Tiber river Ramsar site, Central Italy. *International Journal of Aquatic Biology*, *9*(1), 23-32.

Wang, K., Zhang, C., Xu, B., Xue, Y., & Ren, Y. (2020). Selecting optimal bin size to account for growth variability in Electronic LEngth Frequency ANalysis (ELEFAN). *Fisheries Research*, *225*, 105474. https://doi.org/10.1016/j.fishres.2019.105474

Xiang, Y., Gubian, S., Suomela, B., & Hoeng, J. (2013). Generalized simulated annealing for efficient global optimization: the GenSA package for R. *The R Journal*, *5*(1), 13-28.

Yılmaz, E., Harlıoğlu, A. G., & Yılmaz, A. (2011). The relationships between length-weight, and meat content of freshwater crayfish (Astacus leptodactylus Eschscholtz, 1823) caught from Gaga Lake (Ordu-Turkey)[in Turkish]. *Ege Journal of Fisheries and Aquatic Sciences, 28*(3), 75-80.

Yüksel, F., & Duman, E. (2011). The investigation of the crayfish (Astacus leptodactylus Eschscholtz, 1823) population amplitude in Keban dam lake [in Turkish]. *Journal of FisheriesSciences.com*, *5*(3), 226-239. https://doi.org/doi: 10.3153/jfscom.2011027

Yüksel, F., & Duman, E. (2012). An Investigation on Some Morphological Characteristics of Crayfish in Keban Dam Lake [in Turkish]. *Journal of FisheriesSciences. com*, *6*(4), 271-281.

Yüksel, F., Demirol, F., & Gündüz, F. (2013). Leslie Population Estimation for Turkish Crayfish (*Astacus leptodactylus* Esch., 1823) in the Keban Dam Lake, Turkey. *Turkish Journal of Fisheries and Aquatic Sciences*, *13*, 835-839. https://doi.org/DOI: 10.4194/1303-2712-v13_5_07