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ARAŞTIRMA MAKALESİ **RESEARCH PAPER**

Estimating age structure of *Liocarcinus depurator* along the western Black Sea coast of Türkiye using the Bhattacharya method [*]

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Abstract: A total of 2,233 *Liocarcinus depurator* samples were collected during beam trawl surveys along the northwestern Black Sea coast of Türkiye to analyse the population's age structure. The male-to-female ratio was 2:1. Length-frequency distributions were estimated for four age groups using the Bhattacharya method, with carapace lengths of 0^+ = 15.51 mm, I^+ = 23.76 mm, II^+ = 31.29 mm, and III^+ = 36.49 mm for males, and 0^+ = 15.35 mm, I^+ = 21.36 mm, II^+ = 27.18 mm, and III^+ = 30.50 mm for females. For combined sexes, lengths were 0^+ = 15.35 mm, I^+ = 22.65 mm, II^+ = 30.81 mm, and III^+ = 36.59 mm. One-way ANOVA showed significant differences in mean length among age groups for the pooled sample, as well as for males and females separately (all $p < 0.001$). Independent t-tests found no significant difference between sexes in age group 0^+ ($p = 0.59$), but significant differences in age groups I, II, and III ($p < 0.05$ for all). Males were generally larger than females in older age groups, indicating apparent sexual dimorphism and different growth patterns in the population. These findings provide baseline data on the population dynamics of *L. depurator* in the Black Sea, which are useful for fisheries management and conservation.

Keywords: Age structure, crab biology, fisheries management, *Liocarcinus depurator*, population dynamics, turkish western black sea coast.

Bhattacharya yöntemi kullanılarak Türkiye'nin Batı Karadeniz kıyılarında *Liocarcinus depurator*'un yaş yapısının tahmini

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Öz: Türkiye'nin kuzeybatı Karadeniz kıyılarında, popülasyonun yaş yapısını belirlemek amacıyla, toplam 2.233 *Liocarcinus depurator* yengeci algarna (çerçeveli trol) operasyonları ile toplanmıştır. Erkek-dişi oranı 2:1 olarak hesaplanmıştır. Bhattacharya yöntemi kullanılarak dört yaş grubu için uzunluk-frekans dağılımları tahmin edildi; erkekler için kabuk uzunlukları 0^+ = 15,51, I^+ = 23,76, II^+ = 31,29 ve III^+ = 36,49 mm; dişiler için 0^+ = 15,35, I^+ = 21,36, II^+ = 27,18 ve III^+ = 30,50 mm olarak belirlenmiştir; birleşik cinsiyetler için toplam uzunluklar 0^+ = 15,35, I^+ = 22,65, II^+ = 30,81 ve III^+ = 36,59 mm olarak belirlenmiştir. Tek yönlü ANOVA, birleştirilmiş örneklemde ve ayrıca dişiler ve erkekler için ayrı ayrı yaş grupları arasında ortalama uzunlukta önemli farklılıklar olduğunu göstermiştir (tümü $p < 0,001$). Bağımsız t-testleri, yaş grubu 0^+'da cinsiyetler arasında önemli bir fark olmadığını ortaya koyarken ($p = 0,59$), yaş grupları I^+, II^+ ve III^+' da önemli farklılıklar gözlemlenmiştir (tüm karşılaştırmalar için $p < 0,05$). Erkekler, genel olarak yaşlı kohortlarda dişilerden daha büyüktü, bu da popülasyonda belirgin cinsel dimorfizm ve farklı büyüme modellerini yansıtmaktadır.

Anahtar kelimeler. Yaş yapısı, yengeç biyolojisi, balıkçılık yönetimi, *Liocarcinus depurator*, popülasyon dinamikleri, türkiye batı karadeniz kıyıları.

INTRODUCTION

Decapod crustaceans, such as shrimp, lobsters, and crabs, play a vital role in both wild-capture and aquaculture fisheries, significantly supporting global food security and the health of marine ecosystems (Kaya et al., 2009). According to the Food and Agriculture Organization (FAO), global crab production reached approximately 1.525 tons in 2022, highlighting their economic and ecological importance (FAO, 2022). As a primary food source for humans (Vogt, 2012), decapods play a key role in nutrient cycling and food web stability, making them essential for understanding marine ecosystem dynamics.

[*] *This study was produced from the master thesis of Aziz Gümüşler.* *Bu çalışma Aziz Gümüşler'in yüksek lisans tezinden üretilmiştir.*

Among these decapods, *Liocarcinus depurator* (commonly known as the "harbour crab") is widely distributed along European and Mediterranean coasts, including the North Sea, Atlantic Ocean, and the Black Sea (Ateş, 1999; Horton & Lilley, 2008; Telnes, 2012). Although not a major commercial species in Türkiye due to its small size and limited meat yield, *L. depurator* holds ecological significance as a prey item for benthic fish and an indicator of environmental health. Its adaptability, flexible feeding strategies, and efficient larval dispersal further underscore its role in coastal ecosystem structure and function.

Morphologically, *L. depurator* is characterized by a pale reddish-brown carapace adorned with transverse rows of hairs and crenulated ridges. The species is easily identifiable by its distinctive violet-tinted paddle on the fifth pereopod and anterolateral edges, which bear five sharp teeth (Hill, 2008). Adults typically reach a (CL) of up to 40 mm and a carapace width (CW) of 50 mm, inhabiting muddy and sandy substrates at depths ranging from 50 to 150 m, with records extending to 400 m (Minervini et al., 1982; Rufino, 2004). As an omnivorous scavenger and predator, *L. depurator* feeds on a diverse diet, including crustaceans, molluscs, polychaetes, ophiuroids, algae, and small fish (Freire et al., 1996).

Accurate estimation of life-history traits, including growth rates, age at maturity, mortality, and longevity, is crucial for evaluating population dynamics, reproductive potential, and resilience to environmental and human-induced stressors (Campana, 2001; Beamish & McFarlane, 1983). However, determining age in crustaceans poses unique challenges due to their moulting cycle, which removes calcified structures that could otherwise serve as age indicators (Anderson, 1982; Beamish & McFarlane, 1983). Unlike fish, which can be aged using otoliths or scales, crustaceans often require indirect methods such as length-frequency analysis to estimate growth parameters (Millar & Meyer, 2000). Since inaccurate age estimates can lead to overexploitation and flawed conservation strategies, reliable aging techniques are essential for sustainable fisheries management (Campana, 2001). Current approaches to determining crustacean age can be categorized into three main groups, each with varying levels of accuracy. Lipofuscin quantification measures the buildup of metabolic "age pigments" in neural tissues using histological and image analysis (Kilada & Driscoll, 2017; Ju et al., 1999; Sheehy, 1990). Growth band analysis involves counting presumed annual growth increments in calcified structures such as gastric mill ossicles or eyestalk cuticles (Kilada et al., 2012; Becker et al., 2018; Carmichael, 2013). Indirect methods include size-frequency distributions (LFD), mark-recapture studies, and molt cycle monitoring, which provide insights into population-level cohorts rather than precise individual ages.

Although extensive research has been conducted on *L. depurator* in European waters (Lebour, 1928; Ingle, 1985; Freire, 1996; Rufino et al., 2006), there have been few studies in the Eastern Black Sea (Onay & Bilgin, 2022; Onay & Bilgin, 2021; Aydın et al., 2013). Research on the biology and ecology of this species in the western Black Sea, especially along the Turkish coast, remains limited. Because of the species' prevalence and ecological importance in the region, addressing this knowledge gap is crucial for sustainable fisheries management and marine conservation. This study is the first to estimate the age structure of *L. depurator* populations along Türkiye's southwestern Black Sea coast through LFD. The results are expected to provide vital data for understanding population dynamics, supporting sustainable harvesting, and guiding conservation efforts for this ecologically important crustacean species.

MATERIAL AND METHOD

This study was carried out seasonally from November 2017 to August 2018 along Türkiye's northwestern Black Sea coast, where *L. depurator* was sampled at five locations using beam trawl nets (Figure 1). To identify the mobile macrofauna, a beam trawl with a 2 m width and a 15 mm mesh size at the cod-end was employed on the' Black Sea Research" vessel belonging to Recep Tayyip Erdoğan University. Five stations at different depths (10 m, 20 m, 30 m) were sampled. Each trawl operation lasted approximately 20 minutes, covering an area of roughly 2,100 square meters per operation (Figure 1).

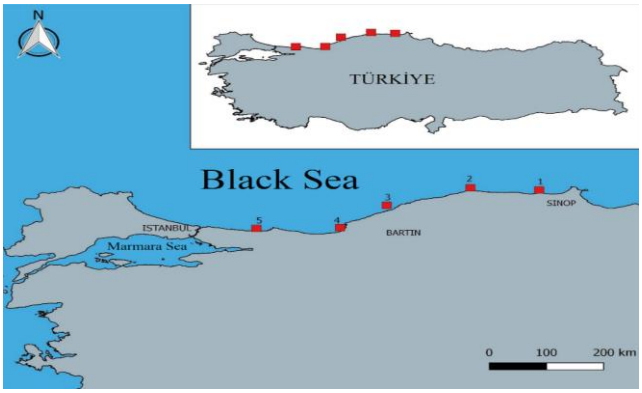

Figure 1. Study area

The collected macrofauna was passed through a 0.5 mm sieve. The CL and CW of the *L. depurator* samples were measured in the lab with a caliper to an accuracy of 0.05 mm.

In our study, we used one of the most effective methods for determining the age of crustaceans, the length-based approach developed by Bhattacharya. This model estimates the number of age classes in the sample using length frequency data. The Bhattacharya method, implemented in the LFSA computer program, divides the LFD into distinct normal distributions, allowing the

identification of different sample cohorts. The average lengths of the frequencies obtained with this method were plotted over a time series, and assumed cohorts were identified using modal progression analyses (Bilgin et al., 2006). In our study, all analyses were conducted using the FISAT-II software, based on 1 mm length groups, as described by Bilgin et al. (2006) and Ricker (1975).

Statistical Analysis: Statistical analyses were conducted using the Sigma Plot software. One-way ANOVA was applied to evaluate length differences among age groups within each sex, while independent t-tests were performed to compare length differences between males and females within the same age groups.

RESULTS AND DISCUSSION

In this study, a comprehensive sample of 2,233 *L. depurator* specimens was collected during beam trawl surveys along the northwestern Black Sea coast of Türkiye, providing robust data for analyzing the species' age structure and growth patterns. The specimens ranged in CL from 6.20 mm to 36.47 mm, with 1,488 males and 745 females, resulting in a male-to-female sex ratio of 2:1. This ratio aligns closely with previous observations in the eastern Black Sea region, such as those reported by Aydın et al. (2013) for the Ordu Province coasts, suggesting a consistent demographic trend across Turkish Black Sea populations. Such a male bias could stem from ecological factors, such as differential mortality rates, habitat preferences, or sampling biases inherent to beam trawl methods; however, further targeted studies would be needed to confirm causality.

Using the Bhattacharya method within the FISAT-II software, length-frequency distributions were decomposed into four distinct age cohorts (0^+ to III^+), excluding 390 specimens that did not fit the modal progression criteria. This exclusion highlights the method's sensitivity to outliers, ensuring more reliable cohort separation. The estimated mean CL for each age group, stratified by sex and combined, are detailed in Table 1.

Table 1. Estimated carapace lengths for female, male, and sexes combined age groups (mm) of *L. depurator* using the Bhattacharya method.

Age	N	Female	S.D	N	Male (CL)	S.D	N	Sexes combined (CL)	S.D
0^+	80	15.35	2.52	200	15.51	1.76	319	15.35	1.61
I^+	510	21.39	2.93	575	23.76	2.75	1159	22.65	2.53
II^+	113	27.18	2.30	246	31.29	2.17	317	30.81	1.35
III^+	18	30.5	1.50	47	36.49	1.58	48	36.59	0.91

S.D: Standard deviation.

For males, lengths progressed as follows: 0^+ = 15.51 mm (SD = 1.76), I^+ = 23.76 mm (SD = 2.75), II^+ = 31.29 mm (SD = 2.17), and III^+ = 36.49 mm (SD = 1.58). Females showed smaller sizes overall: 0^+ = 15.35 mm (SD = 2.52), I^+ = 21.39 mm (SD = 2.93), II^+ = 27.18 mm (SD = 2.30), and III^+ = 30.50 mm (SD = 1.50). When sexes were pooled, the combined lengths were 0^+ = 15.35 mm (SD = 1.61), I^+ = 22.65 mm (SD = 2.53), II^+ = 30.81 mm (SD = 1.35), and III^+ = 36.59 mm (SD = 0.91). These values indicate a clear growth trajectory, with incremental increases across age groups, and underscore that males generally outpace females in size attainment, particularly in older cohorts (as visualized in Figures 3–5, which illustrate the modal distributions for females, males, and combined sexes, respectively).

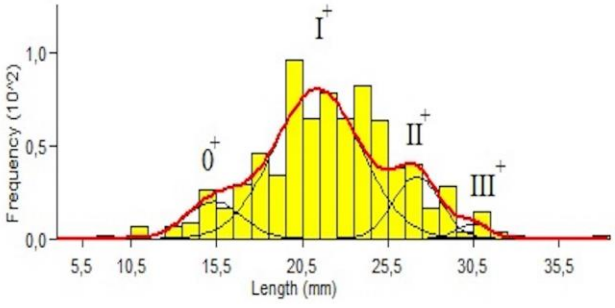

Figure 2. Carapace Length groups corresponding to age groups of female *L. depurator*

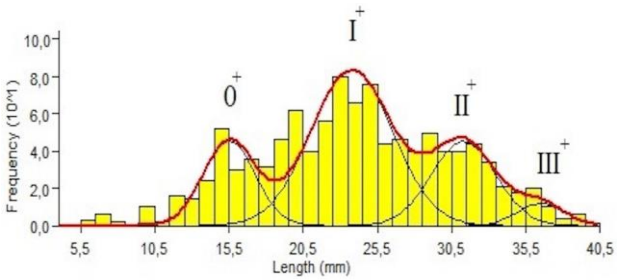

Figure 3. Length groups corresponding to the age groups of male *L. depurator.*

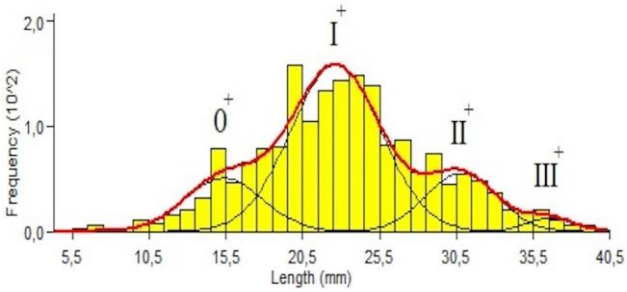

Figure 4. Lengths corresponding to age groups of sexes combined *L. depurator.*

From our standpoint, these length estimates appear reasonable for a small portunid crab such as *L. depurator*, considering its reported maximum size of up to 40 mm CL in the literature (e.g., Minervini et al., 1982). The Bhattacharya method, which relies on length-frequency data, is particularly appropriate in this context, as direct aging approaches (e.g., lipofuscin quantification

or growth band analysis) are costly and impractical for large datasets. Nevertheless, the method carries certain limitations, including its assumptions of constant growth rates and limited cohort overlap—factors that may be challenged by seasonal recruitment pulses in the Black Sea's dynamic environment. The relatively small standard deviations observed in older age groups (e.g., III^+, SD = 0.91 mm combined) indicate tighter clustering, potentially reflecting reduced growth variability after maturity or selective mortality among slower-growing individuals. CL data of *L. depurator* by sex and estimated age groups are presented in Table 2.

Table 2. Mean carapace length (mm, ±SD) of *L. depurator* corresponding to sex and age group, ANOVA and t-test results.

Age group	Female (n)	Male (n)	ANOVA F (df)	p-value	t-test (df)	p-value
0^+	80	200	—	—	t (278) = 0.55	0.59
I^+	510	575	—	—	t (1085) = 5.16	<0.001
II^+	112	246	—	—	t (358) = 1.47	0.04
III^+	18	47	—	—	t (65) = 4.19	<0.001
Combined	719	1067	F (3,1784) = 3934.81	<0.001	—	—
Female	—	—	F (3,716) = 349.45	<0.001	—	—
Male	—	—	F (3,1064) = 1969.76	<0.001	—	—

The patterns observed in Table 2, particularly the emergence of significant sexual dimorphism in the carapace length CL of *Liocarcinus depurator* from age group I onward, are consistent with broader trends seen in brachyuran crabs. Sexual size dimorphism (SSD), where males are generally larger than females, is common among decapod crustaceans and is often associated with distinct energy allocation strategies and reproductive roles (Candiotto et al., 2023). From a life-history perspective, females often dedicate substantial energy to reproductive processes, such as vitellogenesis, egg production, and brooding, which can restrict their somatic growth after maturation (Silva et al., 2014; Colpo et al., 2022). Conversely, males tend to continue somatic growth longer, sometimes investing more in traits that enhance mating competition, such as larger bodies or chelipeds (Fazhan et al., 2021). Notably, within the Portunidae family, which includes *L. depurator*, male-biased SSD is often reported (Fazhan et al., 2021). Research on related species suggests that larger male size may boost competitive ability, mate guarding, or reproductive success, while female size may reflect trade-offs with reproductive output. These findings align with foundational theories on crustacean growth and dimorphism. For instance, Hartnoll (2006) provided a framework for understanding growth trajectories and the trade-offs between somatic growth and reproduction in decapods (Hamasaki et al., 2024; Silva et al., 2014). Additional studies in Brachyura indicate that ontogenetic changes characterized by minimal size differences in the juvenile stage followed by divergence are typical in crab development patterns (Hamasaki et al., 2024; Marochi et al., 2019).

Statistical validation reinforces the robustness of these age groupings. One-way ANOVA confirmed highly significant differences in mean CL among age groups for the pooled sample ($F(3,1784) = 3934.81$, $p < 0.001$), females alone ($F(3,716) = 349.45$, $p < 0.001$), and males alone ($F(3,1064) = 1969.76$, $p < 0.001$), as summarized in Table 2. This indicates distinct cohort separation, with no evidence of merging distributions that might undermine the Bhattacharya decompositions. Independent t-tests between sexes within age groups revealed no difference in the juvenile 0^+ cohort ($t(278) = 0.55$, $p = 0.59$), but significant dimorphism emerged thereafter: I^+ ($t(1083) = 5.16$, $p < 0.001$), II^+ ($t(356) = 1.47$, $p = 0.04$), and III^+ ($t(63) = 4.19$, $p < 0.001$). Males were consistently larger in these older groups, a pattern I interpret as reflective of sexual size dimorphism (SSD) standard in brachyurans.

This SSD aligns with evolutionary theories: females may allocate more energy to reproduction (e.g., egg brooding), limiting somatic growth post-maturity, while males invest in larger sizes for mating advantages like competition or guarding (Hartnoll, 2006; Fazhan et al., 2021). Within Portunidae, male-biased SSD is prevalent (Candiotto et al., 2023), and our data show ontogenetic progression minimal juvenile differences followed by divergence mirroring patterns in related species (Hamasaki et al., 2024; Marochi et al., 2019). Environmentally, the Black Sea's conditions might amplify this, as resource scarcity could exacerbate trade-offs. However, I note a potential study limitation: the t-test for II^+ ($p = 0.04$) is marginally significant, possibly due to sample imbalance ($n_{female} = 112$ vs. $n_{male} = 246$), suggesting larger samples could refine precision.

Overall, these results not only validate the Bhattacharya method for crustacean age estimation in data-limited regions but also highlight *L. depurator*'s ecological resilience as a scavenger in benthic communities. The observed growth dimorphism and age structure imply differential vulnerabilities—e.g., larger males might face higher fishing pressure if targeted indirectly via bycatch. For conservation, integrating these findings into ecosystem models could aid in assessing the biodiversity of the Black Sea under climate change. Future work might incorporate mark-recapture or molecular ageing to cross-validate, enhancing accuracy beyond length-based inferences.

Comparative literature on *L. depurator* age structure reveals variability across regions, which enriches the interpretation of our findings. For instance, Rufino et al. (2006) estimated a 3–4 year lifespan along the Iberian

Mediterranean coast, closely matching our four identified cohorts (implying a similar longevity). In contrast, Abelló (1986) reported 4–5 age groups in the western Mediterranean, while Fernández et al. (1991) noted a shorter 18-month lifespan in Galician Atlantic populations (Table 3.).

Table 3. Age structure on *Liocarcinus depurator* in different habitats.

Habitat	Age	Literature
Iberian Mediterranean	3 – 4 years	Rufino et al., 2006
Galician Atlantic	18 months	Fernandez et al., 1991
Western Mediterranean	4 – 5 years	Albello, 1986
Western Black Sea	3 – 4 years	This study

These discrepancies likely arise from environmental gradients: the Black Sea's lower salinity, variable temperatures, and nutrient dynamics may moderate growth compared to Mediterranean or Atlantic sites. Factors such as predation pressure, food availability (e.g., polychaetes and molluscs as per Freire et al., 1996), and anthropogenic stressors (e.g., pollution or trawling) could further modulate these patterns. In the Turkish context, our results extend prior eastern Black Sea studies (e.g., Onay & Bilgin, 2021, 2022), filling a gap for the western coast and highlighting regional consistency in sex ratios but potential local differences in growth due to bathymetric variations (our samples from 10–30 m depths).

CONCLUSION

This study presents the first age estimation of *L. depurator* populations along the western Black Sea coast of Türkiye using the Bhattacharya method. A total of 2,233 individuals were analysed through length-frequency distributions, and four distinct age classes (0^+ to III^+) were successfully identified. The results indicated a male-biased sex ratio of 2:1, consistent with previous findings from other regions of the Black Sea.

Statistical analyses revealed no significant difference in mean CL between sexes in the 0^+ age group. However, significant differences were observed in all other age groups, with males displaying higher growth rates and larger body sizes than females. These findings suggest a sexually dimorphic growth pattern, likely influenced by biological and environmental factors. The observed age structure and growth dynamics align with existing literature from other geographical regions, affirming the validity of the Bhattacharya method for age estimation in this species. Furthermore, the study underscores the ecological significance of *L. depurator* as a pivotal benthic species within coastal ecosystems. It further emphasizes the critical need for sustained monitoring programs to advance sustainable fisheries management and biodiversity conservation in the Black Sea region. The research also contributes supporting data for refining stock assessments and monitoring frameworks.

In summary, these findings address a vital knowledge gap on the age and growth dynamics of *L. depurator* in Turkish waters, thereby establishing a foundational reference for subsequent scientific work in stock assessment, ecosystem modeling, and conservation planning.

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Authorship Contribution Statement: Ahmet Mutlu Gözler contributed to the study through funding acquisition, writing – review & editing, investigation, formal analysis, and conceptualization. Aziz Gümüşler was responsible for resources, investigation, formal analysis, and data curation, Erhan Çiloğlu contributed with writing – review & editing, writing – original draft, methodology, investigation, data curation, and conceptualization.

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