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SHORT COMMUNICATION

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Confirmation of the occurrence of three fish species in Maltese waters based on specimens collected through the EC's Data Collection Framework

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ABSTRACT

Based on the examination of recently available actual specimens, obtained through the reporting required by Member States for the European Commission's Data Collection Framework, three fishes whose presence in Maltese waters was uncertain, are now confirmed as occurring: *Dentex maroccanus* Valenciennes, 1830, *Sphyraena viridensis* Cuvier, 1829, and *Sphyraena sphyraena* Linnaeus, 1758. Accurate species identification is essential for reliable data collection during routine monitoring activities. It is suggested that in local fisheries records, *D. maroccanus* was previously misidentified as *D. macrophthalmus*, while despite past reports of alien sphyraenids, current findings confirm only native Mediterranean species of *Sphyraena* to be present in Maltese waters.

KEYWORDS: Commercial Fishing, Fish biology, Malta, Marine surveys, Misidentifications

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1. Introduction

Almost 550 species of fish have been reported at one time or another from Maltese waters (the General Fisheries Commission for the Mediterranean [GFCM] Geographical Subarea [GSA] 15). These were most recently reviewed by Borg et al. (2023), who authenticated 412 species, rejected 78 species, and considered 53 as likely occurring but whose presence needs confirmation. Specimens of three species which became available recently allowed us to confirm the occurrence of the Morocco dentex, *Dentex maroccanus*, in Maltese waters and to resolve the identity of the large and small species of barracuda (genus *Sphyraena*), both of which are relatively common, but which have frequently been misidentified**.**

2. Methods

Specimens of all three species discussed in this paper were obtained through routine activities of the Data Collection Framework (European Commission, n.d.), which is a national obligation for EU Member States, including Malta. Part of this obligation requires data collection on commercial fishing activities, such as '*lampara*' purse-seines and trammel nets, as well as fisheries-independent research surveys such as the MEDITS trawl survey (MEDITS working group, 2017). Following capture, the geographical coordinates were recorded and the specimens were stored on ice before being transported to the laboratory. Biometric data, sex, and maturity were recorded for each individual (Appendix 1). The maturity was determined according to the FAO maturity atlas (Follesa and Carbonara, 2019), and photographs were taken to record the specimens. Identifications were based on a detailed study of morphological and coloration characteristics as given in Bauchot et al. (1987) and Louisy (2020).

3. Results and Discussion

3.1. *Dentex maroccanus* Valenciennes, 1830.

Twenty-two individuals of *Dentex maroccanus* (Morocco dentex) were caught during the MEDITS trawling survey on 25th July 2023 at coordinates N 35° 56.0040', E 15° 5.9100'. These fish were caught from trawls at a depth of approximately 105m.

All individuals had 12 hard spines and 10-11 soft rays on the dorsal fin. The eyes were large with a diameter more or less equal to the length of the snout, with a yellow outer iris and an inner black pupil. The body was reddish-pink in colour, which was particularly vivid when they were freshly caught, and a small black spot was present at the base of the pectoral fins; the edge of the caudal fin was lined in red. All these features are characteristic of this species (Bauchot et al., 1986) (Figure 1).

Figure 1. Image showing one of the *Dentex maroccanus* individuals recorded during the 2023 MEDITS survey**.**

3.2. *Sphyraena sphyraena* Linnaeus, 1758 and *Sphyraena viridensis* Cuvier, 1829.

Sphyraena sphyraena: Eleven individuals of the European barracuda (*S. sphyraena*) were captured through '*lampara*' purse-seine fishing on two occasions: 25th September and 25th October 2023 from coordinates N 35° 50.3520', E 14° 35.5638' and N 35° 53.1780', E 14° 45.7140' respectively, and all from a depth of approximately 90m.

These individuals all exhibited an elongated body with a pointed head, a protruding lower jaw terminating in an upward curve, and a mouth lined with sharp, long, needle-like teeth. The posterior edge of the pectoral fins did not coincide with the origin of the pelvic and dorsal fins. Vertical banding on the lateral side of the body was absent, and the operculum and preoperculum of these individuals were completely covered with scales. Above the lateral line, the body was greenish-yellow, whilst below it was a silvery-white (Figure 2).

Sphyraena viridensis: Three individuals of the yellowmouth barracuda (*S. viridensis*) were caught on 14th February 2024 using a trammel net, from off the northeast coast of Malta at coordinates N 35° 57.6660', E 14° 24.0060' from a depth of approximately 25m.

Similarly to the previous species, these specimens displayed an elongated body, a pointed head, a protruding lower jaw curved upward, and a mouth lined with needle-like teeth. Again, as in *S. sphyraena*, the posterior edge of the pectoral fins did not coincide with the origin of the pelvic and dorsal fins. However, unlike *S. sphyraena*, the lateral sides of the body had very clearly visible vertical bands, and the posterior edge of the preoperculum lacked any scales. Above the lateral line, the body was a dark blackish blue and was of a dull grey colour below it (Figure 3).

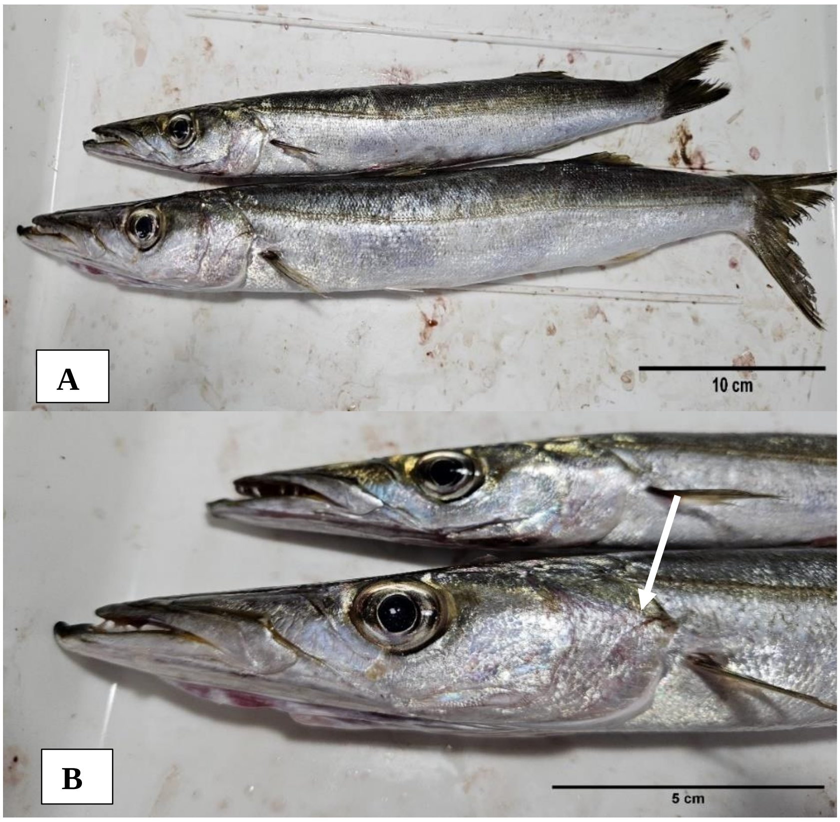

Figure 1. Image of two individuals of *Sphyraena sphyraena* caught during '*lampara*' purse-seine fishing in 2023. (A) shows the entire specimens, whilst (B) shows a close-up view of the head highlighting the presence of scales on the operculum and preoperculum (arrow).

Figure 2. Images showing one of the *Sphyraeana viridensis* individuals caught by trammel net in 2024. (A) displays the entire fish, whilst (B) shows a close-up view of the head, highlighting the lack of scales along the posterior edge of the preoperculum (arrow).

The distribution of *Dentex maroccanus* extends across the southern and eastern areas of the Mediterranean, recently including the Adriatic Sea and the Sea of Marmara, and the Eastern Atlantic Ocean, with records ranging from the Bay of Biscay to the Gulf of Guinea (Mina et al., 2023 and references therein; Grech et al., 2023). In their critical review of Maltese fishes, Borg et al. (2023) list this species as requiring confirmation since it has never been officially recorded from Maltese waters. It is the authors' view that there is a high probability that *D. maroccanus* was encountered in the past, but had most likely been misidentified as *Dentex macrophthalmus* (Bloch, 1791), which also occurs locally. The latter is similar in morphology; however, it lacks the black spot near the pectoral fins, while the edge of the caudal fin is lined in white rather than red, and the eye diameter is notably larger than the length of the snout (Fischer et al., 1987). This species is also known to occupy similar habitats and depth ranges to *D. maroccanus,* although these ranges vary depending upon environmental conditions (Maravelias et al., 2007). Neither *D. maroccanus* nor its congener *D. macrophthalmus* are commercial species, and while both are caught by trawling, they are normally discarded. Data from onboard observations and the annual MEDITS trawl survey show that *D. maroccanus* is actually more common than *D. macrophthalmus* (personal observations). Distinguishing between the two species makes monitoring of fishing discards more accurate.

Identification of species belonging to *Sphyraena* has been a recurrent problem in the Mediterranean Sea, as a result of similarities in morphology and of overlap in habitat, depth range, and niche of the species. Nominally, seven species of *Sphyraena* have been reported; however, fewer species may in fact occur, particularly due to uncertainty in the identity of recently introduced alien sphyraenids, which have been recorded under various names, some of which are regarded as synonyms (Kiparissis et al., 2020). There is confusion in the literature between *Sphyraena chrysotaenia* Klunzinger, 1884, and *Sphyraena pinguis* Günther, 1874, and between *Sphyraena flavicauda* Rüppell, 1838, and *Sphyraena obtusata* Cuvier, 1829. CIESM's atlas of exotic fishes in the Mediterranean Sea (Golani et al., 2021) considers *S. chrysotaenia* and *S. flavicauda* as the two alien sphyraenids present, whereas Louisy (2020) has suggested these aliens to be *S. pinguis* and *S. obtusata*.

According to the critical review of Borg et al. (2023), only the native Mediterranean *S. viridensis* has been authenticated to occur in Maltese waters, but at least one other species of *Sphyraena* of unknown identity is also present. Both *S. chrysotaenia* and *S. sphyraena* have been reported, but due to the confused taxonomy of the former and because older published records do not separate *S. sphyraena* from *S. viridensis*, Borg et al. (2023) consider both species to need authentication.

4. Conclusion

Through the present study, two species of *Sphyraena* – *S. viridensis* and *S. sphyraena* – have been confirmed as occurring locally, both of which are native Mediterranean species. Up to the time of writing, there are still no confirmed local records of any alien sphyraenid. The larger *Sphyraena* is frequently consumed locally, even if not highly sought after; these fish therefore have a low commercial interest. Both species are routinely encountered during monitoring activities, and differentiation between them is important for accurate data collection purposes.

Acknowledgment

We would like to thank colleagues within the "Marine Biology and Conservation" section of Aquatic Resources Malta (ARM) for their help in collection and storage of samples.

Compliance with Ethical Standards

Conflict of interest
The authors declare that they have no competing interests.

Ethical approval
Ethics committee approval is not required.

Data availability
Not applicable.

Consent for publication
Not applicable.

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Appendix 1:

Dentex maroccanus biometric data:

Table 1. Biometric data obtained from the 22 individuals of *Dentex maroccanus*. All length parameters are in mm, whilst weight is in g.

N.	SL	TL	FL	BD	PDL	PAL	CFL	HL	PeFL	PFL	ED	W	S	M
1	198	217	241	84	55	124	42	67	68	42	21	232.8	M	3
2	164	183	205	65	58	100	31	51	53	32	19	142.5	F	2B
3	184	207	230	71	65	114	46	62	58	36	22	188.9	M	2B
4	166	184	209	64	46	101	44	54	51	34	18	138.4	F	3
5	175	197	220	69	58	102	43	59	51	36	21	169.1	F	2B
6	150	168	191	60	51	97	39	49	49	30	18	113.5	M	3
7	171	192	218	67	62	114	46	62	53	34	22	170.3	F	3
8	166	186	208	65	58	102	43	51	49	33	18	142.6	F	2B
9	173	192	218	67	57	105	48	59	52	35	20	152.5	F	2B
10	168	186	210	65	63	101	43	58	56	34	20	151.5	F	3
11	151	172	193	64	51	93	38	53	53	33	19	138.7	F	3
12	156	177	200	63	59	97	40	53	54	33	19	140.1	F	3
13	163	182	204	62	51	101	41	55	52	34	18	137.7	F	3
14	154	174	197	62	56	93	39	52	51	31	17	128.6	F	3
15	166	187	210	65	53	101	40	56	56	30	18	133.8	F	3
16	169	192	216	64	55	98	40	58	56	35	19	135.2	M	2B
17	162	182	203	61	54	99	41	57	54	33	20	136.2	F	3
18	147	165	187	55	52	92	37	52	50	31	18	107.7	F	3
19	159	175	198	62	48	95	38	51	51	34	16	115	F	3
20	145	161	180	57	50	88	38	50	53	32	18	112.4	F	3
21	167	188	212	65	58	101	42	57	59	36	20	148.5	M	2B
22	155	171	198	57	56	99	38	54	48	32	18	108.2	F	3
Average	**164.05**	**183.55**	**206.73**	**64.27**	**55.27**	**100.77**	**40.77**	**55.45**	**53.50**	**33.64**	**19.05**	**142.92**		
Std. dev.	**12.26**	**13.28**	**14.05**	**5.82**	**4.81**	**8.01**	**3.68**	**4.54**	**4.33**	**2.59**	**1.56**	**28.71**		

N.: Individual number, SL: Standard length, TL: Total length, FL: Fork length, BD: Body depth, PDL: predorsal length, PAL: preanal length, CFL: Caudal fin length, HL: head length, PeFL: Pectoral fin length, PFL: pelvic fin length, ED: eye diameter, W: weight, S: Sex and M: maturity.

Sphyraena sphyraena **biometric data:**

Table 2. Biometric data obtained from the 11 individuals of *Sphyraena sphyraena*. All length parameters are in mm, whilst weight is in g. The date of capture of individuals 1-5 (25/08/23) whilst for 6-11 (25/10/23).

N.	SL	TL	FL	BD	PDL	PAL	CFL	HL	PeFL	PFL	ED	W	S	M
1	396	400	446	40	177	274	42	114	38	30	15	255.1	F	3
2	371	377	418	40	166	258	41	110	35	30	17	270	F	3
3	328	331	364	37	147	220	37	99	28	27	14	184.5	M	3
4	321	328	359	37	144	218	34	98	30	25	14	165.2	M	2C
5	313	317	355	37	140	213	38	95	34	27	13	166.3	M	3
6	304	310	344	39	134	208	31	92	28	26	12	151.8	M	2C
7	260	266	297	28	117	183	30	82	26	23	10	96.8	M	2C
8	314	320	357	37	142	218	39	95	29	27	13	181.2	M	2C
9	298	302	338	33	136	207	37	90	29	25	11	144.7	M	2C
10	255	264	292	32	115	178	32	80	26	21	11	90.6	M	2C
11	269	274	302	34	120	183	34	80	26	22	10	107.8	M	2C
Average	**305.47**	**311.26**	**345.21**	**34.84**	**137.32**	**210.42**	**35.53**	**92.42**	**29.26**	**25.21**	**12.32**	**156.46**		
Std. Dev.	**54.67**	**54.62**	**60.18**	**4.92**	**23.42**	**36.52**	**5.33**	**13.81**	**5.06**	**3.88**	**2.14**	**70.09**		

N.: Individual number, SL: Standard length, TL: Total length, FL: Fork length, BD: Body depth, PDL: predorsal length, PAL: preanal length, CFL: Caudal fin length, HL: head length, PeFL: Pectoral fin length, PFL: pelvic fin length, ED: eye diameter, W: weight, S: Sex and M: maturity.

***Sphyraena viridensis* biometric data:**

Table 3. Biometric data obtained from the 3 individuals of *Sphyraena viridensis*. All length parameters are in mm, whilst weight is in g.

N.	SL	TL	FL	BD	PDL	PAL	CFL	HL	PeFL	PFL	ED	W	S	M
1	650	663	740	73	284	480	89	194	64	51	22	1363.6	F	4A
2	572	583	656	68	252	399	79	173	59	50	22	964.3	M	4A
3	508	515	588	58	224	351	74	157	53	44	20	632.9	F	4A
Average	**576.67**	**587.00**	**661.33**	**66.33**	**253.33**	**410.00**	**80.67**	**174.67**	**58.67**	**48.33**	**21.33**	**986.93**		
Std. Dev.	**71.11**	**74.08**	**76.14**	**7.64**	**30.02**	**65.20**	**7.64**	**18.56**	**5.51**	**3.79**	**1.15**	**365.88**		

N.: Individual number, SL: Standard length, TL: Total length, FL: Fork length, BD: Body depth, PDL: predorsal length, PAL: preanal length, CFL: Caudal fin length, HL: head length, PeFL: Pectoral fin length, PFL: pelvic fin length, ED: eye diameter, W: weight, S: Sex and M: maturity.

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RESEARCH ARTICLE

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The Effect of Different Stock Densities on the Growth of Bristlenose Pleco, *Ancistrus multispinis* (Regan, 1912) Fry

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ABSTRACT

This study examined the growth performance of bristlenose pleco (*Ancistrus multispinis*) fry raised at five different stocking densities. For this purpose, five experimental groups were formed, each consisting of three replicates: 1 fry/L (d1), 2 fry/L (d2), 4 fry/L (d4), 6 fry/L (d6), and 8 fry/L (d8). The experiment used fry produced in the laboratory, with average initial live weights of 0.0275 ± 0.004 g and average total lengths of 1.46 ± 0.049 cm. The study lasted a total of 90 days. At the end of the experiment, the number of live fry in each group was recorded, and weight and length measurements were taken. According to these measurements, the average length of the fry in the 1 fry/L group (d1) was 3.1 cm, and the average weight was 0.321 g, while in the 8 fry/L group (d8), the length was found to be 2.8 cm, and the weight was 0.249 g. The size differences between groups were examined, and it was found that the d1 group showed statistically significant differences when compared to the other groups. The data obtained indicate that fry of *A. multispinis* grew more in lower stocking densities, such as 1 fry/L, compared to other groups. Based on these results, it can be said that utilizing lower stocking densities, such as 1 fry/L, is advantageous in the growth of *A. multispinis* fry.

KEYWORDS: *Ancistrus*, stock density, growth, aquarium.

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1. Introduction

Stock density is one of the critical parameters in aquaculture and directly affects the growth performance, health, welfare, and economic sustainability of fish production (Liu et al., 2014; Abe et al., 2019; Liu et al., 2021). Particularly in intensive farming systems, determining and implementing optimal stock density is vital. Inappropriate high stock densities can adversely affect growth, feed intake, feed conversion ratio, behavior, and health (Ellis et al., 2002; Ashley, 2007). High stock density can exert pressure on the living space of fish and water quality, thereby increasing stress levels. This condition elevates cortisol levels in fish, suppressing the growth hormone (GH) and insulin-like growth factor-I (IGF-I) axis (Liu et al., 2013). Furthermore, high stock density increases the formation of reactive oxygen species (ROS), leading to oxidative stress (Braun et al., 2010). In stressed fish, blood glucose is considered a reliable indicator of stress, while serum protein levels reflect the metabolic, nutritional, and immune status of the fish (Ruane et al., 2001; Ni et al., 2014; Tahmasebi-Kohyani et al., 2012). For these reasons, stock density must be well-regulated in aquaculture. Optimal stock density varies by fish species. For instance, it has been reported that stock densities exceeding 50 kg/m³ in Atlantic salmon farming lead to deterioration in water quality (Liu et al., 2017). In some species, fish larvae raised at high stock densities have shown increased cannibalism, reduced feed intake, and decreased growth performance (de Barros et al., 2019; Santos et al., 2020).

While low stock density can lead to inefficiencies in space utilization, high stock density can result in production losses and economic damage. Therefore, it is essential to determine and implement optimal stock density specific to each species for sustainable aquaculture (Can et al., 2023). This approach allows for the optimization of both the economic sustainability of production and the welfare of the fish (Refaey et al., 2018; Lupatsch et al., 2010).

This study investigates the growth performance of juvenile bristlenose pleco (*A. multispinis*), a popular aquarium fish species with high economic value, at different stock densities.

2. Materials and Methods

In this study, the broodstock fish available in our laboratory were used to obtain juveniles. Our laboratory infrastructure is equipped with all the machinery and equipment necessary to produce this species until they reach broodstock size. At the beginning of the study, the juveniles to be used in the experiment were produced. After successfully completing the production process, newly hatched juveniles were kept in larval rearing tanks (40 cm X 30 cm X 40 cm) until their yolk sacs were depleted and they began to consume artificial micro-particle feed. Approximately on days 30-35 post-hatching, the total lengths and weights of the juveniles were measured, and they were transferred to experimental tanks of 5 liters each. The experiment lasted for 90 days.

The research was conducted in the following general order:

- Enough juveniles were obtained from the broodstock.
- Experimental setups were established.
- Live weight and length measurements of the juveniles were taken at the beginning of the experiment.
- No anesthetic was applied during the measurements.
- The experiments were initiated.

- Three replicates were created for each group.
- At the end of the experiment, length and weight measurements were taken.
- The weight and length data obtained at the end of the experiment, along with survival rates, were statistically compared and analyzed.
- For statistical analyses, after checking the assumptions for differences in length among the experiments, the Kruskal-Wallis test was conducted due to the failure to meet the assumptions. The Dunn test was performed to identify which experiments showed differences.
- All groups were fed with the same brand of commercial fish feed (0.5-0.8 microns, ALLTECH) in the same amounts and number of feedings. At the end of the experiment, the survival and growth rates among the groups were compared. Water quality conditions were maintained within similar ranges across all groups.

This study was designed to determine the effect of stock density on growth; the number of individuals stocked in each group varied. The stock densities and live counts applied in the experimental groups are as follows:

- In Group 1 (d1), 1 juvenile was stocked per liter, totaling 15 juveniles, with 5 juveniles used in each replicate tank.
- In Group 2 (d2), 2 juveniles were stocked per liter, totaling 30 juveniles, with 10 juveniles used in each replicate tank.
- In Group 3 (d4), 4 juveniles were stocked per liter, totaling 60 juveniles, with 20 juveniles used in each replicate tank.
- In Group 4 (d6), 6 juveniles were stocked per liter, totaling 90 juveniles, with 30 juveniles used in each replicate tank.
- In Group 5 (d8), 8 juveniles were stocked per liter, totaling 120 juveniles, with 40 juveniles used in each replicate tank.

Each of the replicate tanks used in the experiment had a water capacity of 5 liters. A total of 0.02 grams of feed per fish per liter was provided, which amounts to a total of 0.1 grams of feed per meal for 5 fish in 5 liters.

3. Results and Discussion

In the experiment testing the effects of stock density on the growth and survival rates of juvenile bristlenose pleco, the stock densities were applied as shown in the table below. The average total length of the juveniles at the beginning of the experiment was measured at 1.46 ± 0.049 cm, and the average live weight was 0.0275 ± 0.004 g.

In the dataset testing the effect of stock density on juvenile growth, five experiments were established based on the number of juveniles (Table 1). Descriptive statistics and graphs for total length (cm) and live weight (g) were obtained from the collected data, and the Kruskal-Wallis test was conducted to assess differences among the experiments (Table 2, Table 3).

To examine whether there were differences in length among the experiments, the assumptions were checked for compliance, and due to the failure to meet these assumptions, the Kruskal-Wallis test was conducted. According to the test results, the null hypothesis that there is no difference among the experiments was rejected, and the differences among the experiments were statistically significant ($p < 0.05$). The Dunn test was performed to identify which experiments showed differences. The Kruskal-Wallis chi-squared = 18.321, df = 4, p-value = 0.001068.

Based on the results from the Dunn test, the differences between Experiment 1 (d1) and Experiments 4 (d4), 6 (d6), and 8 (d8) were statistically significant.

Table 1. Descriptions of the groups and the number of juveniles in the stock density experiment.

Experimental Groups	Stock Density (juvenile /L)	Number of Juveniles in Each Replicate Tank (fish / 5L)	Total Number of Juveniles Used in Each Group (individuals) (= 3 replicates)
d1	1	5	15
d2	2	10	30
d4	4	20	60
d6	8	30	90
d8	10	40	120

Table 2. Descriptive statistics of the end-of-experiment data for total length (cm) across groups.

	Groups	n	min	max	median	iqr	mean	sd	se	ci
1	d1	14	2,8	3,5	3,1	0,2	3,129	0,202	0,054	0,116
2	d2	30	2,1	4	3	0,5	2,973	0,383	0,07	0,143
3	d4	57	2,4	3,4	2,8	0,4	2,816	0,249	0,033	0,066
4	d6	82	2,2	3,5	2,9	0,3	2,859	0,255	0,028	0,056
5	d8	117	2,1	3,7	2,8	0,4	2,834	0,305	0,028	0,056

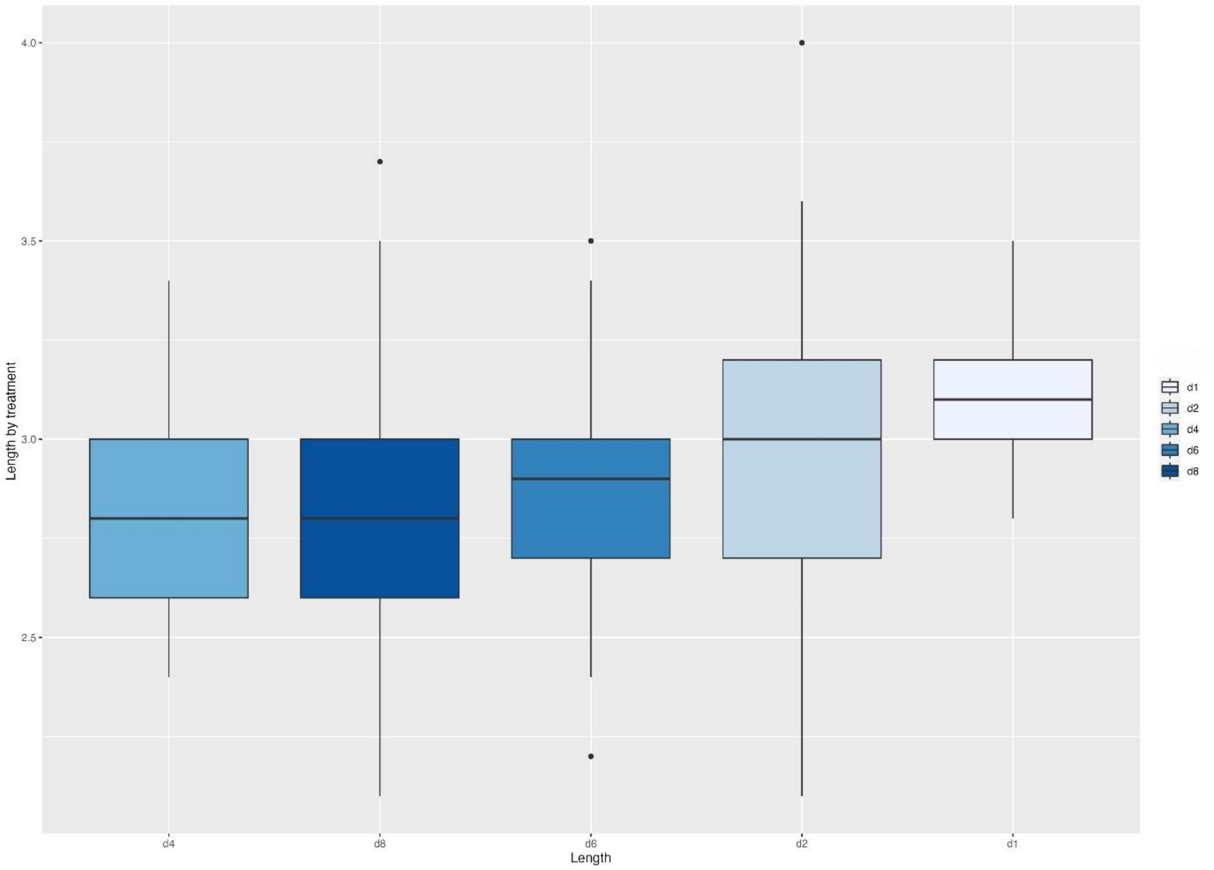

Figure 1. Differences in total length (cm) among groups at the end of the experiment.

To examine whether there were differences in weight among the experiments, the assumptions were checked for compliance, and due to the failure to meet these assumptions, the Kruskal-Wallis test was conducted (Table 3, Figure 2). According to the results of the Kruskal-Wallis test, the null hypothesis that there is no difference among the experiments was rejected, and the differences among the experiments were statistically significant ($p < 0.05$). The Dunn test was performed to identify which experiments showed differences. The Kruskal-Wallis chi-squared = 20.157, df = 4, p-value = 0.0004649.

Based on the results from the Dunn test, the differences between d1 and d4, as well as between d6 and d8, were statistically significant. The differences between d2 and d1, d6, and d8 were not significant. Differences were observed in the pairwise comparisons.

Additionally, a regression model was conducted to analyze the relationship between weight and length (Figure 3). The logarithm of weight and length was taken to perform the regression analysis. Below are the scatter plots for the weight-length relationship for this experiment.

To interpret the scatter plots of the weight-length graphs in more detail, it is important to examine the data distribution, trends, and possible outliers in each graph.

In the d1 graph, a clear positive relationship between weight and length is observed. As length increases, weight also appears to increase. The data generally exhibit a normal distribution, although some points may be more distant than others. Outliers may represent a few data points with lengths significantly higher than normal but with low weights.

In the d2 graph, there is a strong positive relationship between length and weight. It is understood that longer individuals are generally heavier. The data align well with a linear model overall. However, some points distinctly fall outside the distribution. Outliers may represent juvenile individuals that fall within a certain length range but have unexpectedly low weights.

In the d4 graph, a positive relationship between weight and length is observed, but there is more dispersion. This suggests that some individuals may be lighter or heavier than expected. The data are spread over a wider range, which may reflect a mixture of different samples. Outliers may represent a few data points with lengths significantly higher than normal but with low weights.

Table 3. Descriptive statistics of the end-of-experiment data for live weight (g) across groups.

Groups	n	min	max	median	iqr	mean	sd	se	ci
d1	14	0,21	0,44	0,315	0,088	0,321	0,062	0,017	0,036
d2	30	0,13	0,58	0,29	0,14	0,301	0,102	0,019	0,038
d4	57	0,13	0,39	0,23	0,08	0,243	0,061	0,008	0,016
d6	82	0,11	0,45	0,25	0,075	0,255	0,065	0,007	0,014
d8	117	0,07	0,49	0,24	0,12	0,249	0,078	0,007	0,014

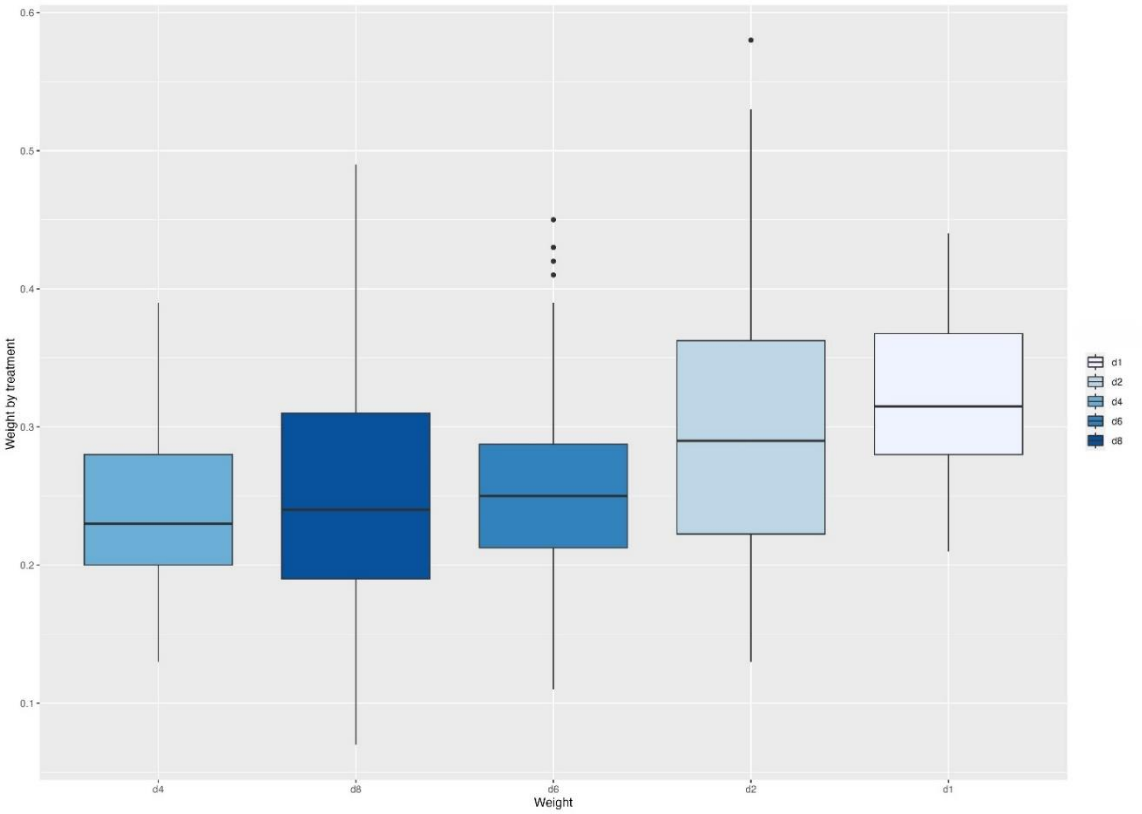

Figure 2. Differences in live weight (g) among groups at the end of the experiment.

In the d6 graph, there is again a positive relationship between weight and length. However, some points are noticeably distant from the others. Although the data generally align with a linear model, some points distinctly fall outside the distribution. Outliers may represent individuals within a certain length range but with unexpectedly low weights.

In the d8 graph, a strong positive relationship between weight and length is observed. As length increases, weight also appears to increase. The data generally exhibit a normal distribution, although some points may be more distant than others. Outliers may represent a few data points with lengths significantly higher than normal but with low weights.

Overall, a positive relationship between length and weight is observed in all graphs. Outliers may reflect abnormal conditions of specific samples. The normality of the distribution indicates the homogeneity or heterogeneity of the dataset. A heterogeneous distribution may reflect a mixture of different samples.

In Figure 4, five different scatter plots illustrate the relationships between "logL" (the logarithm of length) and "logW" (the logarithm of weight).

In the d1 graph, a weak relationship is observed; the data points are scattered and do not show a clear linear trend. Some points in this graph fall outside the general distribution, indicating the presence of outliers.

In the d2 graph, a strong positive relationship is evident; the data points exhibit a distinct linear trend, and there is an overall normal distribution, clearly illustrating the relationship between length and weight.

In the d4 graph, a positive relationship is observed, but there is more dispersion compared to the d2 graph. Some points in this graph also fall outside the general distribution, which may reflect abnormal conditions for certain species.

In the d6 graph, a strong positive relationship is present; the data points show a clear linear trend, and outliers are less pronounced, indicating that the dataset is more homogeneous.

In the d8 graph, a strong positive relationship between logL and logW is observed; the data points exhibit a distinct linear trend and generally show a normal structure. Outliers are less pronounced compared to other graphs.

Overall, strong positive relationships between length and weight are observed in the d2 and d6 graphs. The d1 and d4 graphs show more dispersion and outliers, while the d8 graph presents a more stable relationship due to the logarithmic transformation.

When examining the box plot comparing the lengths of juvenile bristlenose pleco (*A. multispinis*) across different experimental groups (d1, d2, d4, d6, d8) (

Figure **1**), the median line within the boxes for the d1 and d2 groups indicates that the lengths of juveniles in these groups are more homogeneous. This suggests that the growth conditions for juveniles in these groups are similar, resulting in comparable growth performance.

The d4 and d8 groups have higher median length values. Notably, the median of the d8 group is significantly higher than that of the other groups, indicating that the juveniles in these groups are generally longer and have better growth conditions.

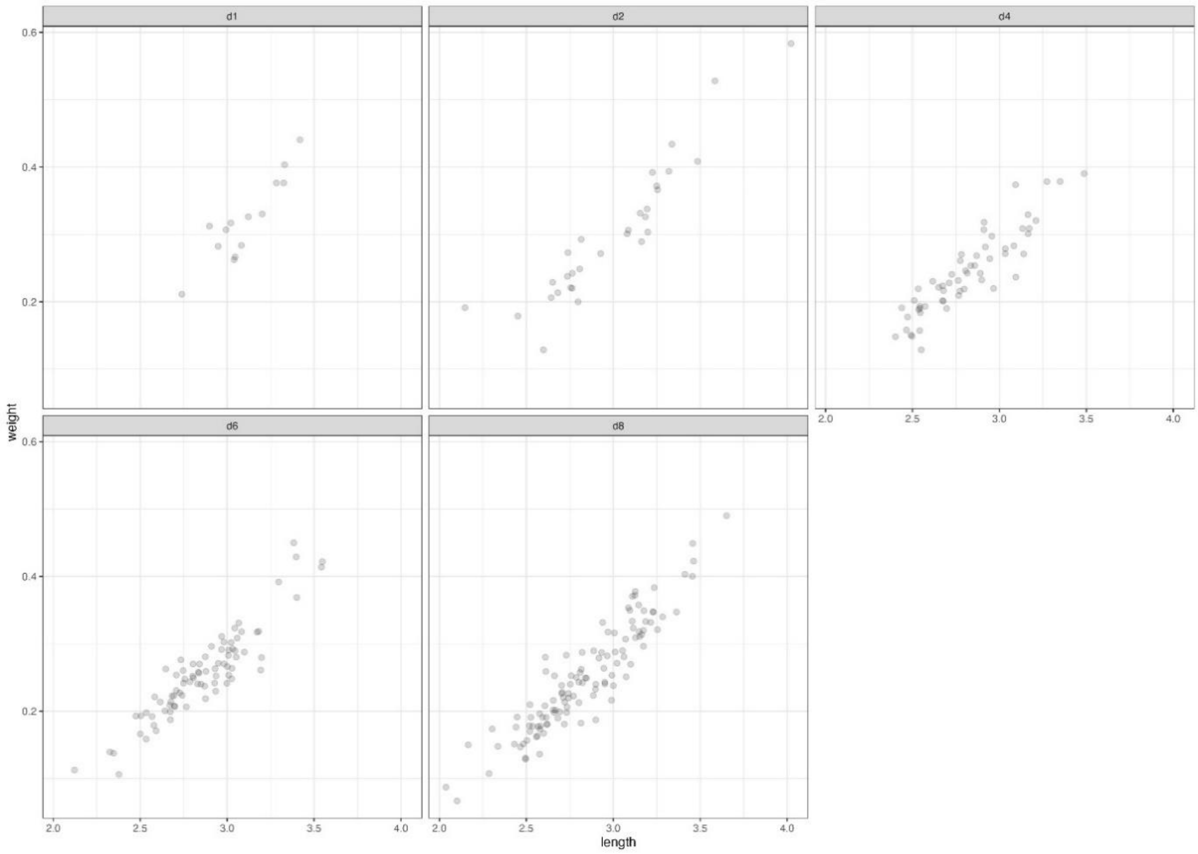

Figure 3. Scatter plots of weight-length relationships from the experiments conducted to test the effect of stock density on growth.

The d6 group has the lowest median length value, suggesting that the growth performance of juveniles in this group is weaker compared to the other groups and that they may have been exposed to potentially adverse environmental or nutritional conditions.

The boxes for the d1 and d2 groups have a narrower range, indicating that the lengths of juveniles in these groups exhibit less variability. This may suggest that the growth conditions for juveniles in these groups are more stable and that they face fewer stress factors.

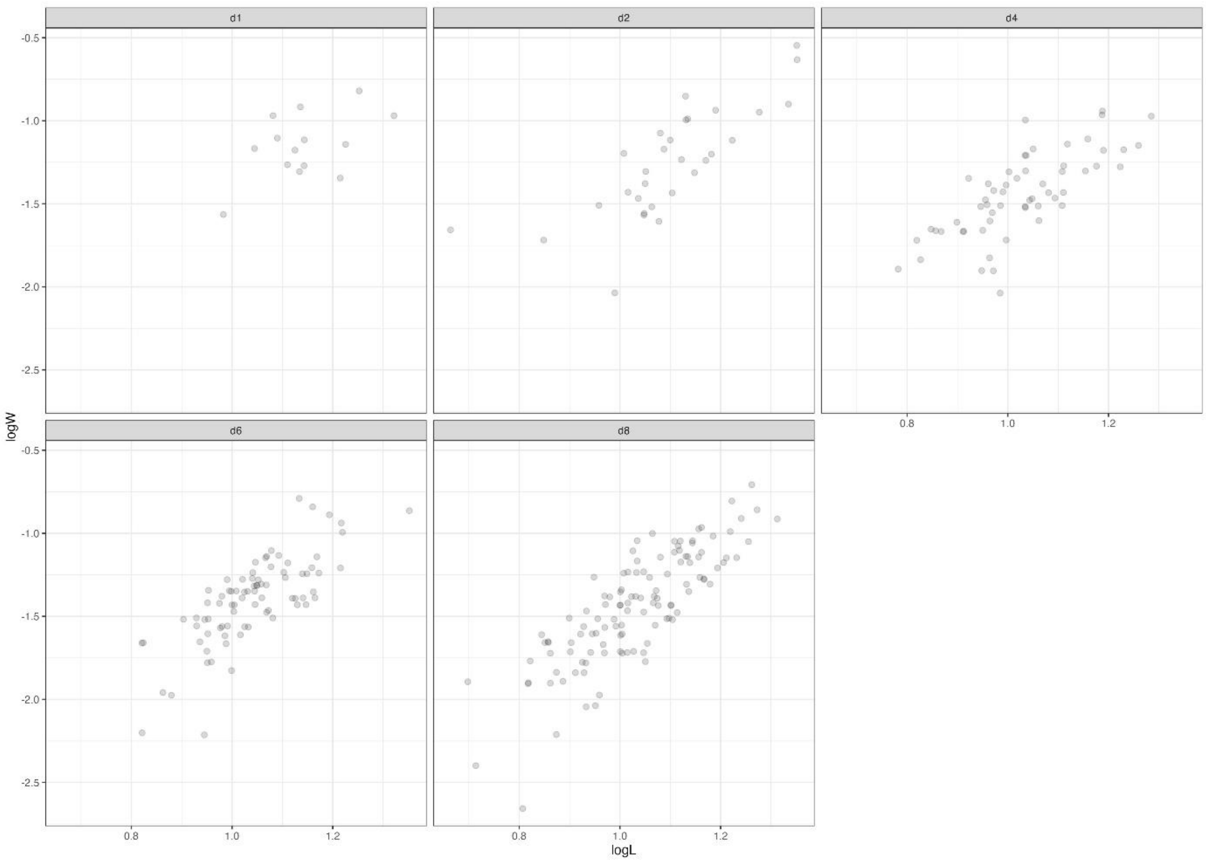

Figure 4. Scatter plots showing the relationship between the logarithm of length ("logL") and the logarithm of weight ("logW") at the end of the experiment across groups.

The d4 and d8 groups have a wider range of lengths, indicating greater variability among the lengths of juveniles. This may suggest that juveniles in these groups have different growth rates and may have been exposed to varying nutritional or environmental conditions.

In the d6 group, one or more outliers are observed. These outliers indicate that some juveniles in this group are significantly shorter than expected. This may suggest that the health or growth conditions of these juveniles are more unfavorable compared to others. The presence of outliers could negatively impact the overall growth performance of this group and is a situation that producers should be aware of.

This graph (

Figure **1**) clearly illustrates how the lengths of juvenile bristlenose pleco vary across different experimental groups. Notably, the d4 and d8 groups have longer juveniles, while the d6 group exhibits a shorter and more variable length distribution.

These findings provide important insights into understanding the effects of different stock densities on juvenile length.

As clearly seen in the graph (

Figure **1**), it can be understood that the fish in the d1 group, stocked at 1 fish per liter, and the fish in the d2 group, stocked at 2 fish per liter, may differ in total length from the other groups. It is observed that there are no differences among the other groups (d4, d6, and d8). This suggests that using stocking rates of 1 fish per liter or 2 fish per liter for juvenile bristlenose pleco may be somewhat more advantageous. However, this situation will ultimately be determined by analyzing multiple parameters, considering operational cost calculations in intensive production tanks and the specific conditions of the operation.

This study investigates the effects of different stock density ratios on the growth of juvenile bristlenose pleco (*Ancistrus multispinis*). The findings indicate that existing aquaculture practices need to be reviewed and improved. The research results reveal that stock density has a significant impact on the growth of juvenile bristlenose pleco. It was observed that lower stock densities enhance the growth performance of the fish without negatively affecting survival rates. This finding is supported by the work of Bolasina et al. (2006), which states that lower stock density increases growth performance by reducing stress levels. It is known that high stock density increases competition among fish, leading to a decrease in food resources and an increase in stress levels. A study by Karakatsouli et al. (2008) indicated that high stock density negatively affects the body moisture content of fish and results in adverse outcomes for growth. Therefore, determining the optimal stock density in bristlenose pleco aquaculture is critical for economic efficiency.

Determining the optimal stock density can affect not only growth performance but also the overall health of the fish. It should be noted that fish raised at high densities are more susceptible to diseases, which can lead to economic losses for producers. For example, the increase in stress-related diseases in fish raised at high densities can raise costs for producers (Jorgensen et al., 1993; Lambert and Dutil, 2001). Stock density is a critical parameter that significantly impacts the growth performance, health, and welfare of fish in aquaculture. As one of the many parameters to consider in fish farming, stock density directly affects the availability of food resources and water quality. Therefore, this study investigates the growth performance of juvenile bristlenose pleco, a commercially valuable aquarium fish species, at different stock densities. High stock density can increase social interactions and competition among fish, leading to elevated stress levels. Stress negatively affects the growth hormones and insulin-like growth factors in fish, adversely impacting their growth performance (Liu et al., 2017). For instance, a study conducted on goldfish (*Carassius auratus*) (Niazie et al., 2013) examined the growth and survival rates of fish stocked at densities of 6, 9, 12, and 15 fish per aquarium. Another study on guppies (*Poecilia reticulata*) reported that high stock density negatively affected growth performance (Khan et al., 2022). As a result, it was found that increasing stock density adversely affected the growth indices of fish, although survival rates did not show significant differences among different stock densities. Similar results were observed in our study, indicating that the increased stress levels due to social interactions and competition among fish held at high densities negatively affected their growth performance.

The effects of stock density vary among species (Foster and Vincent 2004). For example, a study on *Siganus rivulatus* found that experiments conducted at densities of 10, 20, 30, and 40 fish per aquarium showed no negative effects of high stock density on growth and survival rates (Saoud et al., 2008). This suggests that the social structure and behavior of this species may reduce competition even at high densities. The effects of stock density on fish growth performance are also related to stress and energy requirements (High density increases the energy requirements of fish, which can negatively impact growth and feed utilization (Leatherland and Cho, 1985). Additionally, high stock density can lead to the deterioration of water quality and the accumulation of metabolic waste, adversely affecting fish growth performance (Braun et al., 2010). Regular monitoring of water quality and the implementation of appropriate water change rates can positively influence the health and growth of fish (Ebeling and Timmons, 2012). For example, a study by Santos et al. (2020) observed that increasing water change rates improved water quality, thereby maintaining fish health and enhancing growth performance. Similarly, a study conducted on goldfish (Shete et al., 2013) reported that low stock density potentially allowed for improved water quality. The effects of stock density also vary according to the age groups of the fish. Larval stages are more sensitive to high stock density, which can lead to negative outcomes such as cannibalism, reduced feed intake, and decreased growth performance (de Barros et al., 2019; Santos et al., 2020). Therefore, determining the optimal stock density should take into account the ecological characteristics and life strategies of the species.

In this study with juvenile bristlenose pleco, it was observed that the juveniles grew better at low stock density (1 juvenile/L). This finding is consistent with studies on goldfish (*Carassius auratus*) and guppies (*Poecilia reticulata*) (Khan et al., 2022). Additionally, it is known that social behaviors also influence growth, alongside stock density. The social hierarchy and interactions among fish become particularly pronounced at high densities. For example, a study on clownfish (*Amphiprion percula*) found that changes in social interactions under high stock density conditions negatively affected growth performance. The effects of stock density vary according to the age groups of the fish. Larval stages are more sensitive to high stock density, which can lead to cannibalism, reduced feed intake, and consequently affect growth performance (de Barros et al., 2019; Santos et al., 2020). Studies have shown that determining the optimal stock density, especially at this stage, is vital. In this study, experiments were conducted during the early juvenile period to determine the optimal stock density for the bristlenose pleco species. From this perspective, it is evident that a method supported by scientific studies was applied.

The effects of stock density can also have significant implications for the overall health of the fish; it should be noted that fish raised at high densities are more susceptible to diseases, which can lead to economic losses for producers. In particular, the stress conditions caused by high stock density weaken the fish's immune system, leading to increased susceptibility to diseases (Björnsson et al., 2006). Therefore, considering these factors, it is essential to regularly monitor and improve water quality. If appropriate water quality cannot be maintained, aquaculture practices conducted at high densities can jeopardize fish health and increase production costs.

Findings on how to optimize species-specific stock density in fish farming are also important for future research. As demonstrated in this study, low stock density practices provide better growth conditions for fish. However, attention must also be paid to other factors such as water quality management, feed quality, feeding frequency, and water change strategies, in addition to stock density. For example, a study on goldfish showed that the combination of low stock density and highwater change rates improved growth performance. Furthermore, considering stock density not only as an economic factor but also acknowledging its environmental impacts is crucial for sustainable aquaculture.

In Türkiye, it appears that traditional methods commonly used in bristlenose pleco farming are not supported by modern scientific findings. It seems that current producers are hesitant to transition to new methods based on their past experiences. However, this study emphasizes the importance of implementing new methods. Optimizing stock density ratios can enhance production efficiency and economic returns. Recent research findings clearly indicate that stock density has multifaceted effects on fish species. For instance, studies on discus fish (*Symphysodon aequifasciatus*) have shown that high stock density negatively affects growth performance and leads to changes in social behavior (Chong et al., 2002). It has also been highlighted that high stock density should be considered, especially in conjunction with water change rates.

4. Conclusion

In conclusion, stock density is a multidimensional parameter that must be considered in fish farming, yielding significant biological and economic implications. Low stock density is generally associated with better growth performance, while high stock density can lead to stress and growth pressures, resulting in negative outcomes. Therefore, determining the optimal stock density in aquaculture is critical for both fish welfare and economic sustainability. Future research should provide more data on optimal stock density for different species, and this data should contribute to the development of sustainable aquaculture practices.

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Compliance with Ethical Standards

Conflict of interest
The authors declare that they have no competing interests**.**

Ethical approval
All procedures involving fish were approved by the Local Ethics Committee for Animal Experiments of Çanakkale Onsekiz Mart University (Approval date: 23.12.2022; Approval number: 2022/12-01), and were conducted in accordance with national and institutional guidelines for the care and use of animals.

Data availability
Not applicable.

Consent for publication
Not applicable.

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RESEARCH ARTICLE

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Assessment of Growth and Mortality Parameters of Four Commercial Fish Species from Lekki Lagoon Nigeria

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ABSTRACT

This study assessed the growth and mortality parameters of four commercial fish species (*Chrysichthys nigrodigitatus* (Lacepède, 1803), *Coptodon zillii* (Gervais, 1848), *Ethmalosa fimbriata* (Bowdich, 1825) and *Elops lacerta* (Valenciennes, 1847) from Lekki Lagoon, Nigeria. Fish specimens were collected monthly from five landing sites (Wharf, Agbalegiyo, Ebute-Oni, Ilumofin and Luboye). Specimens were collected using proportional sampling based on the level of fishing activities between January and December, 2022. Estimation of growth parameters was performed according to the growth equation: $L_t = L_\infty - (1- e^{-K(t-to)})$ by von Bertalanffy with the Length Frequency Data Analysis (LFDA) package. The length-converted catch curve model was adopted for the estimation of mortality parameters using FiSAT II software. Results showed that *C. nigrodigitatus* exhibited the highest growth rate (K = 1.30 yr^{-1}) and exploitation rate (E = 0.83) with an asymptotic length ($L\infty$) of 53.94 cm. However, *C. zillii* exhibits the lowest growth curvature (K = 0.44 yr^{-1}) with $L\infty$ = 39.15 cm and an exploitation rate of 0.42. *E. fimbriata* showed a rapid growth rate (K = 1.15 yr^{-1}) but low exploitation (E = 0.12), while *E. lacerta* exhibited moderate growth rate (K = 0.58 yr^{-1}) and low exploitation (E = 0.16). It is concluded that *C. nigrodigitatus* is overfished in the lagoon, which demands a closed season and small mesh size restriction to prevent recruitment overfishing. The low exploitation levels of *E. fimbriata* and *E. lacerta* means that these stocks are currently sustainable, but there is a need to monitor them to avoid future over-exploitation.

KEYWORDS: Fish, Sustainability, Population dynamics, Brackish water

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1. Introduction

Fish remains a common source of protein, especially in developing countries. The decline in fish stocks in tropical waters poses challenges of insufficient food availability and unemployment for the growing populations (Belhabib et al., 2019; Chan et al., 2021). It is reported that more than 50 % of coastal communities in the tropics rely on fish products as their major means of survival and source of protein (FAO, 2022). According to the 2021 report of the Federal Department of Fisheries and Aquaculture (FDFA), domestic fish production in Nigeria stands at about 1.1 m tonnes which is only 31% of the country's annual fish demand of 3.5 million tonnes. This wide gap between the quantity of fish produced and the amount demanded makes Nigeria a net importer of fish (Chan et al., 2021). Recent statistics by the Food and Agricultural Organization show that fish consumption in the African region is relatively low with an estimated 10.1 kg per capita per year in 2020 compared to the recommended global threshold of 20.2 kg per capita (FAO, 2022). One of the major reasons for this low production is attributed to the decline in wild stocks as a result of overfishing (Doumbouya et al., 2017). The catch trend of major fish stocks has declined as high as 20-30 % over the last two decades. This decline is reported to have occurred mostly in coastal waters dominated by artisanal and small-scale fisheries. Globally, about 35 % of fish stocks were reported as over-exploited in 2019 which is about a 10 % rise in the last 5 decades indicating a steady decrease in sustainable fish stocks as a result of over-exploitation and ineffective management policies (FAO, 2022).

Fish stock assessment remains a valuable tool for fisheries managers. It provides essential information on the growth indices of fish species and their mortality parameters which are crucial in making accurate decisions for sustainable management and conservation of these aquatic resources (Abdul et al., 2023). Furthermore, through fish stock assessment, responsible fishing practices that ensure sustainable utilization of aquatic resources are encouraged, thus improving the livelihood of fishing communities (Santo et al., 2022). Fish stock assessments therefore are the right tool for maintaining ecological stability and economic well-being. To proffer solutions to challenges like overfishing and pollution for the sustenance of coastal waters and their biodiversity, efforts from all stakeholders are required. Assessment of fish stocks can be carried out with length-frequency data (Pasisingi et al., 2021). Traditional methods for estimating fish growth rely on measuring both the length and age of fish species (Quinn and Deriso 1999;) which could be costly and tedious as a result of inconsistent early growth trends.

Lekki Lagoon is a habitat for various species including *Chrysichthys nigrodigitatus* (Lacepède, 1803), *Coptodon zillii* (Gervais, 1848), *Ethmalosa fimbriata* (Bowdich, 1825) and *Elops lacerta* (Valenciennes, 1847) and many other fishes, all exhibiting different growth patterns influenced by its unique environmental conditions of both fresh and marine water, making it brackish water (Emmanuel and Chukwu, 2010; Abdul, 2015; Akinsanya et al., 2021). Few studies by Abdul et al. (2012) and Abdul (2015) have provided information on the growth and mortality indices in the lagoon. Thus, there is insufficient information on the population dynamics of these commercial fish stocks. Therefore, this paper aims to make available the latest information on the growth and mortality parameters of these selected fish stocks for effective management and conservation strategies.

2. Materials and Methods

2.1 Study Area

This study was conducted in Lekki Lagoon. Lekki Lagoon is situated on latitude 4°00' and 4°15' E and longitude 6°25' and 6°37' N in Nigeria (Figure 1). The lagoon is about 64 m deep with a surface area of 247 m^2 (Akinsanya et al., 2019). It is a combination of wetlands from different creeks along the southwestern coast of Nigeria. The lagoon extends about 200 km from the Dahomey border to the Niger Delta (Adekoya, 1995). The freshwater Epe Lagoon is connected to it to the east, while the brackish water Lagos Lagoon runs into the coastal water body from the west (Akinsanya et al., 2019).

2.2 Sampling Procedures

Specimens were collected from five landing sites (Wharf, Agbalegiyo, Ebute-Oni, Ilumofin, and Luboye) using proportional sampling which depended on the level of fishing activities. Sampling was carried out between January – December 2022. A total of 18,001 fish specimens of the selected fish stocks were collected from the local commercial fishermen immediately after harvesting using various fishing gear types which were seine nets, gillnets, cast nets, and traps. Fish identification keys (Olaosebikan and Raji, 2013) were used in identifying samples at the species level. Fish specimens were measured from the end of the snout to the tip of the caudal fin to the nearest ±0.1 cm for the total length (TL) using an ichthyoboard, while the weight was taken at the nearest ±0.01 g using an electronic weighing balance (MH-999) according to Dienye et al. (2021). Fish specimens for *E. lacerta* were not landed for January, November, and December during the study period.

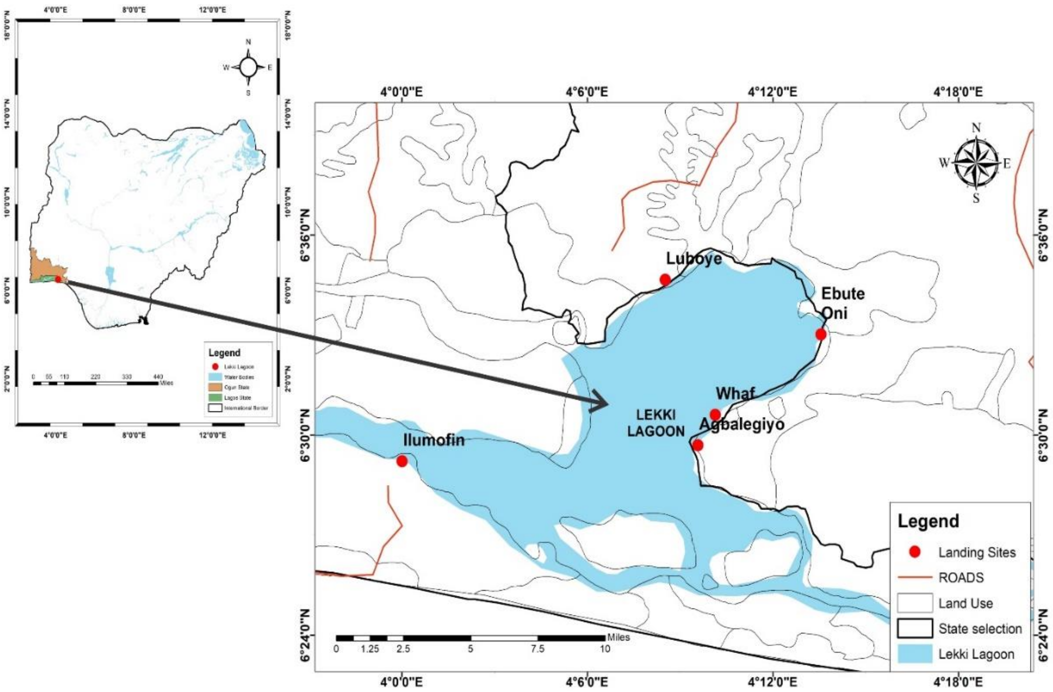

Figure 1. Study area showing sampling sites (Source: Field Survey, 2022)

2.3 Growth parameters

The length-frequency data were analyzed using Length Frequency Distribution Analysis software (LFDA) version 5.0 (Kirkwood et al., 2003) developed by the Marine Resources Assessment Group (MRAG), United Kingdom. Data collected were pooled monthly and sorted into a class size of 1 cm and the number of occurrences was recorded against every class size for all selected fish species. This grouped data was then entered into the LFDA software taking note of the sample timings by entering the dates for sample collection. The growth parameters estimated were considered to align with the growth equation: $L_t = L_\infty (1- e^{-K(t-to)})$ of von Bertalanffy (Sparre and Venema, 1992). Estimation of the von Bertalanffy growth parameters: asymptotic length (L_∞), growth coefficient (K), and hypothetical age (t_o) were determined by grid boundaries using Electronic Length Frequency Analysis (ELEFAN) as reported by Maguza-Tembo et al. (2009). Data and frequency plots were carried out using the 'Data'.

2.4 Mortality parameters (Z, M, F)

The parameters $L\infty$ and K were used as input to length-converted catch curve analysis to obtain estimates of the total annual instantaneous mortality (Z) following (Ricker W, 1980):

$N(t) = N_0 e^{-Zt}$;

N (t) is the number of survivors at time t; N_0 is the initial number of individuals at time t_0 taken as origin; Z is the total mortality.

Natural mortality (M) was estimated using the empirical formula of (Pauly D, 1980):

$Log (M) = -0.0066 - 0.2790 Log (L\infty) + 0.6543 Log (K) + 0.4634 Log (T)$;

With *"T"* as the mean environmental temperature (°C).

The mean annual habitat temperature for the current study was 28.55°C.

The fishing mortality rate (F) was calculated as:

$F = Z-M$ (Abowei et al., 2010).

The exploitation rate (E) was computed as:

$E = F/Z$ (Pauly, 1985).

The exploitation rate indicates whether the stock is lightly ($E < 0.5$) or strongly ($E > 0.5$) exploited, based on the assumption that the fish are optimally exploited when F = M or E = 0.5 (Gulland, 1971).

3. Results

3.1 Length Frequency Distribution

Figure 2 shows that *C. nigrodigitatus* exbited a wide size range of 5.5 cm – 64.0 cm TL. The highest frequency occurred between sizes 12.0-16.9 cm TL and the lowest at both extremes. *C. zillii* from the lagoon (Figure 3) exhibits a skewed distribution, with the highest frequencies between 15.0-17.9 cm and much lower frequencies at both smaller (8.2-10.9 cm TL) and larger (30.0-36.8 cm) sizes. The length distribution for *E. fimbriata* (Figure 4) presents a smaller size range of 6.4 – 22.5 cm TL. A single peak appears between length sizes 10.0-11.9 cm TL while very low frequencies exist beyond this size. *E. fimbriata* shows a distribution that could be suggestive of a population dominated by a few cohorts or size groups. *E. lacerta* (Figure 5) however presents a bimodal distribution within the range of 12.8 to 25.2 cm TL, with peaks at 15.0-16.9 cm TL and 23.0-24.9 cm TL, and very low frequencies in between.

3.2 Growth Parameters

The fitted non-seasonal von Bertalanffy Growth Function using ELEFAN of the four fish species is presented in Figures 6 – 9. The asymptotic lengths (L_∞) of *C. nigrodigitatus*, *C. zillii*, *E. fimbriata*, and *E. lacerta* were calculated as 53.94, 39.15, 22.14, and 28.40 cm, respectively. *C. nigrodigitatus* recorded the highest growth rate (1.30 yr^{-1}) while *C. zillii* had the smallest growth rate of 0.44 yr^{-1}. The age of the fish species at zero length (t_0) were -0.16, -0.73, -0.23, and -0.18 for *C. nigrodigitatus*, *C. zillii*, *E. fimbriata*, and *E. lacerta*, respectively.

3.3 Mortality Parameters

Estimations for mortality parameters from the linearized length-converted catch curve analysis by FiSAT software are presented in Table 1. *C. nigrodigitatus* has a total mortality rate (Z) of 10.67 yr^{-1} with a natural mortality rate (M) of 1.82 yr^{-1} and fishing mortality rate (F) of 8.85 yr^{-1} giving a high exploitation rate (E) of 0.83. Mortality parameters for *C. zillii* are 1.70 yr^{-1}, 0.98 yr^{-1}, 0.72 yr^{-1}, and 0.42 for total mortality, natural mortality, fishing mortality, and exploitation rates, respectively. Fishing mortality and exploitation rates for *E. fimbriata* and *E. lacerta* are (0.28 yr^{-1} and 0.12) and (0.25 yr^{-1} and 0.16), respectively.

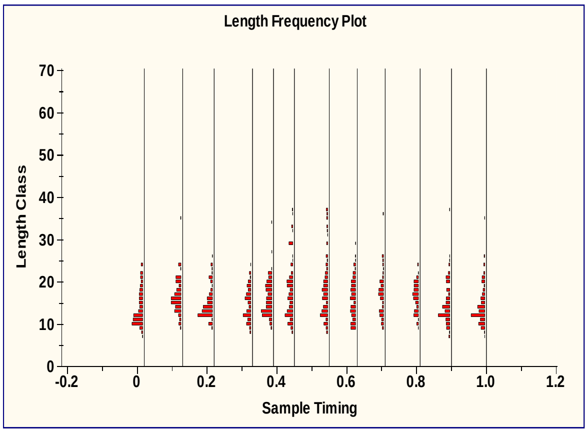

Figure 2. Length-frequency distribution output from LFDA for *Chrysichthys nigrodigitatus* from Lekki Lagoon

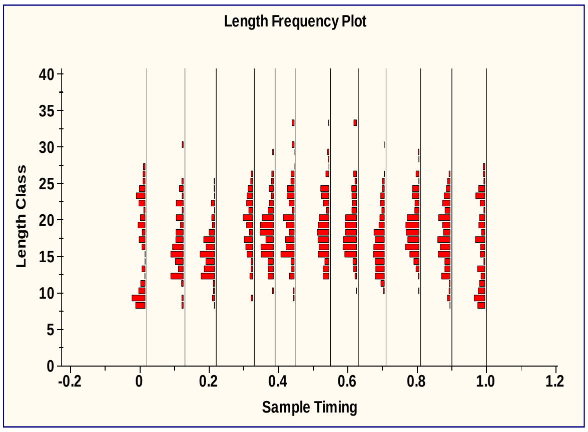

Figure 3. Length-frequency distribution output from LFDA for *Coptodon zillii* from Lekki Lagoon

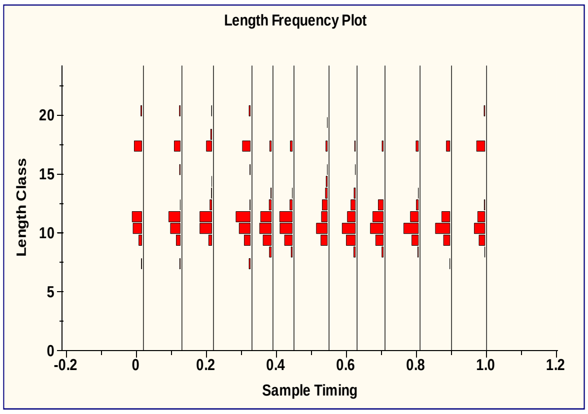

Figure 4. Length-frequency distribution output from LFDA for *Ethmalosa fimbriata* from Lekki Lagoon

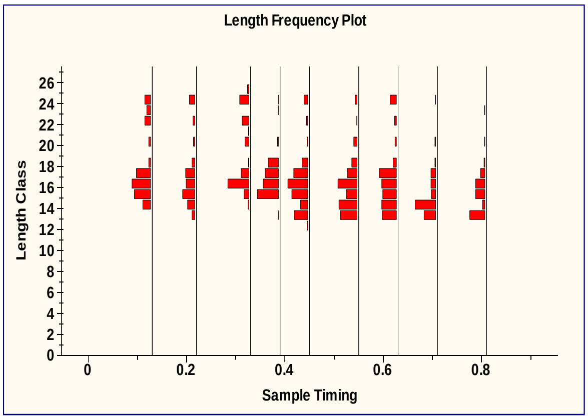

Figure 5. Length-frequency distribution output from LFDA for *Elops lacerta* from Lekki Lagoon

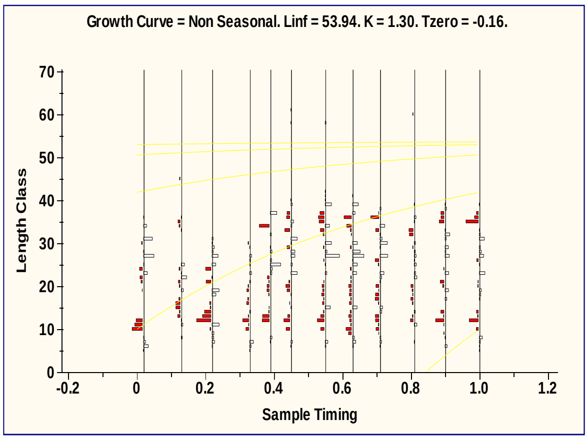

Figure 6. Converted (fitted) non-seasonal growth curve from LFDA for *C. nigrodigitatus* from Lekki Lagoon
Hint: Yello line-von Bertalanffy growth model fit

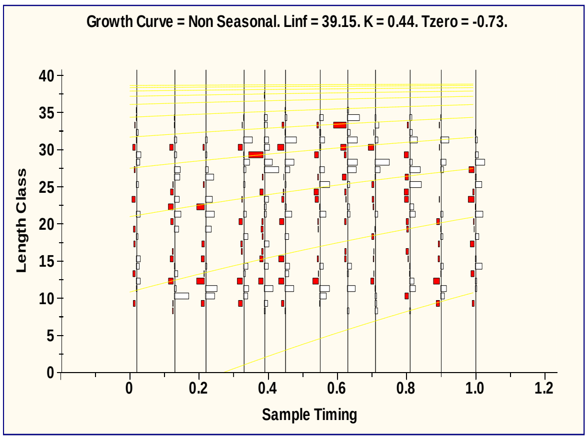

Figure 7. Converted (fitted) non-seasonal growth curve from LFDA for *C. zillii* from Lekki Lagoon
Hint: Yello line-von Bertalanffy growth model fit

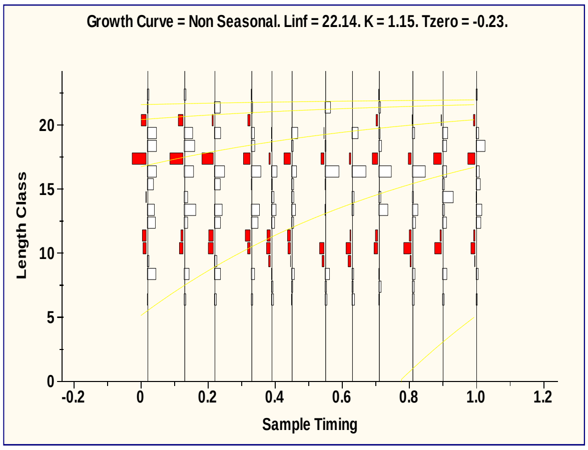

Figure 8. Converted (fitted) non-seasonal growth curve from LFDA for *E. fimbriata* from Lekki Lagoon
Hint: Yello line-von Bertalanffy growth model fit

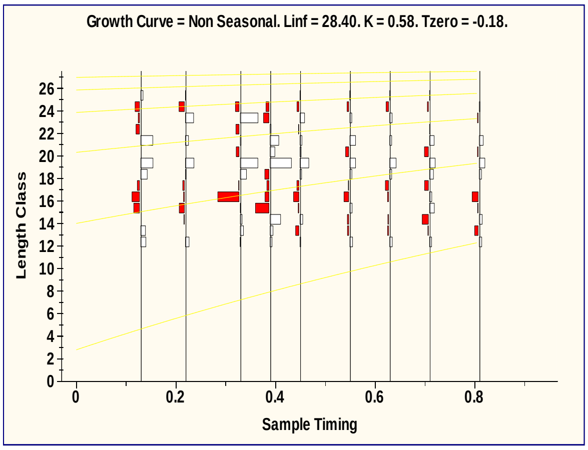

Figure 9. Converted (fitted) non-seasonal growth curve from LFDA for *E. lacerta* from Lekki Lagoon
Hint: Yello line-von Bertalanffy growth model fit

Table 1: Estimated mortality parameters of selected fish species in Lekki Lagoon

Fish Species	**Z (yr^{-1})**	**M (yr^{-1})**	**F (yr^{-1})**	**E**
Chrysichthys nigrodigitatus	10.67	1.82	8.85	0.83
Coptodon zillii	1.70	0.98	0.72	0.42
Ethmalosa fimbriata	2.43	2.15	0.28	0.12
Elops lacerta	1.53	1.28	0.25	0.16

Key: Z= Total mortality, M = Natural mortality, F = Fishing mortality and E= Exploitation rate

4. Discussion

4.1 Length Frequency Distributions

The length-frequency distributions observed for the four fish species in Lekki Lagoon presents information on the population structure and exploitation patterns. The total length of *Chrysichthys nigrodigitatus* ranged between 5.0 and 64.9 cm TL which shows a wide population spread. This is in agreement with the research of Abdul (2015) who reported active recruitment and exploitation of young individuals in the same lagoon. The length size recorded by *C. nigrodigitus* in current study is however dissimilar with the findings of Amponsah (2024) in Lake Volta, Ghana who reported smaller maximum lengths. This could be due to differences in fishing gear selectivity, lagoon productivity and fishing pressure. *Coptodon zillii* exhibited a length distribution skewed toward smaller individuals with dominant sizes between 15.0–17.9 cm TL. An explanation to this distribution pattern could be the widespread use of small-mesh nets as reported by Abdul et al. (2012). Amponsah (2024) also reported similar modal sizes from Lake Volta. This means that the fish species is under comparable exploitation pressure across regions. The narrow size range (6.0–22.9 cm TL) and dominant modal length (10.0–11.9 TL) cm exhibited by *Ethmalosa fimbriata* shows that recruitment comprised primarily juvenile individuals. This is in agreement with findings by Ama-Abasi and Holzloehner (2002) in the Cross River Estuary, where distinct juvenile and adult size classes were reported. The reason for the smaller sizes recorded in Lekki Lagoon could be due to environmental differences specifically lower salinity levels which can constrain the distribution and growth of the fish species. *Elops lacerta* shows a bimodal length distribution (12.8–25.2 cm TL) with frequencies being highest at 15.0–16.9 cm TL and 23.0–24.9 cm TL. This could mean the presence of at least two active cohorts within the population. Loukou et al. (2021) reported broader range and larger sizes in the Ivorian exclusive economic zone. A possible explanation could be that there reduced fishing pressure and better migratory routes in open coastal waters. The partial enclosure of the Lekki Lagoon could be the reason for the presence of limited maximum sizes. Another reason may be that fishing pressure is higher in Lekki Lagoon.

4.2 Growth Parameters

Growth parameters are critical in carrying out stock assessments. Growth coefficient (K) refers to the rate at which a fish grows to its final size while the maximum theoretical mean length that it can attain if it grows throughout its life in a natural habitat is called the asymptotic length (L_∞) (Dienye et al., 2021). These growth dynamics presents species-specific life history traits and are influenced by ecological conditions (Rangely et al., 2023). *C. nigrodigitatus* recorded an asymptotic length (L_∞) and growth coefficient (K) of 53.94 cm and 1.30 yr^{-1}, respectively. This is dissimilar with the findings of Martin et al. (2021) in Aghien Lagoon, Côte d'Ivoire (L_∞ = 38.1 cm SL, K = 0.48 yr^{-1}). The growth parameters recorded for *C. nigrodigitatus* in this present study are also different from those reported by Abdul (2015) who recorded a smaller asymptotic length (L_∞) of 49.88 cm and a higher growth coefficient (K) of 1.45 yr^{-1} for *C. nigrodigitatus* from the same lagoon. Furthermore, the current findings contradict the result of Ouattara et al. (2023) in Buyo Lake of Côte d'Ivoire. They estimated a higher asymptotic length (L_∞ = 69.35 cm) and a slower growth rate of 0.78 year^{-1} and reported that the species exhibited a long survival time in the lake. Fish species with higher growth coefficients generally grow faster to their asymptotic length. Phenotypic plasticity is conferred by fish maturing at smaller sizes in response to fishing pressure, which may explain the lower K value recorded in the present study. Amponsah (2024) however, reported similar values, a lower L_∞ (27.3 cm) but moderately high K (0.57 yr^{-1}) for the same species in Lake Volta.

C. zillii recorded an L_∞ of 39.15 cm and a low K of 0.44 yr^{-1} which is consistent with previous estimates in West African waters by Amponsah (2024) who reported L_∞ = 30.4 cm and K = 0.38 yr^{-1}. These values are associated with relatively slow-growing species with a longer lifespan. An explanation for the lower K value recorded may also be associated with a stable habitat and reduced metabolic demands especially in less turbulent lagoon environments. The values for asymptotic length and growth rate for *E. fimbriata* in the present study were 22.14 cm and K = 1.15 yr^{-1}. This means that *E. fimbriata* is a short-lived but fast-growing species. This is similar with findings of Ama-Abasi and Holzloehner (2002), who documented high growth rate by the fish species even though their modal lengths extended to 33 cm in coastal habitats larger than those seen in Lekki Lagoon. The discrepancy may be as a result of differences in environmental variables as the species thrives in saline conditions which are more prominent in estuarine and coastal environments unlike Lekki Lagoon which is predominantly a freshwater ecosystem. Moreso, *E. lacerta* showed moderate growth with L_∞ = 28.40 cm and K = 0.58 yr^{-1}. This is similar to estimates by Dienye et al. (2021) in Obuama Creek (L_∞ = 30.13 cm, K = 1.1 yr^{-1}) but much lower than Loukou et al. (2021) in Côte d'Ivoire (L_∞ = 60.38 cm, K = 0.39 yr^{-1}). The lower maximum size in Lekki Lagoon could be attributed to restricted migratory pathways and habitat fragmentation compared to the Ivorian exclusive economic zone which is more or less an open marine ecosystem. Several factors such as environmental conditions, fishing pressure, food availability, pollution levels and habitat type could be responsible for the overall variation in growth parameters among species and across regions (Santos et al., 2022).

4.3 Mortality Rates

Mortality estimates are responsible for the assessment of the sustainability of fish populations under exploitation. *C. nigrodigitatus* presents the highest total mortality (Z = 10.67 yr^{-1}) and fishing mortality (F = 8.85 yr^{-1}) with an exploitation rate (E = 0.83) which is much higher than the optimal exploitation level (E = 0.5). This indicates severe overfishing similar with findings by Martin et al. (2021) in Aghien Lagoon (E = 0.74), thus suggesting the need for urgent regulatory intervention such as closed seasons or gear restrictions. *C. zillii* on the other hand presented lower mortality values (Z = 1.70 yr^{-1}; F = 0.72 yr^{-1}) and an exploitation rate (E = 0.42) which is close to the sustainable threshold. This means that the fish species is optimally exploitated in the lagoon. This result corroborates the reports of *C. zillii* been prolific, thus sustaining its population. Incidentally, Amponsah (2024) reported a similar exploitation rate (E = 0.42) for the same species in Lake Volta, although his study indicated underexploitation based on E_{msy} = 0.56 which requires ecosystem-specific benchmarks. A relatively low fishing mortality (F = 0.28 yr^{-1}) and an exploitation rate of 0.12 was recorded by *E. fimbriata*. This means that it is significantly underexploited. The low fishing pressure shows that the stock is currently sustainable despite the high natural mortality (M = 2.15 yr^{-1}). This could be due to the low salt content of the lagoon that may act as a partial refuge. The present study supports the reports of Ama-Abasi and Holzloehner (2002) which stated the ecological importance of estuarine habitats as nursery grounds for the fish species. Similary, *E. lacerta* recorded low fishing mortality (F = 0.25 yr^{-1}) and an exploitation rate of 0.16. These values are consistent with the values reported by Loukou et al. (2021) who documented an exploitation rate, of 0.49 in Côte d'Ivoire. The fish species is also underfished as the values of the current study fall below the sustainable limit. The fishing mortality recorded in this study is also similar with value reported by Dienye et al. (2021).

5. Conclusion

Relevant information on population dynamics has been provided by this study on the growth and mortality rates of the four fish species. *Chrysichthys nigroditatus* and *Ethmalosa fimbriata* were more exploited, thus exhibiting rapid growth and high mortalities. Management measures such as size limits, closed season, and small mesh size regulations are required to avoid recruitment overfishing of these fishes. It is also important to monitor the populations of *Coptodon zillii* and *Elops lacerta* to avert any future over-exploitation. Therefore, the collaborative efforts of all stakeholders in the fisheries sector are required to ensure the sustainability of fishery resources in the lagoon.

Compliance with Ethical Standards

Conflict of interest

The authors declare that they have no competing interests.

Ethical approval

Ethics committee approval is not required.

Data availability

Not applicable.

Consent for publication

Not applicable.

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ARAŞTIRMA MAKALESİ

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Ergani Baraj Gölünün (Diyarbakır) Su Kalitesi Özellikleri

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ÖZET

Bu çalışma, Ergani Baraj Gölü (Diyarbakır) su kalitesi kriterlerinin incelenmesi amacıyla Haziran 2021- Haziran 2022 yılları arasında aylık örneklemeler üzerinden yürütülmüştür. Yerinde yapılan ölçümlerde ortalama su sıcaklığı 19.0 °C, Eİ 344.6 µS/cm, ÇO 9.8 mg/L, OD %115.4, tuzluluk ‰ 0.20 ve pH 8.4 mg/L olarak bulunmuştur. Laboratuvar analizlerinde ise ortalama bulanıklık 10.5 NTU, AKM 12.3 mg/L, Ca 51.0 mg/L, Mg 20.8 mg/L, Na 5.8 mg/L, toplam sertlik 212.8 mg/L, toplam alkalinite 164.5 mg/L, CO_3 8.2 mg/L, HCO_3 186.6 mg/L, NO_2 0.02 mg/L, NO_2-N 0.01 mg/L, NO_3 2.7 mg/L, NO_3-N 0.6 mg/L, SO_4 23.4 mg/L, NH_3 0.18 mg/L, NH_3-N 0.15 mg/L, NH_4 0.19 mg/L, PO_4 0.16 mg/L, Zn 0.15 mg/L, Al 1.9 µg/L, Fe 0.02 mg/L, Ni 0.01 mg/L, Co 0.02 mg/L, Mn 0.05 mg/L, Mo 0.2 mg/L, Cr 0.003 mg/L, CN 0.001 µg/L, F 0.19 mg/L, K 1.7 mg/L, Si 1.4 mg/L ve SiO_2 3.0 mg/L olarak belirlenmiştir. Çalışmada bakır, ölçüm aralığı altında bulunmuştur. Yapılan analizlerin mevzuata göre değerlendirilmesi sonucu içme suyu olarak kullanılabilmesi için bulanıklık ve askıda katı madde açısından TS 266'ya göre önlem alınması gerektiği belirlenmiş, tüm parametreler YSKY, EU ve WHO'ya göre de değerlendirmeler yapılmıştır.

ANAHTAR KELİMELER: Ergani Baraj Gölü, Su kalitesi, Diyarbakır.

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Water Quality Properties of Ergani Dam Lake Water, Diyarbakır-Türkiye.

ABSTRACT

This study, was carried out on monthly samples between June 2021 and June 2022 in order to examine the water quality criteria of Ergani Dam Lake (Diyarbakır). In field measurements were found as average water temperature 19.0 °C, EC 344.6 µS/cm, dissolved oxygen 9.8 mg/L, oxygen saturation %115.4, salinity ‰ 0.20 and pH 8.4 mg/L. Laboratory analyzes were found as average turbidity 10.5 NTU, total suspended solid 12.3 mg/L, Ca 51.0 mg/L, Mg 20.8 mg/L, Na 5.8 mg/L, total hardness 212.8 mg/L, total alkalinity 164.5 mg/L, CO_3 8.2 mg/L, HCO_3 186.6 mg/L, NO_2 0.02 mg/L, NO_2-N 0.01 mg/L, NO_3 2.7 mg/L, NO_3-N 0.6 mg/L, SO_4 23.4 mg/L, NH_3 0.18 mg/L, NH_3-N 0.15 mg/L, NH_4 0.19 mg/L, PO_4 0.16 mg/L, Zn 0.15 mg/L, Al 1.9 µg/L, Fe 0.02 mg/L, Ni 0.01 mg/L, Co 0.02 mg/L, Mn 0.05 mg/L, Mo 0.2 mg/L, Cr 0.003 mg/L, CN 0.001 µg/L, F 0.19 mg/L, K 1.7 mg/L, Si 1.4 mg/L and SiO_2 3.0 mg/L. In the study, copper was found under the measurement range. As a result of the evaluation of the analyzes made according to the legislation, it was determined that precautions should be taken in terms of turbidity and suspended solids according to TS 266 in order to be used as drinking water, and all parameters were evaluated according to YSKY, EU and WHO.

KEYWORDS: Ergani Dam Lake, Diyarbakır, Water Quality.

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1. Giriş

Canlıların yaşam kaynağı olan, medeniyetin temel simgelerinden olan ve aynı zamanda yaşam ortamı olan su, dünyada en fazla bulunan ama kullanılabilir miktarı kıt olan bir maddedir. Su, nüfus artışı ve endüstriyel gelişim nedeniyle aşırı kirlenmesinden dolayı son yıllarda önemi giderek artmaktadır (Şen, 2016). Yaşamın temel unsurlarından biri olan su, aynı zamanda medeniyetin gelişiminde vazgeçilmez bir unsurdur (Gümüş vd., 2013).

Yeryüzünün %71'inin sularla kaplı olduğunu, bu suların %97'sinin okyanuslarda ve denizlerde olduğunu, geriye kalan %3'lük suyun %2,997'sinin buzullarda, %0,003'lük kısmının ise göllerde, akarsularda ve yeraltı sularda olduğunu, dünyadaki su kütlesinin insanlar tarafından kullanılabilir bakımından pek te fazla olmadığını ve yegane en değerli nesnenin su olduğunu belirtmiştir (Bhandari, 2003).

Dünyadaki tatlısu aynaklarında bir artış olmadığından ve hali hazırda var olan kaynakların kirlenme nedeniyle kullanılamaz hale gelmesinden dolayı, temiz suya olan gereksinim her geçen gün artmaktadır (Akgül, 2006). Bu nedenlerden dolayı, mevcut su kaynakların kalitesini belirlemek ve devamlı izlemek için çalışmaların sürekli olarak yapılması büyük bir önem sahiptir.

2019 yılında faaliyete alınan Ergani Baraj Gölü'nün su kalitesi kriterleri hakkında şu ana kadar herhangi bir çalışmaya rastlanmamıştır. Bu çalışma ile bölge için önemli bir su kaynağı olan baraj gölünün su kalitesi özellikleri incelenmiştir. Çalışma kapsamında alınan su numunelerinde ağır metal ve fizikokimyasal parametreler ulusal ve uluslararası mevzuatlara göre değerlendirilerek mevcut durumun belirlenmesi amaçlanmıştır.

2. Materyal ve Metot

Diyarbakır'ın kuzeybatısında yer alan Ergani ilçesi sınırları içinde bulunan Ergani Baraj Gölü (Şekil 1), temelden 54 m yüksekliğinde, yaklaşık 14 milyon metreküp suyu depolama kapasitesine sahip, sulama amaçlı inşa edilmiş, 1.861 hektar tarım alanının sulamasına katkı sağlamaktadır. Baraj gölünde Haziran 2021-Haziran 2022 tarihleri arasında 38°15'54.91" Kuzey enlemi ve 39°41'28.32" Doğu boylamı koordinatlarında bulunan baraj bendi bölgesinden aylık olarak yerinde ölçümlerle su sıcaklığı, tuzluluk, elektriksel iletkenlik (Eİ), çözünmüş oksijen (ÇO), oksijen doygunluğu (OD) ve pH HACH 40D marka multimetre ile, alınan su örneklerinde DSİ Laboratuvarında Thermo Scientific-Dionex marka iyon kromatografi cihazıyla sodyum (Na), Van YYÜ Su Ürünleri Fakültesi Su Kalitesi ve DSİ Laboratuvarında titrimetrik yöntemlerle Kalsiyum (Ca), Magnezyum (Mg) ve Toplam Sertlik (TS), klorür (Cl), Karbonat (CO_3), Bikarbonat (HCO_3) ve Toplam Alkalinite (TA) (APHA, 1989; Çetinkaya, 2003), HACH 2100Q marka Türbidimetre cihazıyla bulanıklık, HACH DR 5000 spektrofotometre cihazı ile HACH standart metotları kullanılarak Askıda Katı Madde (AKM), Nitrat (NO_3), Nitrat Azotu (NO_3-N), Nitrit (NO_2), Nitrit Azotu (NO_2-N), Amonyum (NH_4), Amonyak (NH_3), Amonyak Azotu (NH_3-N), Fosfat (PO_4), Fosfor (P), Fosfor Oksit (P_2O_5), Sülfat (SO_4), Potasyum (K), Bakır (Cu), Alüminyum (Al), Çinko (Zn), Demir (Fe), Florür (F), Silisyum (Si), Silisyum Oksit (SiO_2), Molibden (Mo), Mangan (Mn), Nikel (Ni), Kobalt (Co), Krom (Cr) ve Siyanür (CN) analizleri yapılmıştır (HACH, 2010).

Şekil 1. Ergani Baraj Gölü (Google earth, 10.02.2025).

Çalışmadan elde edilen sonuçlar; Türkiye İçme Suyu Standardı (TS 266), Yerüstü Su Kalitesi Yönetmeliğ (YSKY), Dünya Sağlık Örgütü (WHO) ve Avrupa Birliği'ne (EU) göre değerlendirilmiştir.

3. Bulgular ve Tartışma

Dicle Nehrine dökülen ve Boğaz Deresi üzerinde kurulmuş olan Ergani Baraj Gölü sularından elde edilen yerinde ölçümler ve titrimetrik analizlerden elde edilmiş olan sonuçlar Tablo 1'de, fizikokimyasal analiz sonuçları Tablo 2'de ve metal analizi sonuçları Tablo 3'te verilmiştir.

Ergani Baraj Gölü'nde su sıcaklığı 6.0-31.5°C arasında, ortalama 19.0°C olarak ölçülürken (Tablo 1), Kaya (2023), Devegeçidi Baraj Gölü'nde 21.1 ºC, Baykal vd. (2004), Devegeçidi Baraj Gölü'nde 3-28ºC, Sepil (2020), Nemrut Krater Gölü'nde 18.10 ºC olarak ölçmüştür. Su sıcaklığı bakımından Ergani Baraj Gölü YSKY'ye göre I. kalite sınıfı içinde yer almıştır (YSKY, 2015). TS 266 (2005) göre tavsiye edilen sınırlar içerisinde yer almaktadır (TSE, 2005). Ayrıca Ergani Barajındaki su sıcaklığı yıl boyunca değerlendirildiğinde ekim ve nisan ayları arasında 6 ay süreyle alabalık yavrularının ağ kafeslerde büyütülmesinin uygun olacağı kanaatine varılmıştır.

Ergani Baraj Gölü'ndeki çözünmüş oksijen miktarı 7.1-12.9 arasında, ortalama 9.8 mg/L ve oksijen doygunluk (OD) değeri % 115.4 olarak ölçülmüştür (Tablo 1). Kaya ve Şen (2022) Kabaklı Göleti'nde 9.4 mg/L, Sepil (2020), Nemrut Krater Gölü'nde 9.72 mg/L, Varol (2010), Dicle Barajı'nda 8.18-13.25 mg/L, Şen ve Şekerci (2019) Karasu'da 10.03 mg/L, Bulum (2015), Bendimahi'de 10.86 mg/L olarak ölçmüştür. Bu çalışmanın ortalama çözünmüş oksijen değeri YSKY'ye (2015) göre su kalite sınıflarından I. sınıf olarak ölçülmüştür (YSKY, 2015).

Ergani Baraj Gölü'nden alınan su örneklerinde ortalama tuzluluk değeri ‰ 0.2 olarak hesaplanmıştır. Çalışmadaki Cl değeri ise 5.3 mg/L (Tablo 1) olarak belirlenmiş olup, YSKY ve TS 266 göre 1. sınıf kalitede olduğu belirlenmiştir (TSE, 2005; YSKY, 2015).

Çalışma sularında ortalama elektriksel iletkenlik değeri 344.6 µS/cm (Tablo 1) olarak belirlenirken, Kaya (2023), Devegeçidi Baraj Gölü'nde 406.8 µS/cm, Sepil (2020), Nemrut Krater Gölü'nde 434.20 µS/cm, Bekleyen (1993) Kabaklı Göleti'nde 210–230 µS/cm, Bayram (2016), Güzelkonak Deresi'nde 350 µS/cm olarak belirtmişlerdir. Ergani Baraj Gölü'ndeki Eİ değeri; YSKY göre I. sınıf, TS 266'da (2005) ve EU'da belirtilen değerlere uygun olduğu bulunmuştur (TSE, 2005; YSKY, 2015; EU, 2023).

Çalışmanın ortalama pH değeri 8.4 iken (Tablo 1), Kaya ve Şen (2022) Kabaklı Göleti'nde 8.58, Şen ve Aksoy (2015), Bulakbaşı Suyu'nda 7.85-8.83 aralığında olduğunu bildirmişlerdir. Çalışmanın pH değeri hafif alkali özellikte olup, YSKY'ya göre I. sınıf su kalitesindedir (YSKY, 2015). pH değeri bakımında; Ergani Baraj Gölü suları hem balık yetiştiriciliği (pH 6.5-9.0) için hem de TS 266'ya (2005) göre de ≥ 6.5 ve ≤ 9.5 arasında olduğundan içme suyu açısından uygundur (Türkman vd. 1999; Emre ve Kürüm, 2007). Ayrıca EU'da (2023) verilen sınır değerleri arasında kaldığı tespit edilmiştir (EU, 2023).

Bu araştırmada ortalama bulanıklık değeri 10.5 NTU belirlenmiş (Tablo 1), Kaya (2023), Devegeçidi Baraj Gölü'nde 20.6 NTU, Bulum (2015) Bendimahi'de 10.68 NTU olarak bildirmiştir. İçme suyu açısından; TS 266'da (2005) verilen standartlara göre yüksek çıkmıştır (TSE, 2005). Çalışmanın ortalama AKM değeri ise 12.3 mg/L olarak ölçülmüş olup, (Tablo 1) TS 266'da bulunan değerin üzerinde çıkmıştır (TSE, 2005). Ancak bu problemlerin filtrelemeyle giderilebileceği düşünülmektedir.

Çalışma sularında ortalama magnezyum değeri 20.8 mg/L olarak ölçülürken, kalsiyum değeri ise 51.0 mg/L olarak belirlenmiştir (Tablo 1). Bu çalışmadan elde edilen kalsiyum ve magnezyum verileri hem dünya geneli içme sularında hem de ülkemiz içme suları miktarlarına göre uygun bulunmuştur. Su örneklerinde ortalama toplam sertlik değeri 212.8 mg/L olarak belirlenmiştir (Tablo 1) olup, çalışmanın verileri içme ve balıkçılık açısından sorun teşkil etmeyecek değerlerdedir (TSE, 2005; Emre ve Kürüm, 2007).

Çalışmadaki su numunelerinin ortalama karbonat, bikarbonat ve toplam alkalinite değerleri sırasıyla 8.2, 186.6 ve 164.5 mg/L olurken (Tablo 1), Kaya ve Şen (2022) Kabaklı Göleti'nde karbonat, bikarbonat ve toplam alkaliniteyi 13.78, 182.54 ve 161.38 mg/L olarak bulmuşlardır. Alabalık yetiştiriciliğinde alkalinite değerinin 10-400 mg/L aralığında olması istenirken, bu çalışmada toplam alkaninitesi sınır değerin içinde bulunmuştur (Emre ve Kürüm, 2007).

Bu çalışmada ortalama nitrat 2.7 mg/L, nitrat azotu 0.6 mg/L olarak belirlenmiştir (Tablo 2). Kaya (2023), Devegeçidi Baraj Gölü'nde 5.3 mg/L, Kaya ve Şen (2022) Kabaklı Göleti'nde 4.98 mg/L, Şen ve Aksoy (2015) Bulakbaşı Nehri'nde 4.74 mg/L, Şen ve Şekerci (2019) Karasu Nehri'nde 4.1 mg/L olarak ölçmüşlerdir. Çalışmanın nitrat değeri diğer çalışmaların değerlerine benzerlik göstermiş olup, TSE, EU ve WHO standartlarına göre içme suyu açısından uygun değerlerde bulunmuştur. Ayrıca YSKY'e göre de I. sınıf su kalitesinde olduğu saptanmıştır (TSE, 2005; YSKY, 2015; WHO, 2022; EU, 2023).

Çalışmanın bir diğer parametresi olan ortalama nitrit miktarı 0.02 mg/L, nitrit azotu 0.01 olarak bulunmuştur (Tablo 2). Şen ve Aksoy (2015) Bulakbaşı Nehri'nde 0.020 mg/L, Şen ve Şekerci (2019) Karasu

Nehri'nde 0.017 mg/L, Bulum (2015), Bendimahi'de 0.018 mg/L olarak bildirmiştir. Bu çalışmadan elde edilen veriler TS 266, YSKY, EU ve WHO değerleriyle uyumlu olduğu ve Alabalık yetiştiriciliği açısından uygun olduğu belirlenmiştir (TSE, 2005; Emre ve Kürüm, 2007; YSKY, 2015; WHO, 2022; EU, 2023).

Ergani Baraj Gölü'nde ortalama olarak amonyum 0.19 mg/L, amonyak 0.18 mg/L ve amonyak azotu 0.15 mg/L olarak belirlenmiştir (Tablo 2). Çavuş ve Şen (2021), Aygır gölünde amonyum, amonyak ve amonyak azotu değerlerini 0.06, 0.52 ve 0.44 mg/L olarak bildirmişlerdir. Çalışma sularında amonyum ve amonyum azotu değerleri YSKY'nde I. sınıf su kalite özelliğinde, TS-266'da belirtilen değerler içerisinde bulunmuştur. Ayrıca amonyum değeri EU'da verilen limit değerinin altında uygun olduğu saptanmıştır (TSE, 2005; YSKY, 2015; EU, 2023).

Çalışmanın fosfor değeri 0.05 mg/L olup, su örneklerinde ortalama fosfat değeri 0.16 mg/L olarak belirlenmiştir (Tablo 2). YSKY'de II. sınıf su kalitesinde, TS-266'da ise sınır değerlerde olmuştur. (TSE, 2005; YSKY, 2015).

Ortalama sülfat değeri 23.4 mg/L olarak ölçülmüştür (Tablo 2). Kaya (2023), Devegeçidi Baraj Gölü'nde 50.3 mg/L olduğunu bildirmiştir. Çalışmamızın sülfat değeri, YSKY'de I. sınıf ve TS 266 ile EU'da verilen limitlere göre uygun sınırlar içinde yer almıştır (TSE, 2005; YSKY, 2015; EU, 2023).

On üç aylık potasyum değeri ortalama 1.7 mg/L olarak hesaplanmıştır. Ayrıca çalışmanın bir diğer su kalite parametresi olan sodyum 5.8 mg/L olarak bulunmuştur (Tablo 2). Çalışmadaki SAR değeri 0.1723 meq/L olarak hesaplanmıştır. SAR değerlerini; Kaya (2023), Devegeçidi Baraj Gölü ve göle dökülen akarsularda 0.5165 meq/L, Kaya vd. (2023) Kabaklı Göletinde 1.46 meq/L, Çavuş ve Şen (2021) Aygır Gölü'nde 0.5736 olarak hesaplamıştır. Ergani Baraj Gölü'ndeki suyun sulama bakımından uygun olduğu ve C_2-S_1 sulama sınıfına dahil edildilği belirlenmiştir.

Ergani Baraj Gölü'nden alınmış olan su örneklerinde ağır metal analiz sonuçlarında ortalama Al 1.9 µg/L, CN 0.001 µg/L, Zn 0.15 mg/L, F 0.19 mg/L, Fe 0.02 mg/L, Mn 0.05 mg/L, Cr 0.003 mg/L ve Ni 0.01 mg/L olarak bulunmuştur (Tablo 3). Çalışmadaki bu sonuçlar; YSKY göre I. kalite su niteliğine sahip olup, Türkiye, EU ve WHO içme suları yönetmenliklerinde belirtilen standartlara uygun olduğu belirlenmiştir (TSE, 2005; YSKY, 2015; EU, 2023).Ergani Baraj Gölü'nde yapılan Cu analiz sonuçları ölçüm aralığı altında olduğu için tespit edilememiştir.

Çalışmadaki ortalama silisyum 1.4 mg/L, silisyumoksit 3.0 mg/L olarak tespit edilmiştir (Tablo 3). Kaya (2023), Devegeçidi Baraj Gölü'nde silisyum ile silisyumoksit 3.3 ve 7.0 mg/L, Kaya ve Şen (2022) Kabaklı Göleti'nde silisyum ile silisyumoksit 2 ve 4.75 mg/L, Varol (2010), Dicle Baraj Gölü'nde silisyumoksit 6.4-19.3 mg/L aralığında bulmuştur.

Ergani Baraj Gölü'nden alınan sudan ortalama molibden 0.2 mg/L olarak belirlenmiştir (Tablo 3). Ülkemiz'de ve Avrupa'da Mo'ya ait herhangi bir standartda rastlanılmamıştır. Ayrıca kobalt değeri ise 0.02 mg/L olarak belirlenirken (Tablo 3), YSKY göre II. sınıf kalitede olduğu saptanmıştır (YSKY, 2015).

Tablo 1. Ergani Baraj Gölü'ne ait yerinde ölçümler ve titrimetrik analiz sonuçları

Aylar	Parametreler Sıcaklık (°C)	ÇO (mg/L)	OD (%)	pH	EC (µS/cm)	Tuzluluk (‰)	Cl_2 (mg/L)	Ca (mg/L)	Mg (mg/L)	Toplam Sertlik (mg/L)	CO_3 (mg/L)	HCO_3 (mg/L)	Toplam Alkalinite (mg/L)	AKM (mg/L)	Bulanıklık (NTU)
Haz.21	31.5	9.1	139.5	8.91	239	0.16	3.55	56	31	268	12	158.6	160	21	23.2
Tem.21	28.5	8	113	8.33	271	0.17	12.43	41.6	50.6	312	12	195.2	190	4	6
Ağu.21	29.8	7.1	106.5	8.98	278	0.18	10.65	51.2	46.7	320	12	244	230	10	7
Eyl.21	21.3	8.6	90.1	8.28	313	0.23	4.14	42.6	13.7	163	öla	174.5	143	47.3	23
Eki.21	16.5	10.3	117	8.35	341	0.17	3.95	47.7	14.3	177.9	6.9	185.1	157.5	6.5	8.7
Kas.21	12.5	9.5	115	8.25	390	0.23	4.32	45	18	186.5	öla	183	150	8	10
Ara.21	6.7	12.9	116	8.13	400	0.24	3.98	51.7	13.2	183.3	öla	208	170.5	8.6	10
Oca.22	6	12.3	110.1	7.8	721	0.35	4.47	61	22	242.9	öla	208.6	171	16	10.4
Şub.22	10.2	11.2	111.1	8.09	346	0.17	4.62	61.8	12.9	207.3	öla	208	170.5	9.3	11
Mar.22	12.4	11	114.2	8.35	273	0.17	3.92	62.6	11.4	203.1	28.9	184.8	175.5	8.7	11.5
Nis.22	21.9	9.3	119.1	8.25	323	0.16	4.93	56.3	12.1	190.2	öla	193.4	158.5	5.3	5.3
May.22	24.3	10.3	139.3	8.54	293	0.18	3.9	43.3	11.9	157.2	12.5	147.2	131.5	10.4	5.7
Haz.22	25	8	109	8.39	292	0.17	3.73	41.7	12.5	155.8	22.8	135.6	131	4.4	5.2
Ortalama	19.0±2.4	9.8±0.5	115.4±3.7	8.4±0.1	344.6±34.0	0.2±0.01	5.3±0.8	51.0±2.2	20.8±3.8	212.8±15.5	8.2±2.7	186.6±8.0	164.5±7.2	12.3±3.2	10.5±1.7

*öla: ölçüm aralığı altında

Tablo 2. Ergani Baraj Gölü'ne ait fizikokimyasal analiz sonuçları

Aylar	Parametreler												
	NO_3 (mg/L)	NO_3-N (mg/L)	NO_2 (mg/L)	NO_2-N (mg/L)	NH_4 (mg/L)	NH_3 (mg/L)	NH_3-N (mg/L)	PO_4 (mg/L)	P (mg/L)	P_2O_5 (mg/L)	SO_4 (mg/L)	K (mg/L)	Na (mg/L)
Haz.21	0.5	0.1	0.014	0.004	0.09	0.08	0.07	0.11	0.04	0.08	21	1.2	5.24
Tem.21	öla	öla	0.007	0.002	0.1	0.09	0.08	0.08	0.03	0.06	26	1.1	5.4
Ağu.21	0.15	0.05	0.008	0.003	0.06	0.06	0.05	0.03	0.01	0.02	24	1.1	6.1
Eyl.21	1.3	0.1	öla	öla	0.31	0.3	0.24	0.13	0.04	0.1	25	1.8	5.74
Eki.21	1.2	0.3	0.005	0.002	0.15	0.14	0.12	0.01	öla	0.01	28	3.2	6
Kas.21	2.2	0.5	öla	öla	0.14	0.13	0.11	0.03	0.01	0.02	24	2.1	6.2
Ara.21	5.4	1.2	0.039	0.012	0.28	0.26	0.21	0.28	0.09	0.2	22.4	1.9	6.48
Oca.22	6.1	1.38	0.019	0.006	0.26	0.24	0.2	0.09	0.03	0.07	27	2.4	5.51
Şub.22	7.79	1.76	0.036	0.011	0.24	0.23	0.19	0.02	0.01	0.01	23	1.5	5.81
Mar.22	3.5	0.8	0.053	0.016	0.06	0.05	0.04	0.1	0.03	0.07	20.5	1.3	5.17
Nis.22	2.8	0.6	0.048	0.015	0.16	0.15	0.13	0.77	0.25	0.58	21.8	1.6	6.21
May.22	2.1	0.5	0.016	0.005	0.48	0.45	0.37	0.33	0.11	0.24	20.2	1.3	5.57
Haz.22	2	0.5	0.036	0.011	0.18	0.17	0.14	0.13	0.04	0.09	21.2	1.4	5.59
Ortalama	2.7±0.7	0.6±0.2	0.02±0.01	0.01±0.002	0.19±0.033	0.18±0.031	0.15±0.025	0.16±0.057	0.05±0.02	0.12±0.04	23.4±0.7	1.7±0.2	5.8±0.1

*öla: ölçüm aralığı altında

Tablo 3. Ergani Baraj Gölü'ne ait metal analizi sonuçları

Aylar	Parametreler											
	Al (µg/L)	Zn (mg/L)	Fe (mg/L)	CN (µg/L)	F (mg/L)	Si (mg/L)	SiO_2 (mg/L)	Mo (mg/L)	Mn (mg/L)	Ni (mg/L)	Co (mg/L)	Cr (mg/L)
Haz.21	1	0.46	0.05	öla	0.34	öla	1	öla	0.058	0.01	0.023	öla
Tem.21	3	0.1	0.03	0.001	öla	1	2	0.3	0.055	öla	0.001	0.002
Ağu.21	5	0.1	0.03	öla	0.12	öla	1	0.1	0.045	öla	0.02	0.001
Eyl.21	2	0.24	0.01	öla	0.26	2	5	öla	0.104	0.006	0.048	0.003
Eki.21	5	0.17	0.01	0.001	0.21	1	2	0.3	0.064	0.003	0.021	0.005
Kas.21	2	0.14	0.01	öla	0.24	1	2	öla	0.065	öla	0.024	öla
Ara.21	1	0.1	0.01	0.001	0.26	1	2	0.1	0.053	öla	0.027	öla
Oca.22	öla	0.1	0.01	öla	0.24	2	4	öla	0.08	0.02	0.031	öla
Şub.22	öla	0.08	0.04	0.001	0.17	1	3	öla	0.05	öla	0.028	öla
Mar.22	öla	0.13	0.09	0.003	0.21	4	8	0.4	0.036	0.03	0.024	0.007
Nis.22	öla	0.12	0.01	0.001	0.1	3	5	0.4	0.031	0.008	0.02	öla
May.22	5	0.14	öla	0.002	0.16	1	2	0.2	0.032	0.004	0.031	öla
Haz.22	öla	0.11	öla	0.002	0.13	1	2	0.1	0.026	0.005	0.012	0.016
Ortalama	1.9±0.6	0.15±0.03	0.02±0.01	0.001±0.000	0.19±0.02	1.4±0.3	3.0±0.6	0.2±0.04	0.05±0.006	0.01±0.003	0.02±0.003	0.003±0.001

*öla: ölçüm aralığı altında

4. Sonuç

Diyarbakır İli Ergani İlçesinde yer alan Ergani Baraj Gölü'nün su kalitesine yönelik yapılan bu çalışma, Ergani Baraj Gölü'nün su kalitesi ve kirliliği, sulama suyu, içme suyu ve balıkçılığın değerlendirilmesi açısından yapılan ilk bilimsel çalışmadır. Baraj gölünde 13 ay boyunca her ay arazi çalışmalarında yerinde ölçümler yapılarak ve su numuneleri alınarak analizler yapılmış ve ulusal ve uluslararası yönetmenliklere göre değerlendirilmelerde bulunulmuştur. Bu kapsamda yapılan analizler sonucunda; ortalama su sıcaklığı, pH, elektrik iletkenlik, çözünmüş oksijen, nitrat, nitrit, amonyum, amonyak, demir, alüminyum, çinko, bakır, florür, mangan, nikel, siyanür, krom, silisyum ve sülfat değerleri YSKY'de belirtilen I. sınıf yani yüksek kaliteli sular sınıfına girdiği belirlenmiştir. Çalışmanın su örneklerine ait analiz sonucunda pH değerinin hafif alkali özellikte, sert bir suya sahip ve fosfat değeri bakımından II. sınıf kalitede olduğu belirlenmiştir. Baraj gölünün suyu içme suyu açısından Ülkemizde mevcut olan içme suyu mevzuatlarında belirtilen değere göre uygun olduğu ancak bulanıklık ve askıda katı madde değerlerinin yüksek çıktığı görülmüştür. Baraj gölü tarımsal faaliyetlerden ve yerleşim yerlerinden uzak olmasından dolayı kirlilik yükü taşımadığı yapılan analizler sonucunda tespit edilmiştir. Baraj gölü su sıcaklığı ölçüm sonuçlarına göre 6 ay (nisan-ekim ayları) boyunca kafeslerde alabalık yavrularının yetiştirilmesine uygun olduğu belirlenmiştir.

Sonuç olarak baraj gölü su kalitesi parametreleri bakımından balıkçılık, içme-kullanma, sulama suyu, rekreasyon amaçlarıyla kullanılabileceği düşünülmektedir. Bu çerçevede baraj gölünün fiziko-kimyasal parametreleri bakımından genel olarak iyi sayılabilecek durumda olduğu ve önemli kirlilik kaynaklarının olmadığı, ekolojik dengenin korunması ve sürdürülebilir bir gelişmenin olması için su kaynaklarının akılcı politikalarla yönetilmesi ve sürekli olarak izlenmesi büyük önem arz etmektedir. Ayrıca, Ergani Baraj Gölü'nde daha önce su kalitesinin belirlenmesi açısından bilimsel olarak yapılmış bir çalışmanın olmamasından dolayı ileride yapılacak olan detaylı çalışmalara katkı sağlayacağı düşünülmektedir.

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Etik Standartlara Uygunluk

Çıkar çatışması
Yazarlar herhangi bir çıkar çatışması olmadığını beyan etmektedirler.

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Bu çalışmada, etik kurul onayı gerekli değildir.

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RESEARCH ARTICLE

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Evaluation of the Ecological Dynamics of the Seagrass *Posidonia oceanica* in a Turkish Mediterranean Site Considering the Plant Growth

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ABSTRACT

Vascular angiosperms considered as architectures of homogeneity, dominate the composition, and ecosystem functioning in the Mediterranean Sea. Since the realisation of the factors influencing the ecological and evolutionary dynamics of seagrasses, is critical for the conservational purposes, we aimed to evaluate the ecological dynamics *Posidonia oceanica* meadows in Kızılada, Fethiye-Göcek Special Environmental Protected Area (Muğla, Türkiye) in this study. Considering growth dynamics of the plant, lepidochronological analysis using annual cycles of scale thickness, was conducted both on the orthotropic and the plagiotropic rhizomes. The upper limit of *P. oceanica* meadows, started from a depth of 18.7 m and ended at a depth of 29.7 m in the region. Development of the plagiotropic rhizomes of *P. oceanica* along a line from the upper limit to the lower limit depth, could be rarely seen in the Turkish coasts. Since the growth rates were different between orthotrophic and plagiotrophic rhizomes, the annual growth of the meadow on the line, was calculated by averaging the both of the rhizomes. Considering the results, the annual growth rate of *P. oceanica* decreased with depth and was determined to be minimum at the lower limit depth. The average rate of plagiotropic rhizome elongation, was recorded as 17.8 mm yr^{-1}, while the average of orthotrophic rhizomes was recorded as 8.8 mm yr^{-1}. Lepidochronological analyses verified that *P. oceanica* meadow was estimated to be approximately 2013 years old according to the average annual growth rate of the rhizomes.

KEYWORDS: *Posidonia oceanica*, lepidochronology, plant growth dynamics, productivity, Mediterranean Sea

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1. Introduction

Clonal vascular angiosperms considered as architectures of homogeneity, dominate the composition, biomass, and ecosystem functioning in the coasts of the Mediterranean (Trache et al., 2023). Different plant sizes among seagrasses, describe the variations of productivity between fast-growing (*Zostera*, *Cymodocea*) and slow-growing (*Posidonia*) genera (Hillman et al., 1989). In order to maintain a long life span, the endemic seagrass of the Mediterranean Sea, *Posidonia oceanica* (L.) Delile colonize monospecifically over vast areas in the littoral zones, contributing to the global primary production and to the coastal biodiversity (Ohno, 1970; Ott, 1980; Zupo et al., 1997; De Bodt et al., 2005; Lynch, 2007; Jiao et al., 2011; Van de Peer et al., 2021).

Previous studies verified that the structural species like *P. oceanica* can form continuous beds in the coastal zones from 0–40 m depths (Kuo, 2013), however facing a global regression (Bonacorsi et al., 2013; Sinclair et al., 2016; Digiantonio et al., 2020; Blanco-Murillo et al., 2022). From this point of view, *P. oceanica* is used in the studies conducted in all over the Mediterranean to evaluate its annual productivity and architectural dynamics for reproduction with the environmental variations (Boudouresque et al., 1983).

The seagrass *P. oceanica* shows development with successional morphological sections (Petersen, 1913) such as “rhizome internodes” and “leaf sheaths” (Pergent and Pergent-Martini, 1990; Duarte et al., 1994). A rhizome internode is formed with every new leaf that substituted the older leaves. When the leaf blades fall; the leaf sheath persists attached to the rhizome as ‘scales’ within the matte more than 4 600 years (Boudouresque et al., 1984). In this respect, scale thickness demonstrates the annual cycle in chronological order (Pergent et al., 1989; Pergent, 1990).

Among various methods developed to estimate the primary production, is “lepidochronological analysis”, rather performed on the the fast-growing plagiotropic rhizomes having a greater number of leaves than the orthotropics (Ott, 1980). For this purpose, measurements of leaf and rhizome growth rate and thus, age determination of *P. oceanica* were reported from Spain (Romero, 1989), France (Pergent, 1987; 1990; Pergent et al., 1989; Pergent and Pergent-Martini, 1990; Pergent et al., 1994; 1997; Pergent-Martini et al., 1994), Türkiye (Pergent and Pergent Martini, 1990), Italy (Pergent and Pergent-Martini, 1990; Pergent-Martini et al., 1994; Calvo et al., 1995; Torricelli and Peirano, 1997) and Egypt (Mostafa and Halim, 1995). Another method based on the determination of seagrass age, is the calculation of the internodal length between two successive nodes since one year periods are distinguished as marks of the scales or nodes on the rhizomes (Mossé, 1984; Duarte, 1991). The method is conducted with a standard leaf marking on the basal leaf or on the rhizome meristem (Zieman, 1974; Zieman and Wetzel, 1980; Buia et al., 1992). Moreover, calculation of the internodal length combined with plastochrone interval index (Peirano, 2002), have been performed non-destructively in situ to estimate the growth dynamics of *P. oceanica* and to compare its productivity with other seagrasses (Cebrián et al., 1994; Duarte et al., 1994; Alcoverro et al., 1995; Marbà and Duarte, 1997; Duarte, 1999).

Regarding the Turkish Aegean coasts, most of the studies focus on the relations between the environmental conditions (mainly temperature, light and nutrients) and the distribution of *P. oceanica* meadows along the coasts (Taşkın, 2020; Taşkın et al., 2020a; 2020b). However, the realisation of the factors influencing the ecological and evolutionary dynamics of seagrasses, is critical for future planning of the conservational purposes. Therefore, in this study we aimed to evaluate the ecological dynamics *P. oceanica* meadows in the Aegean Sea considering its growth dynamics. Lepidochronological analysis using annual cycles of scale thickness, was conducted both on the orthotropic and plagiotropic rhizomes to provide data on the previous flowering occasions of *P. oceanica*.

2. Material and Methods

P. oceanica meadows were sampled from Kızılada in Fethiye-Göcek Special Environmental Protected Area (Muğla, Türkiye) (36°39'39" N, 29°03'14" E) (Figure 1). Research site was characterized with hard rocky bottom types, in the form of an almost vertical wall between 0-18 m, the upper limit of the meadows started from 18.7 m depth, and the lower limit depth ended at 29.7 m (Figure 2a-d). The meadows have been developed in the form of lines from the upper limit to the lower limit depth (Figure 3a). Only one line was sampled for lepidochronological analysis from the upper limit depth to the lower limit depth. 33 shoots (11 horizontal and 22 vertical) were collected from different depths (18.7 m, 19 m, 19.3 m, 20.8 m, 22 m, 22.7 m, 23 m, 24.1 m and 26.7 m) from the upper limit to the lower limit. Also, the total length of the same line was measured with a tape measure (Figure 3b). Lepidochronological analysis was conducted according to Pergent (1990) and Mosse (1984). The annual growth of the meadow on the line, was calculated by averaging the plagiotrophic and orthotrophic rhizomes. Spearman rank order correlations were carried out by using PAST software (Hammer et al., 2001).

Figure 1. Research site (Kızılada) in Fethiye-Göcek Special Environmental Protected Area (Fethiye, Muğla, Türkiye).

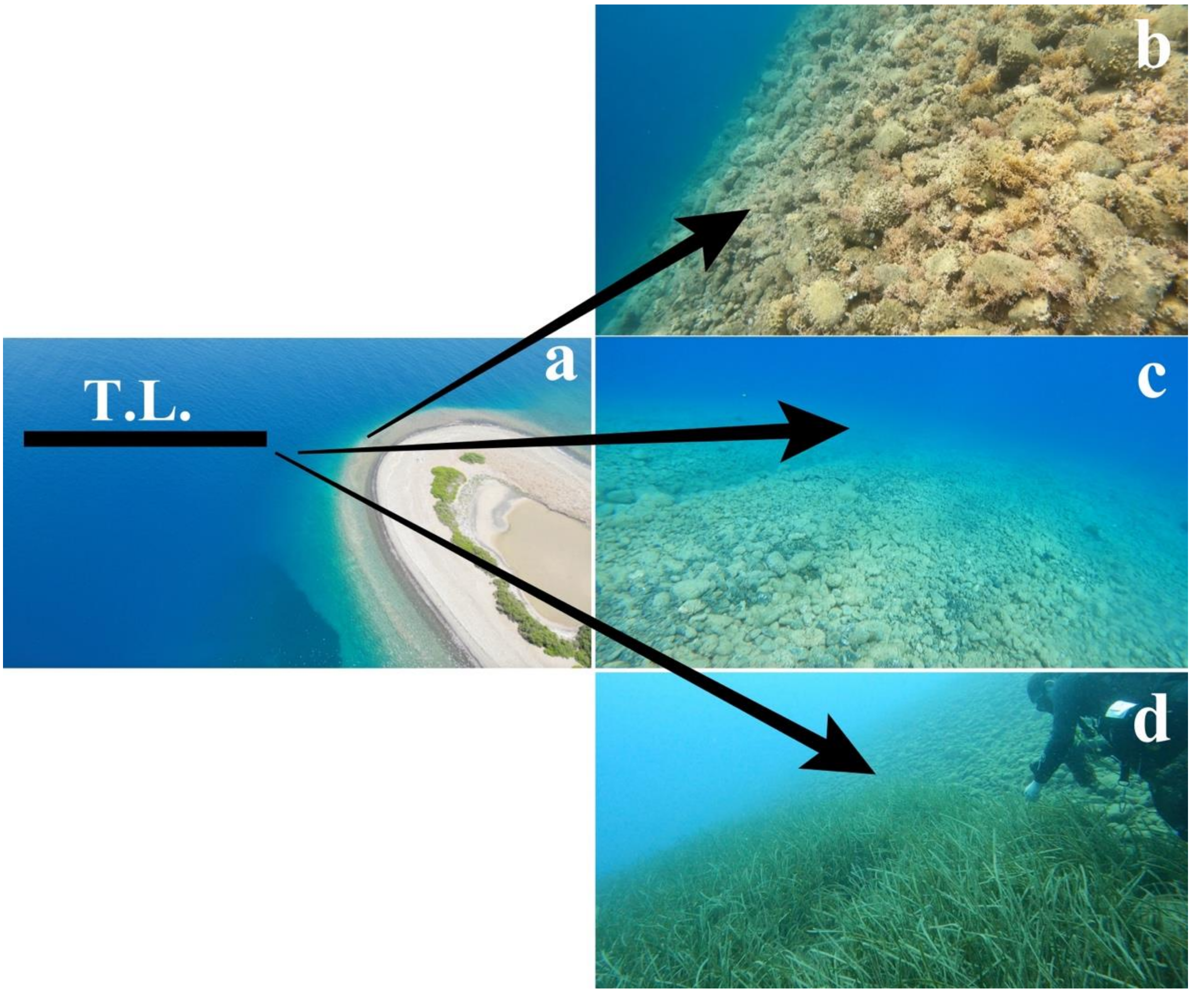

Figure 2. Sampling site (Kızılada) (T.L.: Transect Line) (a), rocky area (b-c), upper limit depth of seagrass (18 m) (d).

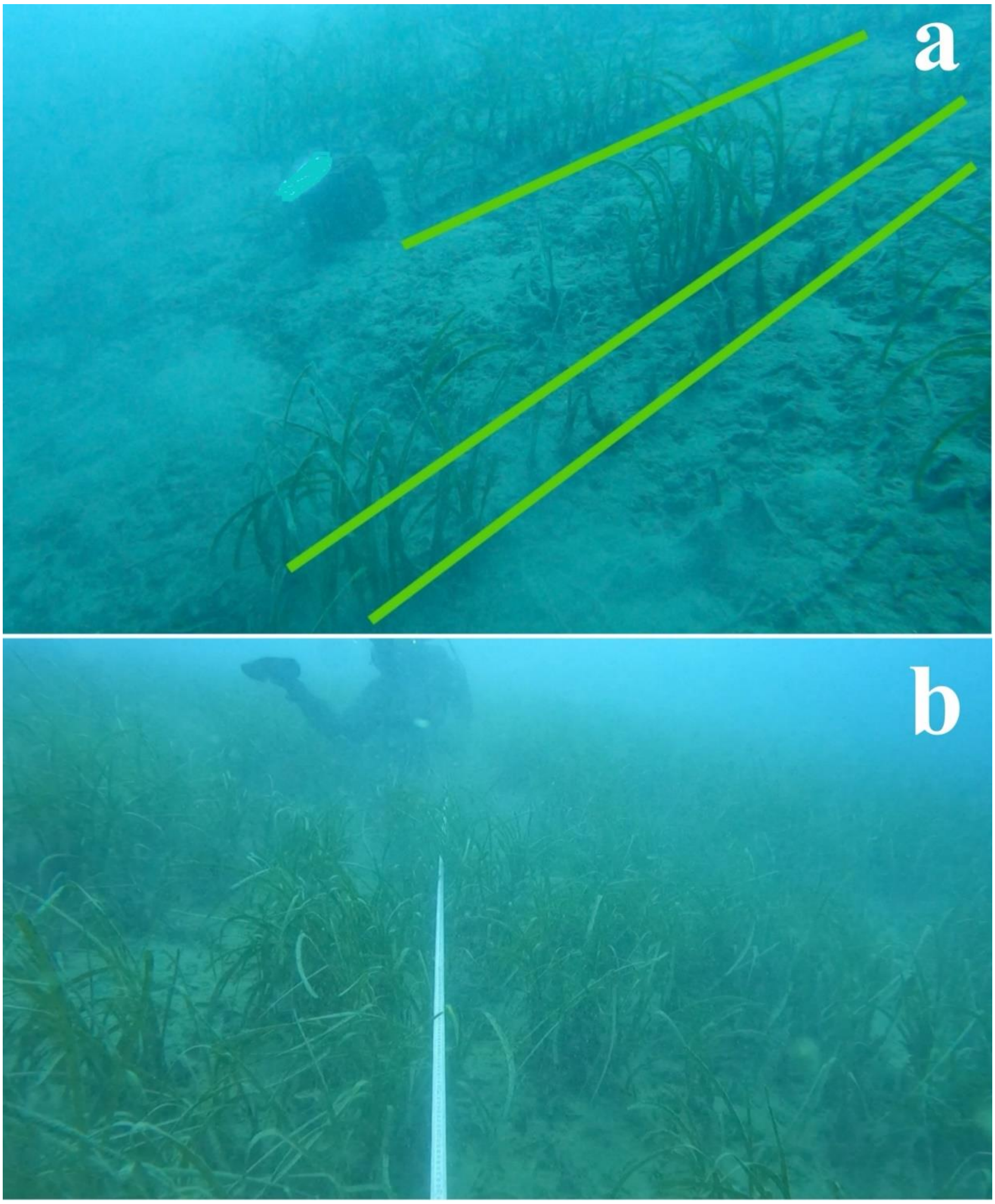

Figure 3. Line-shaped development of the meadow (26 m depth) from the upper limit depth to the lower limit depth and measurement of the meadow distance in sampling site.

3. Results and Discussion

It is possible to obtain data from the shoots of *P. oceanica* meadow to estimate its annual growth rate and age (Christrine Pergent, pers. Comm.). In this study, it was determined that plagiotropic rhizomes of *P. oceanica* meadows in Kızılada, Fethiye-Göcek SPA (Muğla, Türkiye) have been developed along a line from the upper limit to the lower limit depth. This phenomenon could be rarely seen in the Turkish coasts. The upper limit of the meadow started from a depth of 18.7 m, and the lower limit depth was recorded at 29.7 m. The total length of the sampling line was recorded as 26.8 m. Lepidochronological years, rhizomes elongation rates (mm yr^{-1}) and scales thicknesses (µm), were given in Table 1. The average elongation rate of vertical rhizomes (mm/$year^{-1}$) was calculated as 8.82 mm year^{-1}, while that of horizontal rhizomes, was calculated as 17.81 mm year-^{1}. In order to estimate the annual growth rate and the age of the meadows, the average values of plagiotrophic and orthotrophic rhizomes, were given in Table 1. The highest growth rate (45.7 mm) of plagiotrophic rhizomes, was recorded at 22 m depth, and the highest growth rate (29.2 mm) of orthotrophic rhizomes, was recorded at 19.3 m depth. It was determined that the average annual growth rate of the meadow, decreased from the upper limit depth to the lower limit depth. The highest growth rate of rhizomes in 2025 were measured at 19.3 m depth (22.56 mm year^{-1}), followed by 20.8 m (15.54 mm year^{-1}), 18.7 m (14.94 mm year^{-1}), 22 m (10.98 mm year^{-1}), 24.1 m (7.87 mm year^{-1}), 22.7 m (6.24 mm year^{-1}), and 26.7 m (6.65 mm year^{-1}). As a result of measurements performed by lepidochronological analyses in the research area, it was calculated that the meadow was approximately 3038 years old according to the annual average growth rate of only the orthotropic rhizomes and approximately 1504 years old according to the annual average growth rate of only the plagiotrophic rhizomes. However, in this study, the average annual growth rate of both vertical and horizontal rhizomes, was preferred and accordingly, the meadow was calculated to be approximately 2013 years old.

In total, 412 scales were measured from different depths (18.7 m: 76 scales, 19.3 m: 40 scales, 20.8 m: 85 sclaes, 22 m: 43; 22.7 m: 82 scales, 24.1m: 51 scales, and 26.7 m: 23 scales) in May 2025, and scales thickness were recorded as 482,54 µm, 551,81 µm, 565,08 µm, 495,58 µm, 581,51 µm, 636,25 µm and 643,75 µm, respectively. It was determined that the scale thickness increased towards the lower distribution limit depth of the meadow.

Table 1. Rhizome elongation rate (mm yr^{-1}) and scales thickness (µm) of the horizontal and vertical rhizomes of *P. oceanica* from the sampling site (Kızılada, Fethiye, Türkiye).

Sampling Year/Depth	**Number of shoots examined**		**Av. Rhizome elongation rate (mm yr^{-1})**			**Av. Scales thickness (µm)**		
	P	**O**	**P**	**O**	**Av.**	**P**	**O**	**Av.**
2025 / 18,7 m	1	3	25.33	4.55	14.94	438.89	526.19	482.54
2025 / 19,3 m	3	1	15.92	29.20	22.56	603.61	500.00	551.81
2025 / 20,8 m	3	3	24.85	6.22	15.54	564.58	565.58	565.08
2025 / 22 m	2	1	16.28	5.68	10.98	500.16	491.00	495.58
2025 / 22,7 m	0	4	nm	6.24	6.24	nm	581.51	581.51
2025 / 24,1 m	0	4	nm	7.87	7.87	nm	636.25	636.25
2025 / 26,7 m	2	0	6.65	nm	6.65	645.83	nm	645.83
2024 / 19 m	0	3	nm	5.33	5.33	nm	437.33	437.33
2024 / 23 m	0	3	nm	5.48	5.48	nm	424.03	424.03
	11	**22**	**17.81**	**8.82**	**13.31**	**550.61**	**520.24**	**535.43**

P: plagiotrophic rhizome, O: orthotrophic rhizome, Av.: average, nm: not measured.

P. oceanica is a long-lived and slow-growing seagrass species, and the colonization rate of this species, is extremely slow (Marbà et al., 2004). Therefore, based on rhizome growth, a 15 m wide clone of *P. oceanica* would take 350 years to reproduce. The Mediterranean seagrass *P. oceanica* forms a biological structure called a "mat", where it accumulates vast amounts of organic debris (Mateo et al., 1997). Radiocarbon dating of the samples revealed a range of 0-3370 years before present, with average deposition rates of 0.175 cm yr^{-1}. It has been reported that *P. oceanica* meadows can grow continuously for more than 6000-7000 years (Mateo et al., 1997), suggesting that clones can reach a life span of thousand years (Arnaud-Haond et al., 2012).

The growth rates and scales thickness of the horizontal and vertical rhizomes of *P. oceanica* are given in Table 2. Plagiotrophic rhizomes in Corsica have average annual growth rates ranging from 32 to 45 mm yr^{-1} (Gobert et al., 2016). Neither the growth rate nor the primary production of rhizomes of the meadow, were dependent on depth up to 14 m, but a significant decrease in shoots was reported at depths greater than 14 m (Tomasello et al., 2016). In the present study, the annual growth rate of *P. oceanica* decreased with depth and was determined to be minimum at the lower limit of distribution (Table 1). It is thought that the decrease in the annual average growth rate of the meadow from the upper limit depth to the lower limit depth may be related to light penetration. The growth rates of plagiotropic rhizome were given by Mosse, 1984; (as 32.43 mm yr^{-1}), Marbà et al., 2004 (as ave. 20.00 mm yr^{-1}), and Tomasello et al., 2016 (as 40.25 mm yr^{-1}) (Table 2).

Table 2. The growth rates of the horizontal and vertical rhizomes of *Posidonia oceanica* in the Mediterranean coasts.

	Rhizome elongation rate (mm yr^{-1})	
Reference	**P**	**O**
Mosse, (1984) (France)	32.43	5.54
Pergent and Pergent, (1990), Urla (Türkiye)	nd	5.90
Pergent and Pergent, (1990), Banyuls (France)	nd	7.45
Pergent and Pergent, (1990), Port-Cros (France)	nd	5.75
Marbà et al., (2004)	20.00	10.00
Calvo et al., (2006), Sicily (Italy)	nd	19.70
Marbà et al., (2006) (Cyprus, Greece, Italy and Spain)	nd	6.15
Maida et al., (2013), Sicily (Italy)	nd	8.20
Gobert et al., (2016), Corsica (France)	40.25	nd
Tomasello et al., (2016), Sicily (Italy)	nd	10.26
Güreşen et al., (2020), Corsica (France)	nd	4.74
Güreşen et al., (2020), Gökçeada (Türkiye)	nd	6.07
Taşkın et al., (2025), Marmara Sea (Türkiye)	nd	7.02
Taşkın et al., (2025), Kaş (Türkiye)	nd	10.72
Average of rhizome elongation rate (mm yr^{-1})	**30.89**	**8.27**

P: plagiotrophic rhizome, O: orthotrophic rhizome, nd: no data.

P. oceanica plagiotrophic rhizomes show elongation rates 20 (10-60 mm yr^{-1}) much higher than those of orthotrophic rhizomes 10 (1- 40 mm yr^{-1}) in the Mediterranean Sea (Marbà et al., 2004). However, plagiotropic rhizome elongation rate was recorded as 17.81 mm yr-[1] from the Turkish coasts (Table 1). While the average value of orthotrophic rhizomes in the Mediterranean was stated to be 8.27 mm $year^{-1}$ (Table 2), this value was calculated as 8.82 mm year-1 in the study obtained from Fethiye (Türkiye). In the Mediterranean, the meadow was calculated to be approximately 3240 years old according to the annual average growth rate of the orthotrophic rhizome, and approximately 867 years old according to the annual average growth rate of only the plagiotrophic rhizome (Table 2). However, when the annual average growth rate of vertical and horizontal rhizomes, was taken into account as in this study, the meadow was calculated to be approximately 1368 years old.

Number, length and width of leaves in per shoot from the sampling site are given in Table 3. Spearman rank order correlations were used to study the relationship between the metrics (Table 4), and marked correlations are significant at $p < 0.05$.

Table 3. Number, length and width of leaves in per shoot from the sampling area.

Sampling Year/Depth	Number of Leaves	Length of Leaves	Width of Leaves
2025 / 18.7 m	4.0 ± 1.0	259.3 ± 67.6	7.6 ± 0.6
2025 / 19.3 m	4.7 ± 2.1	265.2 ± 21.8	7.8 ± 0.7
2025 / 20.8 m	5.7 ± 0.6	344.9 ± 54.4	8.9 ± 0.3
2025 / 22.0 m	6.5 ± 0.7	282.1 ± 59.1	8.1 ± 0.3
2025 / 22.7 m	6.0 ± 0.8	354.6 ± 66.8	8.8 ± 0.6
2025 / 24.1 m	5.7 ± 1.2	338.4 ± 78.5	8.8 ± 0.23
2025 / 26.7 m	7.0 ± 0.0	344.1 ± 9.6	9.2 ± 0.2
2024 / 19.0 m	5.4 ± 1.2	305.5 ± 103.5	8.6 ± 0.9
2024 / 23.0 m	5.0 ± 0.7	255.7 ± 63.1	8.4 ± 0.8

Table 4. Spearman rank order correlations. Bold correlations are significant at $p < 0.05$.

	Growth rate of plagiotrophic rhizome	Growth rate of orthotrophic rhizome	Scales thickness of plagiotrophic rhizome	Scales thickness of orthotrophic rhizome	Number of leaves	Length of leaves	Width of leaves
Growth rate of plagiotrophic rhizome		0.0833	**0.0167**	0.3333	0.2333	0.5167	0.2333
Growth rate of orthotrophic rhizome	-0.8		0.0833	0.1966	0.4867	0.2675	0.3894
Scales thickness of plagiotrophic rhizome	**-0.9**	1		1	0.2333	0.4500	0.2333
Scales thickness of orthotrophic rhizome	0.6	0.5238	0		0.4867	0.0576	0.2162
Number of leaves	-0.7	0.2874	0.6000	0.2874		**0.0470**	**0.0438**
Length of leaves	-0.3	0.4286	0.5000	0.6905	**0.6860**		**0.0138**
Width of leaves	-0.6	0.3333	0.7000	0.4762	**0.6946**	**0.7833**	

4. Conclusion

The distinction between the two types of rhizomes is never clear-cut, therefore an orthotrophic rhizome may morph into a plagiotrophic again to recolonize an empty area (Mosse, 1984). Most of the lepidochronological studies are performed on orthotrophic rhizomes and since the growth rate will be different, we considered to take the plagiotrophic rhizomes growth into account. Thus, the annual growth of the meadow on the line was calculated by averaging the plagiotrophic and orthotrophic rhizomes.

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Compliance with Ethical Standards

Conflict of interest

The authors declared that for this research article, they have no actual, potential or perceived conflict of interest.

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