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Reef fish community structure and biomass in a fish sanctuary and a proposed marine protected area in Ilocos Sur, Philippines

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Abstract

This study assessed reef fish community structure and biomass in an established fish sanctuary and a proposed marine protected area (MPA) in Sto. Domingo, Ilocos Sur, northwestern Philippines. Underwater fish visual census (FVC) was conducted along belt transects in established Calay-Ab fish sanctuary and the proposed MPA (Calay-Ab-Sived reef), supplemented by assessments of artificial reef structures within the sanctuary. Diversity, evenness, and biomass were estimated using species-specific length–weight relationships. A total of 1562 individuals representing 43 species from 18 families were recorded. The established Calay-Ab fish sanctuary supported 28 species from 13 families, while the proposed MPA harbored 30 species from 16 families. Species diversity was moderate in the established Calay-Ab fish sanctuary (H'=2.719) and low in the proposed MPA (H'=2.485), with very low evenness at both sites (J'≈0.11), indicating dominance by a few species. Fish biomass values were relatively higher in the sanctuary (26.289 MT/km²) than in the proposed MPA (21.849 MT/km²) during the assessment period. Of the 86 AR units deployed, 59 (69%) remained intact and were colonized by macroalgae, gorgonians, reef fishes, and an endangered green sea turtle (*Chelonia mydas*), underscoring their ecological value. The findings provide baseline ecological information that may support future MPA management, monitoring, and conservation planning in Sto. Domingo, Ilocos Sur, Philippines.

Keywords: ARs, Biomass, Diversity, MPAs, Reef fish structure, Sto. Domingo, Ilocos Sur

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1. Introduction

The Philippines is an archipelagic country in Southeast Asia with 7641 islands (Tahiluddin & Sarri, 2022). It is bordered by seas and oceans, with maritime boundaries shared with neighboring Southeast Asian countries. Its marine waters extend approximately 2.2 million km², including its Exclusive Economic Zone (EEZ), and constitute a central part of the Coral Triangle—supporting one of the world's most diverse fish faunas and serving as a biodiversity hotspot (Carpenter & Springer, 2005; Allen, 2008; BFAR, 2025). This unique geographic and ecological setting underpins the country's critical role in global marine biodiversity conservation and regional food security, as its coastal and reef ecosystem sustains millions of livelihoods, supports fisheries production, and serves as vital reservoirs of marine life that contribute to ecological resilience and sustainable resource management (Barut et al., 2004; BFAR, 2025; Novilla & Fabinyi, 2025).

Coral reef ecosystems provide goods and services to a large number of people. These communities depend on them for daily sustenance, income, and other necessities, contributing to the social and economic development of coastal areas (Hoegh-Guldberg et al., 2019). However, these ecosystems are under severe threat. In the Philippines, overfishing, destructive fishing methods, overexploitation, and sedimentation are among the leading threats that have destroyed coral reef areas (Gomez et al., 1994; White et al., 2000; White & Vogt, 2000). These pressures are still escalating and expanding. For instance, Licuanan et al. (2019) reported a decline in coral cover in the major areas identified. They emphasized that Philippine reefs are no longer what they once were in terms of hard coral cover. Reefs are no longer categorized as 'excellent', reinforcing earlier findings that the coral reefs of the country are generally in poor condition (Alcala & Russ, 2002).

Owing to the current condition of the coral reef ecosystem and the goods and services it provides, Novilla and Fabinyi (2025) stressed that careful reconfiguration of governance regarding the conditions of use and access to coral reef areas must be undertaken. To maintain the integrity of coral reef areas, much effort is still needed (Alcala & Russ, 2002). The development of sustainable management regimes, including the establishment of marine reserves, regulation of harvest, enhancement of natural productivity, reef restoration efforts, and other integrated management approaches, is essential to mitigate the decline of coral reefs (White et al., 2000; White & Vogt, 2000; Alcala & Russ, 2002). The dynamics of these strategies must not undermine the livelihood adaptation mechanisms employed, especially for small-scale fishers, while rigid governance shifts are implemented (Hoegh-Guldberg et al., 2019; Novilla & Fabinyi, 2025), particularly in marine waters, which are increasingly viewed as a lucrative frontier for economic development (Bennett et al., 2021). White et al. (2000) and White and Vogt (2000) further highlight that reef management strategies must be a multisectoral effort involving various stakeholders, such as local fishing communities, local government units (LGUs), and other concerned organizations.

Although preserving the reefs is challenging due to social factors (e.g., population growth, poverty) that worsen reef protection and management, saving the Philippine reefs depends on strong political will and societal cooperation through various integrated programs (White et al., 2000; White & Vogt, 2000; Alcala & Russ, 2002). In the country, Marine Protected Areas (MPAs), are among the highlighted devolution of authority transferred under LGUs (White et al., 2002) due to their wider recognition as a key tool for conserving biodiversity and rebuilding fish stocks (White et al., 2002; Halpern, 2003; Russ et al., 2004; Muallil et al., 2019; Galveia & Macusi, 2025) after addressing highlighted drawbacks (Edgar et al., 2014; Galveia & Macusi, 2025) towards the MPA holistic approach. This study aims to provide science-based data on reef fish communities and habitat quality to support marine spatial planning, local fisheries management, and potential MPA expansion at the municipality of Sto. Domingo in the province of Ilocos Sur, northwestern Philippines. Specifically, this study aims to assess reef fish communities by examining their abundance, species diversity, and biomass within existing and proposed MPAs. It also evaluates the condition of artificial reef (AR) structures through the number of intact units and the marine organisms colonizing them and seeks to develop science-based recommendations for the LGU to aid in formulating management plans and policies for coastal fisheries and marine habitat conservation.

2. Material and Method

2.1. Study site

Figure 1 illustrates the locations of the two reef sampling sites in Sto. Domingo, Ilocos Sur: Calay-Ab, an established fish sanctuary, and Calay-Ab-Sived, a proposed MPA. The sites were mapped using a Global Positioning System (GPS). The coral reefs surveyed ranged in depth from 9.14 to 13.75 m in both reef areas. The distance between the Calay-Ab and Calay-Ab-Sived reefs was approximately 500-700 m from each other. A 100-m transect line was laid, with two transects were deployed within the Calay-Ab fish sanctuary, while three transects were laid across the proposed MPA reef area to evaluate fish abundance, diversity, and biomass. The assessment was conducted during a single survey period and therefore represents a rapid ecological assessment or temporal snapshot of the reef fish community structure within the surveyed reef areas.

In addition to the fish visual census (FVC), the monitoring also included an assessment of the AR structures installed at established Calay-Ab fish sanctuary. This involved (1) counting the number of intact AR units, (2) observing and identifying marine organisms attached to the structures, and (3) documenting the presence and types of fish species associated with the ARs. These observations contribute to understanding the ecological performance of ARs in enhancing local biodiversity and supporting fish habitats.

2.2. Reef fish community

The reef fish community was assessed using the fish visual census (FVC) method (Figure 2). The FVC technique is widely used to estimate the diversity, abundance, and size distribution of common, observable reef fishes in areas with good underwater visibility, as described by Eballe (2014) and English et al. (1997). These data provide important indicators of the status and

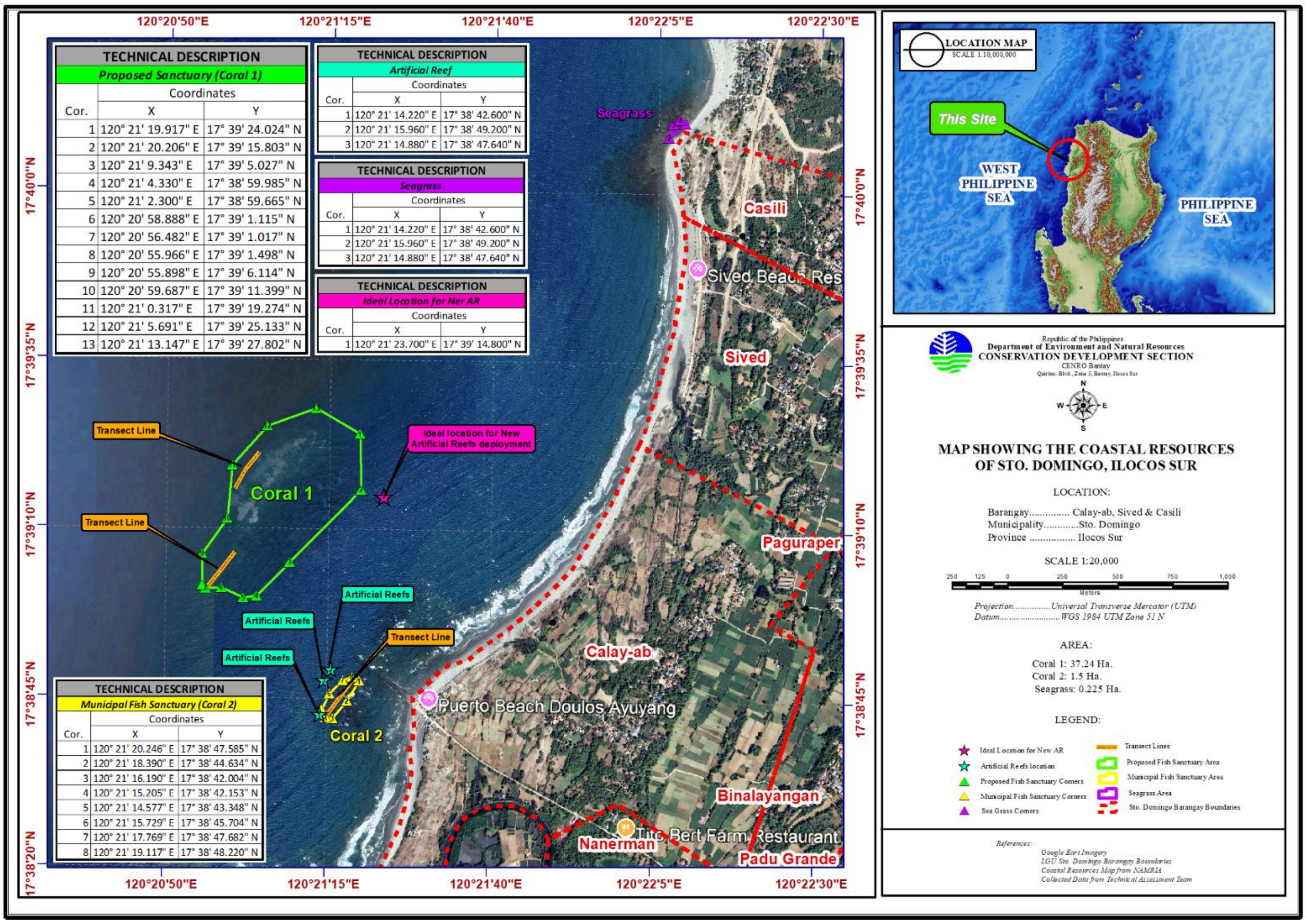

Figure 1. Map showing the assessment site in the municipality of Sto. Domingo, Ilocos Sur, Philippines

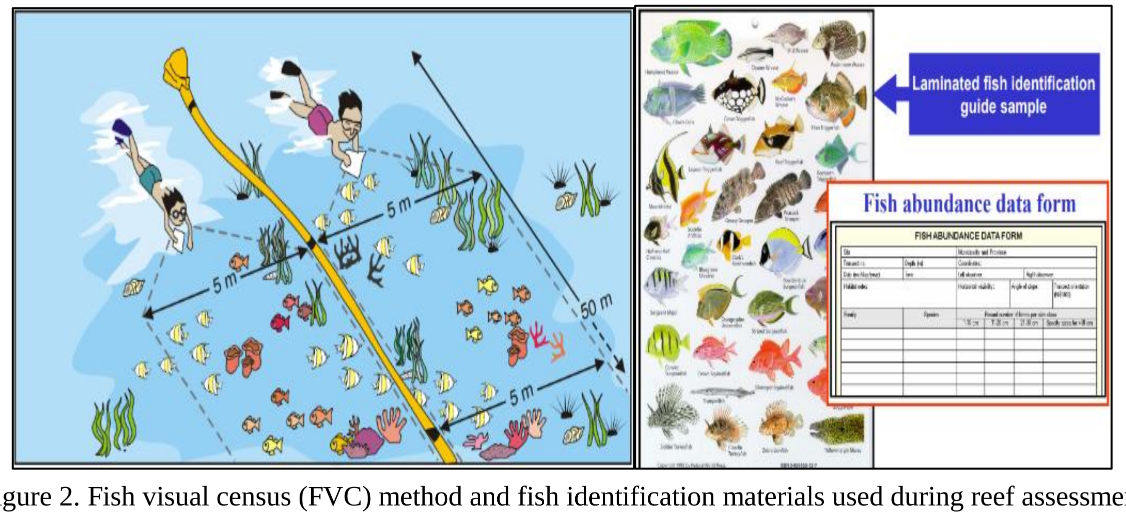

Figure 2. Fish visual census (FVC) method and fish identification materials used during reef assessment

health of fish stocks within the surveyed reef areas. A 100-m transect line was deployed as the survey area, with observations conducted within a 5-m belt on either side, covering a total area of 500 m² per transect. Fish species encountered along the transect were recorded, including counts and estimated lengths (in cm). Fish data were grouped and summarized by species and families to evaluate species diversity and abundance. Mean fish abundance was calculated as the number of individuals observed per 500 m². Biomass estimates were derived using species-specific length-weight relationships, enabling an assessment of total fish biomass within each transect. Dominant fish families and species were identified to reflect the current ecological status of the coral reef habitats.

2.3. Diversity, relative abundance, and frequency

All calculations for relative abundance, Shannon-Wiener diversity index (H'), Pielou's evenness index (J'), and fish biomass were computed using Microsoft Excel 2021 following standard ecological formulas described by Odum and Barrett (2004) and Pielou (1966).

Relative abundance (K) of each fish species was calculated using Odum and Barrett (2004) formula, as:

$$K = \frac{\text{The amount of species (i)}}{\text{The number of individuals of all species}} \times 100 \quad (1)$$

The Shannon-Wiener Index method was used to measure biodiversity in a community, including fish species in aquatic ecosystems using this formula:

$$H' = -\sum (P_i \times \ln(P_i)) \quad (2)$$

Where, H' is the Shannon-Wiener Index; Σ is the sum over all species; Pi is the proportion of individuals belonging to the i-th species in the community; and ln is the natural logarithm.

To describe the index, the criteria given by Gervaňa and Pampilona (2009) in Table 1 are used.

Meanwhile, Pielou's evenness index is used to measure the equitability among species in reef-associated fishes (Pielou, 1966). The evenness index (J) indicates the relative abundance of each species. An index value close to 1 signifies that the individuals are relatively evenly distributed; furthermore, if it is close to 0, it means that the numbers of individuals across species are unevenly distributed.

$$J' = \frac{H'}{\ln S} \quad (3)$$

Where, J' is the evenness index, H' is the diversity index, and S is the number of species. For the evenness criteria, Table 2 is used.

2.5. Data analysis

The study employed a descriptive ecological assessment approach. Data interpretation was based on observed numerical values of fish abundance, diversity indices, evenness, and biomass. No inferential statistical analyses (e.g., Mann–Whitney U test, ANOSIM, or PERMANOVA) were applied because the assessment was intended to provide baseline descriptive information from a single survey period. In addition, the number of transects and sampling replicates was limited, which may not be sufficient to support robust statistical comparisons between reef areas.

Table 1. Diversity index classification scale (Gervaňa & Pampilona, 2009)

Category	H' values
Very high	≥3.5000
High	3.0000-3.4999
Moderate	2.5000-2.9999
Low	2.0000-2.4999
Very low	≤1.9999

Table 2. Evenness index classification scale

Evenness value	Condition of community structures	Category
>0.81	Very equally	Very good
0.61-0.80	More equally	Good
0.41-0.60	Equally	Medium
0.21-0.40	Fairly equally	Poor
<0.20	Not equally	Very Poor

2.4. Biomass

Biomass of fish is commonly computed using a standard length-weight relationship formula in fisheries science, as:

$$W = f(a \times L^b) \quad (4)$$

Where, W is an estimated weight of the fish (in grams); L is the length of the fish (cm); a and b are the species-specific constants; and f is the number of counts of fish species. Table 3 presents the fish density and biomass scale.

Table 3. Fish density and biomass metrics (Nañola et al., 2004)

Category	Fish Density (species/1000 m²)	Fish Biomass (MT/km²)
Very high	>7592	≥41
High	2268-7592	21-40
Moderate	677-2267	11-20
Poor	202-676	6-10
Very poor	<202	≤5

3. Results and Discussion

3.1. Fish abundance and diversity

The FVC identified a total of 43 species and 18 families of reef fishes commonly associated with corals at the study sites (Table 4). Within the Clay-Ab municipal fish sanctuary, a total of 28 species across 13 families were identified. The predominant ten fish families recorded are the Pomacentridae (damselfishes), Mullidae (goatfishes), Lutjanidae (snappers), Labridae

Table 4. Reef fishes identified and their IUCN Red List status in the study sites

Family name	Scientific name	English name	Local name	Study sites: Established Calay-Ab Fish Sanctuary	Study sites: Proposed MPA	IUCN Status
Acanthuridae	*Acanthurus lineatus*	Lined surgeonfish	Pugpugot	✓		LC
	Acanthurus pyroferus	Chocolate surgeon fish	Pugpugot		✓	LC
	Ctenochaetus strigosus	Fivelined bristletooth	Pugpugot	✓	✓	LC
	Naso unicornis	Bluespine unicornfish	Sungayan	✓		LC
Apogonidae	*Fibramia amboinensis*	Amboina cardinal fish	Bagsang-bakes	✓		DD
Balistidae	*Rhinecanthus verrucosus*	Blackbelly triggerfish	Papakol		✓	LC
Chaetodontidae	*Chaetodon unimaculatus*	Teardrop butterfly fish	Par-parya	✓	✓	LC
	Chaetodon punctatofasciatus	Spotbond butterfly fish	Par-parya	✓	✓	LC
	Chaetodon rafflesii	Latticed butterflyfish	Par-parya	✓		LC
	Chaetodon vagabandus	Vagabond butterfly fish	Par-parya		✓	LC
	Chaetodon xanthurus	Pearlscale butterfly fish	Par-parya		✓	LC
	Ostorhinchus bryx	Offshore cardinalfish	Bagsang-bakes	✓		LC
Cirrhitidae	*Cirrhitichthys falco*	Dwarf hawkfish	Angrat		✓	LC
Epinephelidae	*Cephalopholis urodeta*	Darkfin hind	Lapu-lapu	✓	✓	LC
Holocentridae	*Myripristis murdjan*	Pinecone soldierfish	Baratiktik	✓	✓	LC
Labridae	*Bodianus mesothorax*	Splitlevel hogfish	Mol-mol		✓	LC
	Cheilio inermis	Cigar wrasse	Mol-mol	✓		LC
	Gomphosus varius	Bird wrasse	Mol-mol		✓	LC
	Halichoeres hortulanus	Checkerboard wrasse	Mol-mol		✓	LC
	Halichoeres nebulosus	Nebulous wrasse	Mol-mol	✓		LC
	Hemigynus fasciatos	Barred thicklip wrasse	Mol-mol		✓	LC
	Labroides dimidiatus	Bluestreak cleaner wrasse	Mol-mol	✓	✓	LC
Lutjanidae	*Lutjanus lutjanus*	Big-eye snapper	Baratiktik	✓	✓	LC
	Lutjanus russelli	Russell's snapper	Baratiktik	✓	✓	LC
	Lutjanus timorensis	Timor snapper	Bugbugsi	✓	✓	LC
Mullidae	*Parupeneus barberinus*	Dash-and-dot goatfish	Balaki	✓	✓	LC
	Upeneus quadrilineatus	Fourstripe goatfish	Balaki	✓		NE
Pomacanthidae	*Chaetodonplus mesoleucus*	Vermiculated angelfish	Bibiran		✓	LC
	Pomacanthus imperator	Emperor angelfish	Bibiran	✓	✓	LC
Pomacentridae	*Abudefduf vaigiensis*	Indopacific sergeant	Ar-aro	✓	✓	LC
	Neopomacentrus azysron	Yellowtail demoiselle	Ar-aro	✓		LC
	Pomacentrus philippinus	Philippine damsel	Ar-aro	✓	✓	LC
	Pycnochromis caudalis	Blue axil chromis	Ar-aro	✓	✓	LC
	Pygoplites diacanthus	Royal angelfish	Bibiran		✓	LC
Scaridae	*Chlorurus bowersi*	Bower's parotfish	Mol-mol		✓	NT
Scorpaenidae	*Pterois volitans*	Red lionfish	*		✓	LC
Siganidae	*Siganus puellus*	Masked spinefoot	Malaga	✓		LC
	Siganus spinus	little spinefoot	Malaga	✓		LC
	Siganus sutor	Shoemaker spinefoot	Malaga	✓		LC
	Siganus vulpinus	Fox face	Malaga		✓	LC
Tetraodontidae	*Arothron nigropunctatus*	Blackspotted puffer	Butete		✓	LC
Terapontidae	*Terapon puta*	Small-scaled terapon	Baraungan	✓		NE
Zanclidae	*Zanclus cornutus*	Moorish idol	Bayang bayang	✓	✓	LC

** for verification.*
IUCN red list: LC – Least Concerned; VU -Vulnerable; NT – Non-Threatened; DD -Data Deficient; NE – Not Evaluated.

(wrasses), Apogonidae (cardinalfish), Acanthuridae (surgeonfishes), Siganidae (spinefoot fishes), Pomacanthidae (angelfish), Holocentridae (squirrelfishes), and Chaetodontidae (butterflyfishes). The three least represented families are Epinephelidae, Zanclidae, and Terapontidae. The FVC also showed that most species are listed as Least Concern (LC), three as Not Evaluated (NE), and one as Data Deficient (DD) on the IUCN Red List.

Meanwhile, in the proposed MPA, FVC results indicated that 30 species from 16 families were initially observed. The top ten fish families recorded are the Acanthuridae (surgeonfishes), Pomacentridae (damselfishes), Lutjanidae (snapper), Labridae (wrasses), Pomacanthidae (angelfish), Chaetodontidae (butterflyfishes), Epinephelidae (groupers), Mullidae (goatfishes), Balistidae (triggerfish), and Cirrhitidae (hawkfishes). The least are Holocentridae, Zanclidae, Siganidae, Scaridae, Scorpaenidae, and Tetraodontidae families. The FVC also showed that most species are categorized as Least Concerned (LC), with one species classified as Non-Threatened (NT) category based on the IUCN Red List.

For fish counts and abundance, established Calay-Ab fish sanctuary recorded a total of 658 fish individuals across 28 species from 13 families (Table 5). The dominant species were Timor snapper (*L. timorensis*, 13.68%), blue Axil chromis (*P. caudalis*, 12.92%), dash-and-dot goatfish (*P. barberinus*, 9.73%), bluestreak cleaner wrasse (*L. dimidiatus*, 8.05%), and yellowtail demoiselle (*N. azysron*, 7.60%). Species with the lowest abundance included small-scaled terapon (*T. puta*, 0.15%) and lined surgeonfish (*A. lineatus*, 0.15%). These results align with studies by Russ et al. (2004), who found that protected reefs tend to harbor higher abundances of commercially important species such as snappers and goatfishes, reflecting effective management in fish sanctuaries.

Table 5. Fish counts and relative abundance of recorded species in the established Calay-Ab fish sanctuary

Scientific name	English name	Count			Abundance (%)
		T1	T2	Total	
Lutjanus timorensis	Timor snapper	40	50	90	13.68
Pycnochromis caudalis	Blue axil chromis	50	35	85	12.92
Parupeneus barberinus	Dash-and-dot goatfish	60	4	64	9.73
Labroides dimidiatus	Bluestreak cleaner wrasse	38	15	53	8.05
Neopomacentrus azysron	Yellowtail demoiselle	40	10	50	7.60
Upeneus quadrilineatus	Fourstripe goatfish	15	20	35	5.32
Ctenochaetus strigosus	Fivelined bristletooth	20	13	33	5.01
Fibramia amboinensis	Amboina cardinal fish	20	10	30	4.56
Ostorhinchus bryx	Offshore cardinalfish	30	0	30	4.56
Pomacentrus philippinus	Philippine damsel	10	18	28	4.25
Pomacanthus imperator	Emperor angelfish	21	5	26	3.96
Halichoeres nebulosus	Nebulous wrasse	20	5	25	3.80
Siganus spinus	Little spinefoot	0	20	20	3.04
Siganus puellus	Masked spinefoot	8	5	13	1.98
Myripristis murdjan	Pinecone soldierfish	8	5	13	1.98
Cheilio inermis	Cigar wrasse	4	8	12	1.82
Abudefduf vaigiensis	Indopacific sergeant	8	2	10	1.52
Cephalopholis urodeta	Darkfin hind	5	2	7	1.06
Chaetodon unimaculatus	Teardrop butterfly fish	6	0	6	0.91
Naso unicornis	Bluespine unicornfish	3	3	6	0.91
Lutjanus russellii	Russell's snapper	2	3	5	0.76
Zanclus cornutus	Moorish idol	3	1	4	0.61
Chaetodon punctatofasciatus	Spotbond butterfly fish	4	0	4	0.61
Lutjanus lutjanus	Big-eye snapper	3	0	3	0.46
Siganus sutor	Shoemaker spinefoot	0	2	2	0.30
Chaetodon rafflesii	Latticed butterflyfish	0	2	2	0.30
Terapon puta	Small-scaled terapon	1	0	1	0.15
Acanthurus lineatus	Lined surgeonfish	1	0	1	0.15
	Total	420	238	658	100

Table 6. Fish counts and relative abundance of fish species recorded in the proposed MPA in the Calay-Ab-Sived reef area

Scientific name	English name	Count				Abundance (%)
		T1	T2	T3	Total	
Ctenochaetus strigosus	Fivelined bristletooth	109	75	0	184	20.35
Pycnochromis caudalis	Blue axil chromis	79	20	39	138	15.27
Pomacentrus philippinus	Philippine damsel	70	31	15	116	12.83
Acanthurus pyroferus	Chocolate surgeon fish	19	20	45	84	9.29
Lutjanus timorensis	Timor snapper	3	50	0	53	5.86
Lutjanus lutjanus	Big-eye snapper	18	0	18	36	3.98
Cephalopholis urodeta	Darkfin hind	7	3	15	25	2.77
Parupeneus barberinus	Dash-and -dot goatfish	15	4	4	23	2.54
Pomacanthus imperator	Emperor angelfish	13	0	8	21	2.32
Chaetodontoplus mesoleucus	Vermiculated angelfish	10	10	0	20	2.21
Gomphosus varius	Bird wrasse	8	2	10	20	2.21
Bodianus mesothorax	Splitlevel hogfish	10	10	0	20	2.21
Labroides dimidiatus	Bluestreak cleaner wrasse	4	4	8	16	1.77
Hemigymnus fasciatus	Barred thicklip wrasse	8	8	0	16	1.77
Halichoeres hortulanus	Checkerboard wrasse	0	0	16	16	1.77
Myripristis murdjan	Pinecone soldierfish	0	1	14	15	1.66
Cirrhitichthys falco	Dwarf hawkfish	2	2	11	15	1.66
Rhicanthus verrucosus	Blackbelly triggerfish	0	3	12	15	1.66
Zanclus cornutus	Moorish idol	3	3	7	13	1.44
Siganus vulpinus	Fox face	6	0	6	12	1.33
Chaetodon vagabandus	Vagabond butterfly fish	3	3	4	10	1.11
Chlorurus bowersi	Bower's parrotfish	1	0	8	9	1.00
Chaetodon unimaculatus	Teardrop butterfly fish	2	2	3	7	0.77
Abudefduf vaigiensis	Indopacific sergeant	5	0	0	5	0.55
Chaetodon punctatofasciatus	Spotbond butterfly fish	2	2	1	5	0.55
Chaetodon xanthurus	Pearlscale butterfly fish	1	1	2	4	0.44
Pygoplites diacanthus	Royal angelfish	3	0	0	3	0.33
Arothron nigropunctatus	Blackspotted puffer	1	0	0	1	0.11
Lutjanus ruselli	Russell's snapper	1	0	0	1	0.11
Pterrois volitans	Red lionfish	0	0	1	1	0.11
	Total	403	254	247	904	100

Meanwhile, in the proposed MPA in the Calay-Ab-Sived reef area, a total of 904 individuals from 30 species across 16 families were recorded (Table 6). The most abundant species were fivelined bristletooth (*C. strigosus*, 20.35%), blue Axil chromis (*P. caudalis*, 15.27%), Philippine damsel (*P. philippinus*, 12.83%), chocolate surgeonfish (*A. pyroferus*, 9.29%), and Timor snapper (*L. timorensis*, 5.86%). Less abundant species included blackspotted puffer (*A. nigropunctatus*, 0.11%) and Red lionfish (*P. volitans*, 0.11%). The prevalence of herbivorous fishes such as *C. strigosus* and *A. pyroferus* supports observations by Hoey and Bellwood (2009), who emphasized the critical role of herbivores in maintaining coral reef resilience by controlling algal overgrowth.

The common distribution of reef fishes across two reef areas was observed. This provides vital insights into the ecological structure and functioning of each site, as trophic structure reflects the stability of the food web, energy flow, and habitat quality. In the established Calay-Ab fish sanctuary, fish families such as Zanclidae (Moorish idol), Pomacentridae (damselfishes), Labridae (wrasses and hogfishes), Cirrhitidae (hawkfishes), and Scorpaenidae (lionfishes) were observed. These species generally function as herbivores, planktivores, and small invertivores—fulfilling critical roles in algae control, habitat maintenance, and nutrient cycling (Bellwood et al., 2004; Hoey and Bellwood, 2009). Their prevalence indicates that the reef provides an appropriate habitat structure and forage availability, signifying a moderate level of ecological stability. Meanwhile, the target fish group fish population, includes economically important species such as groupers (*Epinephelidae*), snappers (*Lutjanidae*), rabbitfishes (*Siganidae*), and parrotfishes (*Scaridae*). These species are often subject to fishing pressure due to their high commercial value (Cinner et al., 2009; Elston et al., 2020). Their abundance signals the area's importance to fisheries, though it may also indicate potential risks of overexploitation if not sustainably managed. Furthermore, indicator species such as angelfishes (*Pomacanthidae*) and butterflyfishes (*Chaetodontidae*), which are highly sensitive to coral degradation and depend on live coral for food and shelter (Hourigan et al., 1989; Pratchett, 2005; Pratchett et al., 2006).

Meanwhile, a comparable pattern is evident in the proposed MPA, where the target fish observed reinforces the reef's role as a key fishing ground. Species contributing to this group include *Terapontidae*, *Mullidae* (goatfishes), *Lutjanidae*, *Holocentridae* (soldierfishes), and *Acanthuridae* (surgeonfishes), many of which are known for their trophic versatility and ecological importance (Friedlander & Parrish, 1998; Elston et al., 2020). Other species also indicate that the reef is still capable of supporting a wide array of resident fish, including *Pomacentridae*, *Zanclidae*, *Labridae*, and *Apogonidae* (cardinalfishes). This indicates a functionally balanced ecosystem, though perhaps still facing localized stress. Meanwhile, an indicator group of fish is observed; their presence echoes the pattern at the sanctuary site and further suggests suboptimal coral habitat conditions (Wainwright & Bellwood, 2002; Bellwood et al., 2004; Green & Bellwood, 2014). This wide distribution of fish highlights the need for coral habitat restoration and management strategies that protect herbivores and coral-dependent species to maintain ecosystem resilience.

Among the top 20 species documented in Sto. Domingo, Ilocos Sur, data on FVC results from both sites revealed a total of 1562 fish individuals (Table 7). The predominant species include *P. caudalis*, *C. strigosus*, *P. philippinus*, *L. timorensis*, and *P. barberinus*, representing the major fish families Pomacentridae, Acanthuridae, Lutjanidae, and Mullidae. These findings align with the reef fish community structures documented in Philippine reefs (Alcala & Russ, 2006). This suggests a reef ecosystem characterized by a balanced composition of planktivores and herbivores, which are essential for sustaining ecological functions.

Table 7. Top 20 fish species recorded in Sto. Domingo, Ilocos Sur and its diversity indices

Rank	Scientific name	English name	Count		Total Count
			Established Calay-Ab Fish Sanctuary	Proposed MPA	
1	*Pycnochromis caudalis*	Blue Axil Chromis	85	138	223
2	*Ctenochaetus strigosus*	Fivelined bristletooth	33	184	217
3	*Pomacentrus philippinus*	Philippine Damsel	28	116	144
4	*Lutjanus timorensis*	Timor snapper	90	53	143
5	*Parupeneus barberinus*	Dash-and-dot goatfish	64	23	87
6	*Acanthurus pyroferus*	Chocolate Surgeon fish	0	84	84
7	*Labroides dimidiatus*	Bluestreak cleaner wrasse	53	16	69
8	*Neopomacentrus azysron*	Yellowtail demoiselle	50	0	50
9	*Pomacanthus imperator*	Emperor Angelfish	26	21	47
10	*Lutjanus lutjanus*	Big-eye snapper	3	36	39
11	*Upeneus quadrilineatus*	Fourstripe goatfish	35	0	35
12	*Cephalopholis urodeta*	Darkfin hind	7	25	32
13	*Fibramia amboinensis*	Amboina cardinal fish	30	0	30
14	*Ostorhinchus bryx*	Offshore cardinalfish	30	0	30
15	*Myripristis murdjan*	Pinecone soldierfish	13	15	28
16	*Halichoeres nebulosus*	Nebulous wrasse	25	0	25
17	*Bodianus mesothorax*	Splitlevel hogfish	0	20	20
18	*Chaetodonplus mesoleucus*	Vermiculated Angelfish	0	20	20
19	*Gomphosus varius*	Bird wrasse	0	20	20
20	*Siganus spinus*	Little spinefoot	20	0	20
21	Others		66	133	199
		Total	658	904	1562
		H' values	2.719	2.485	2.602 (ave.)
		J' values	0.109	0.108	0.108 (ave.)

For the species diversity index, the established Calay-Ab fish sanctuary exhibited a higher diversity index (*H'*=2.719), categorized as moderate (2.5–2.99), whereas the proposed MPA site demonstrated a slightly lower diversity index (*H'*=2.485), classified as low diversity (2.0–2.49). The average *H'* value for both locations is 2.602, which indicates a moderate level of species diversity overall. These observations indicate variation in fish community composition between the surveyed reef areas. Diversity is often linked to habitat complexity and protection status; protected reefs tend to recruit and host more species due to reduced disturbances and better ecological integrity (Russ et al., 2004; Alcala & Russ, 2006).

Meanwhile, in terms of species evenness, both sites exhibited exceptionally low *J'* values (Calay-Ab = 0.109; Calay-Ab–Sived = 0.108), signifying that fish populations are distributed unevenly, with a limited number of species numerically dominating the community. According to Pielou's classification, values below 0.3 indicate very poor evenness, suggesting ecological stress or imbalance within the system (Pielou, 1966). The low evenness is commonly associated with disturbed or overexploited ecosystems, where competitive exclusion, overfishing, or habitat simplification allows certain resilient or opportunistic species to dominate (McClanahan et al., 1999; Hughes et al., 2007). These conditions may reduce niche availability for less dominant species, leading to skewed community structures. Despite the low evenness, the dominance of commercially important species—such as fivelined bristletooth (*C. strigosus*), chocolate surgeonfish (*A. pyroferus*), Timor snapper (*L. timorensis*), and Dash-and-dot goatfish (*P. barberinus*)—is ecologically and economically significant. These species contribute to reef productivity and local fisheries, highlighting the potential for these reef areas to support sustainable fishery activities, if properly managed.

3.2. Fish biomass

The Fish biomass employs a length-weight relationship to estimate the weight of an individual fish based on its length measured during the FVC. Parameters '*a*' and '*b*' are specific to each fish species and are used to calculate the estimated weight for each species. The estimated weight, when multiplied by the number of fishes, produces the total fish biomass. Therefore, both fish size and abundance (number of individuals) are significant factors in overall fish biomass. Thus, Table 8 presents the total count and average length of fish species from the two assessed sites, utilizing the constants '*a*' and '*b*' obtained from Froese and Pauly (2025). The findings from the FVC indicate that the recorded fish species are typically smaller than the maximum lengths reported in FishBase, however, high biomass estimate was still recorded (Table 9). Observations on the established Calay-Ab fish sanctuary contained slightly larger reef fishes than the proposed MPA. In fisheries, it is often targeted at larger, commercially valuable fish, which reduces biomass and is often due to open access or the absence of regulation. Although reef fishes in the proposed MPA in Calay-Ab–Sived area were generally smaller, their high abundance still contributed considerably to total biomass.

The established Calay-Ab municipal fish sanctuary recorded relatively higher fish biomass (26.289 MT/km^2) than the proposed Calay-Ab–Sived reef area (21.849 MT/km^2) during the assessment period. This observed variation may be associated with differences in protection status, habitat condition, or fishing pressure. However, since the study was based on a single survey event, the findings should be interpreted cautiously and primarily serve as baseline ecological information for future monitoring and management assessments. Numerous studies have shown that well-managed MPAs lead to increased fish biomass, size structure, and species richness due to reduced fishing mortality (Halpern, 2003; Russ et al., 2005). The absence of extractive activities allows larger-bodied and longer-lived species to flourish, enhancing reproductive output and ecological resilience (Mumby & Harborne, 2010). Conversely, proposed MPA, with a wider area than the established Calay-Ab fish sanctuary, has lower biomass and is not formally protected, reflecting continued exposure to fishing pressure, habitat disturbance, or other anthropogenic stressors that limit fish recovery (Jackson et al., 2001). Fishing in unprotected areas often targets top predators and large herbivores, leading to trophic downgrading and reduced ecological complexity (Dulvy et al., 2004). Moreover, habitat quality is dependent to the structurally complex reef features that offer refuge and foraging areas for reef-associated fish (McClanahan et al., 2007). A healthy fish biomass contributes to ecosystem services, such as nutrient cycling and reef maintenance, and provides spillover benefits to adjacent fished areas (Roberts et al., 2001; Russ & Alcala, 2010). Furthermore, a prior investigation also asserts that increased biomass was subjected to overfishing beyond the MPA. In their research, although the existing locally managed MPAs were not sufficiently effective for the management of coral reef fisheries, they were nonetheless superior to the absence of any MPA altogether (Muallil et al., 2019).

Table 8. Average length of reef fishes in Calay-Ab and Calay-Ab-Sived, Sto. Domingo, Ilocos Sur along with the maximum length obtained in FishBase

Scientific Name	English Name	Established Calay-Ab Fish Sanctuary		Proposed MPA		Total Count	Max. Length (cm)	*a*	*b*
		Count	Size Range (cm)	Count	Size Range (cm)				
Pycnochromis caudalis	Blue axil chromis	85	4-5	138	2-3	223	7.5	0.09200	2.415
Ctenochaetus strigosus	Fivelined bristletooth	33	8-10	184	8-9	217	15	0.00222	3.000
Pomacentrus philippinus	Philippine damsel	28	7-8	116	4-5	144	10	0.01130	2.681
Lutjanus timorensis	Timor snapper	90	10-13	53	9-10	143	73.7	0.03820	2.950
Parupeneus barberinus	Dash-and-dot goatfish	64	9-10	23	9-10	87	60	0.00955	3.110
Acanthurus pyroferus	Chocolate surgeon fish	0	0	84	12-13	84	29	0.00179	3.000
Labroides dimidiatus	Bluestreak cleaner wrasse	53	4-5	16	2-3	69	14	0.00760	3.105
Neopomacentrus azysron	Yellowtail demoiselle	50	7-8	0	0	50	7.5	0.02970	2.868
Pomacanthus imperator	Emperor angelfish	26	8-10	21	9-10	47	40	0.09590	2.770
Lutjanus lutjanus	Big-eye snapper	3	9-10	36	15-16	39	35	0.02350	2.807
Upeneus quadrilineatus	Fourstripe goatfish	35	9-10	0	0	35	17	0.00630	3.593
Cephalopholis urodeta	Darkfin hind	7	13-15	25	9-10	32	28	0.02822	2.818
Fibramia amboinensis	Amboina cardinal fish	30	4-5	0	0	30	7	0.02550	2.857
Ostorhinchus bryx	Offshore cardinalfish	30	4-5	0	0	30	5.2	0.00870	3.360
Myripristis murdjan	Pinecone soldierfish	13	9-10	15	8-9	28	60	0.02310	3.267
Halichoeres nebulosus	Nebulous wrasse	25	8-10	0	0	25	12	0.02100	3.000
Bodianus mesothorax	Splitlevel hogfish	0	0	20	4-5	20	25	0.01470	3.000
Chaetodonplus mesoleucus	Vermiculated angelfish	0	0	20	9-10	20	18	0.06010	2.692
Gomphosus varius	Bird wrasse	0	0	20	4-5	20	30	0.01470	3.000
Siganus spinus	little spinefoot	20	4-5	0	0	20	28	0.02640	3.122
Zanclus cornutus	Moorish idol	4	14-15	13	15-16	17	23	0.01720	3.171
Halichoeres hortulanus	Checkerboard wrasse	0	0	16	2-3	16	27	0.01485	3.000
Hemigynus fasciatos	Barred thicklip wrasse	0	0	16	3-4	16	30	0.02890	3.000
Abudefduf vaigiensis	Indopacific sergeant	10	6-7	5	10	15	20	0.08740	2.779
Cirrhitichthys falco	Dwarf hawkfish	0	0	15	2-3	15	8	0.01720	2.977
Rhicanthus verrucosus	Blackbelly triggerfish	0	0	15	9-10	15	23	0.01200	3.080
Chaetodon unimaculatus	Teardrop butterfly fish	6	7-8	7	8-9	13	20	0.05330	2.833
Siganus puellus	Masked spinefoot	13	9-10	0	0	13	38	0.01761	3.028
Cheilio inermis	Cigar wrasse	12	6-7	0	0	12	50	0.00400	3.010
Siganus vulpinus	Fox face	0	0	12	11-12	12	25	0.01616	3.000
Chaetodon vagabandus	Vagabond butterfly fish	0	0	10	6-7	10	23	0.03120	2.953
Chaetodon punctatofasciatus	Spotbond butterfly fish	4	7-8	5	9-10	9	12	0.02470	3.106
Chlorurus bowersi	Bower’s parotfish	0	0	9	11-12	9	40	0.02470	3.140
Lutjanus ruselli	Russell’s snapper	5	9-10	1	16	6	50	0.00708	3.234
Naso unicornis	Bluespine unicornfish	6	12-15	0	0	6	70	0.03140	3.037
Chaetodon xantharus	Pearlscale butterfly fish	0	0	4	8-9	4	14	0.00420	3.808
Pygoplites diacanthus	Royal angelfish	0	0	3	12	3	25	0.00514	3.000
Chaetodon rafflesii	Latticed butterflyfish	2	7-8	0	0	2	18	0.05330	2.833
Siganus sutor	Shoemaker spinefoot	2	8-9	0	0	2	45	0.03280	2.716
Acanthurus lineatus	Lined surgeonfish	1	15	0	0	1	38	0.04750	2.810
Arothron nigropunctatus	Blackspotted puffer	0	0	1	15	1	33	0.00534	3.000
Pterrois volitans	Red lionfish	0	0	1	11-12	1	45.7	0.00520	3.160
Terapon puta	Small-scaled terapon	1	8-9	0	0	1	30	0.01023	3.000
	Total	658		904		1562			

Table 9. Fish biomass of two reef areas in Sto. Domingo, Ilocos Sur, Philippines

Sampling Sites	Biomass (MT/km^2)	
	Established Calay-Ab Fish Sanctuary	Proposed MPA
Transect 1	16.088	8.909
Transect 2	10.201	5.646
Transect 3	-	7.294
Total	26.289	21.849

Collectively, the biomass results within the established Calay-Ab fish sanctuary may suggest improved habitat quality due to current regulations. Nonetheless, the effectiveness of these regulations should be consistently monitored and evaluated to ensure the preservation of fish diversity and the enhancement of fish biomass over time. Additionally, the proposed MPA should not be overlooked, given its promising biomass and potential for substantial spillover benefits when properly conserved and managed, owing to its higher coral cover. These findings strongly support the need for continued, more rigorous enforcement of laws, coupled with the LGU's advocacy for the whole community to encourage the expansion of sanctuary zones. Such measures are essential for maintaining biodiversity and promoting sustainable fisheries in Sto. Domingo and surrounding areas.

3.3. Physical characteristics of AR structure

A total of 86 ARs units were strategically deployed in 2016 off the coast of established Calay-Ab fish sanctuary in Sto. Domingo, Ilocos Sur. Subsequent monitoring revealed that 59 AR units are intact and visible, representing a retention rate of approximately 69% during the assessment. The observed colonization and biological activity around these units suggest that the ARs are performing their intended ecological and fisheries enhancement functions. During field assessments, a diverse range of sessile and mobile marine life was documented (Table 10). Early-stage colonizers included seaweeds such as *Halymenia* spp. and brown macroalgae (Ochrophyta), as well as soft corals, particularly presumptive Gorgonians. These pioneer organisms are well documented to contribute considerably to habitat complexity, thereby promoting successional reef development by providing food and shelter for various reef-associated species (Perkol-Finkel & Benayahu, 2005; Toledo et al., 2020). Their presence signifies the early to mid-successional stage of AR ecological maturation. Similar observations were reported by Toring-Farquerabao et al. (2021) in Tigbauan, Iloilo, Philippines, where deployed ARs were gradually colonized by benthic organisms such as soft corals and sponges and attracted reef fishes over time.

Table 10. Aquatic resources documented in the deployed fish ARs

Aquatic Resources Identified	Phylum/Family	Scientific Name	English/*Local* Name	IUCN Red List Status
Reef Associated-Fish	Lutjanidae	*Lutjanus timorensis*	Timor snapper/*Bugbugsi*	LC
	Zanclidae	*Zanclus cornutus*	*Bayang bayang*	LC
	Tetraodontidae	*Arothron nigropunctatus*	Blackspotted Puffer/*Butete*	LC
	Haemulidae	*Plectorhinchus* spp.	Sweetlips	LC/DD
Reptiles	Cheloniidae	*Chelonia mydas*	Green Sea Turtle	EN
Seaweed	Halymeniaceae	*Halymenia* spp.	Red Algae	DD
	Ochrophyta		Brown Algae	-
Soft corals	Gorgonians		*	-

**for verification*

One of its ecological importance was the sighting of an endangered sea turtle, a species listed under Appendix I of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). Observations of this highly mobile and habitat-sensitive species suggest that the AR site may now serve as a feeding ground or refuge, underscoring its conservation significance for many significant marine resources (Higgins et al., 2022). In addition, several economically and ecologically valuable reef fish species were recorded around the ARs. These include Timor snapper, moorish idol, blackspotted puffer, and Sweetlips. These species are associated with reef-dependent ecological functions such as predation, herbivory, and consumption of plankton, and they rely on structurally complex environments for feeding, shelter, and reproduction (Bohnsack & Sutherland, 1985). Their presence further highlights the role of ARs in enhancing local biodiversity, restoring fish habitats, and potentially boosting the productivity of artisanal fisheries in the long term (Seaman, 2000). Overall, the current biological profile of the ARs reflects positive ecological trends, although continued monitoring is essential to evaluate long-term reef development, structural stability, and fisheries yield. Maintaining these ARs can be a critical strategy for coral reef conservation, particularly in areas where natural reef recovery is limited by anthropogenic pressures.

4. Conclusion

This study provides baseline ecological information on reef fish diversity, abundance, biomass, and artificial reef conditions in Sto. Domingo, Ilocos Sur, Philippines. The assessment documented 1562 reef fish individuals representing 43 species from 18 families across the surveyed reef areas. The established Calay-Ab fish sanctuary recorded slightly higher diversity and biomass values than the proposed MPA area during the assessment period. However, since the study was conducted during a single survey period, the findings represent only a temporal snapshot and should therefore be interpreted cautiously. Furthermore, because the study employed limited sampling replication, the observed variations between reef areas should be regarded as descriptive observations rather than statistically significant differences. Continued long-term monitoring and strengthened coastal management are recommended to further evaluate reef condition, fish community dynamics, and the potential effectiveness of marine protection measures in the area.

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Conflict of interest

The authors declare no conflict of interest.

Ethical Approval

This article does not require ethics committee approval.

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Effects of organic fertilizer applications on marketable yield and tuber size distribution in potato

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Abstract

This study aimed to determine the effects of individual and combined applications of different organic fertilizers on marketable tuber yield and tuber size distribution of potato grown under high-altitude ecological conditions over two growing seasons (2020-2021). In the experiment, cattle (C), sheep (S), vermicompost (V), and poultry (P) manures were applied either individually or in specific combinations. The results indicated that fertilizer treatments significantly affected total yield, marketable yield, and tuber size distribution in both years. Generally, combined applications outperformed individual applications. Specifically, the highest marketable tuber yield (22.0 t ha^{-1}) and marketable tuber proportion (87.9%) were obtained from the T16 treatment. While the highest large tuber yields were recorded in T13 (14.3 t ha^{-1}) and T16 (13.5 t ha^{-1}) treatments, the maximum medium and small tuber yields were found in T11 (9.6 t ha^{-1}) and T4 (3.7 t ha^{-1}) treatments, respectively. Increasing the number of organic fertilizers applied in combination enhanced the proportion of marketable and large tubers while reducing the proportion of small and cull tubers. The application of cattle, sheep, vermicompost, and poultry manures at 25% each of their recommended doses (T16 - C×S×V×P) provided the highest marketable tuber yield and the most balanced size distribution among all treatments. In this treatment, the proportion of marketable tubers reached 87.9%, whereas the cull tuber ratio decreased to 3.6%. The combined use of diverse organic fertilizers enhanced nutrient availability and tuber bulking, providing a sustainable strategy to improve both productivity and market quality in high-altitude potato production. These findings suggest that in high-altitude ecological conditions, the complementary use of diverse organic fertilizers with different characteristics instead of a single fertilizer source is a sustainable and effective method for both yield and market quality.

Keywords: Potato, *Solanum tuberosum*, Organic fertilization, Vermicompost, Poultry, Sheep, Cattle, Tuber size, Marketable yield

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1. Introduction

Potato is a strategic product in global agricultural systems due to their high yield potential and versatile uses, as well as being a primary source of carbohydrates for a significant portion of the world's population. Tubers have a rich nutritional profile, with high energy content, approximately 2.1% protein, starch constituting 75-80% of dry weight, carbohydrates, vitamins C and B, and various mineral elements (Devaux et al., 2014; Ingallina et al., 2020). Owing to these attributes, potatoes have been reported as the fifth most produced agricultural product in the world after sugar cane, maize, rice, and wheat (FAO, 2022).

In recent years, increasing population and food demand have placed potato production at the centre of food security, particularly in developing countries (Vilvert et al., 2022). However, the long-term and intensive use of chemical fertilizers to achieve high yields has caused serious environmental problems such as soil structure degradation, reduced organic matter content, and weakened soil biological activity (Hargreaves et al., 2008; Seaman, 2011). These negative impacts have necessitated sustainable agriculture approaches and alternative nutrient management strategies. In this context, the use of organic fertilizers stands out as an important option in terms of both environmental sustainability and product quality. Numerous studies have reported that organic fertilizers improve soil structure, increasing its aeration and water retention capacity, promoting microbial activity, and contributing to a more balanced supply of plant nutrients (Leytem & Westermann, 2005; Perez et al., 2007; Ahmad et al., 2023). Consequently, the impact of organic fertilization on the yield and quality of potato has become a focal point of intensive research in recent years.

Among animal-based organic amendments, vermicompost (worm castings) is distinguished by its high biological activity and its capacity to enhance the bioavailability of essential plant nutrients. Research indicates that vermicompost applications promote vegetative growth, increase total tuber yield, and improve the percentage of marketable tuber in potato, while also positively influencing tuber size and size distribution (Yourtchi et al., 2013; Kmeťová et al., 2013). Similarly, El-Sayed et al. (2014) demonstrated that organic fertilizer applications lead to significant increases in both total and marketable tuber yields. Poultry manure has likewise been extensively investigated in potato cultivation, primarily due to its substantial nitrogen and phosphorus concentrations. Zandian et al. (2015) reported that poultry manure applications enhanced both the number and weight of tubers within the 25-35 mm diameter range, thereby improving marketable tuber yield. Furthermore, Hussain et al. (2024) documented those various organic fertilizers increased tuber diameter, an effect directly correlated with the nutrient profile of the amendments. Investigations involving leonardite and other organic materials have similarly reported substantial gains in marketable tuber yield (Şanlı et al., 2013). Blecharczyk et al. (2023) demonstrated that in cold environments, low temperatures decelerate nutrient release from organic fertilizers, which fails to satisfy the requirements of potato production and paradoxically results in yield losses. Walia et al. (2023) reported that potato yield under organic fertilizer application increased by approximately 19.79% compared to the sole chemical fertilizer treatment, and within a certain range, the yield increased progressively with the application rate of organic fertilizer. Despite potato can grow in any soil, the crop will perform better if the soil is rich with organic matter (Edwards & Arancon, 2022).

Despite the extensive research conducted on the utilization of organic fertilizers in potato production, there is a paucity of studies that comparatively assess the effects of diverse animal-based organic fertilizers on tuber size distribution and commercial quality. However, tuber size distribution is a quality criterion as decisive as total yield in terms of potato marketability and economic value. The objective of this study is to ascertain the impact of utilizing diverse animal-derived organic materials, including worm, chicken, cattle, and sheep manure, as fertilizers in potato cultivation, on the distribution of tuber size and commercial quality. The study is to contribute to the existing literature on this subject by determining the effects of different types of organic fertilizer and the manner of its application on the marketable tuber ratio of potato.

2. Material and Method

This research was conducted during the summer growing seasons of 2020 and 2021 at the experimental field of the Plant Production Application and Research Center, Atatürk University, Erzurum, Türkiye, to evaluate the effects of various organic fertilizer types and application methods on potato tuber size and tuber size distribution. The experimental site, a high-altitude region situated at an elevation of 1853 m above sea level, is characterized by a continental climate. The region experiences significant diurnal temperature fluctuations, with cold and snowy winters and a notably short growing season. Air temperature, rainfall, and relative humidity during the crop-growing period (May–September) are presented in Figure 1. During both experimental seasons, the average air temperature remained above the long-term average (15.2 °C), reaching 16.5 °C in 2020 and 17.1 °C in 2021. Significant variability was observed in the amount and distribution of precipitation. While the 2020 growing season received considerably higher rainfall (234.6 mm) than the long-term average (180.4 mm), the 2021 season was notably drier, with a total precipitation of only 121.6 mm. During the study years (2020 and 2021), soil analysis of the research area revealed sand contents of 32.1% and 33.7%, silt contents of 36.8% and 46.7%, and clay contents of 26.7% and 29.2%, respectively. The soil texture was identified as clay-loam, with pH values measured at 7.4 and 7.2. In the experimental site soils, where organic matter levels were 1.39% and 1.15%, total nitrogen (N) was determined as 0.07% and 0.06%. Additionally, plant-available phosphorus (P_2O_5) and potassium (K_2O) were measured at 6.6–5.3 kg da^{-1} and 230.8-220.5 kg da^{-1}, respectively. Consequently, the soils were characterized as slightly alkaline, with low levels of total nitrogen, available phosphorus, and lime, and very low organic matter content; conversely, they were found to be rich in plant-available potassium (Sezen, 1991).

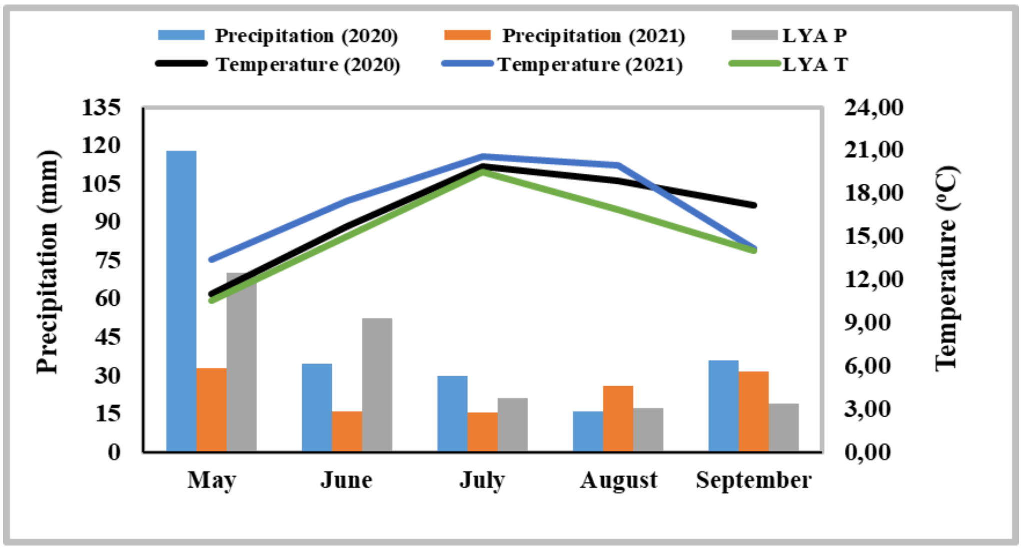

Figure 1. Precipitation and air temperature at the experimental area in the eastern Türkiye in 2020 and 2021 (LYAP: Long-year average precipitation; LYAT: Long-year average temperature)

In the study, the potato cultivar Agria, characterized by high yield potential, medium-to-late maturity, and long-oval tubers with yellow skin and flesh color, was used as plant material. In addition, cattle manure (3 t da^{-1}; 1.64% N, 0.69% P_2O_5, and 0.3% K_2O), sheep manure (2 t da^{-1}; 4.0% N, 0.6% P_2O_5, and 2.9% K_2O), poultry manure (1 t da^{-1}; 25% organic matter, 2% N, 1.91% P_2O_5, 1.88% K_2O, and 37% moisture), and vermicompost (200 kg da^{-1}; 65.5% organic matter, 1.1% N, 30% humic–fulvic acids, 1.5% K_2O, 0.7% P_2O_5, 23% moisture, pH=8.1) were applied as organic fertilizer sources in the experiment.

The experiment was conducted in a Randomized Complete Block Design with three replications (Yıldız, 1994). Organic fertilizers were applied both individual and in specific combinations, uniformly distributed and incorporated into the soil during the plot layout process before planting. Detailed information on the amounts and combinations of the organic fertilizers used is provided in Table 1. Planting was performed on May 4 and 14, 2020 and 2021, at a spacing of 70 cm between rows and 35 cm within rows. To prevent the mixing of fertilizers between treatments, the plots were organized into basins.

Once the plants reached a height of 5–10 cm following emergence, the first hoeing was performed. Approximately 20-25 days later, a second hoeing was carried out, including earthing-up (hilling) applications. Irrigation was initiated at the onset of the flowering stage via the furrow irrigation method. Depending on climatic and soil conditions, the crop was irrigated four times in the first year and six times in the second year, the latter due to higher temperatures and insufficient precipitation. Furthermore, weed control was maintained throughout the growing season through both hoeing and manual weeding. The harvest was conducted between September 24 and 28 in 2020 and 2021, when the foliage turned yellow and dried, stolons detached from the mother plant, and tubers reached a specific size with a firm (non-peeling) skin.

Table 1. Details of treatments used in the experiment in 2020 and 2021

Treatment	Fertilizer and treatment combination	Fertilizer combination ratios
T_1	Control	No fertilizer applied
T_2	Cattle Manure (C)	100%
T_3	Sheep Manure (S)	100%
T_4	Vermicompost (V)	100%
T_5	Poultry Manure (P)	100%
T_6	C×S	50%+50%
T_7	C×V	50%+50%
T_8	C×P	50%+50%
T_9	S×V	50%+50%
T_{10}	S×P	50%+50%
T_{11}	V×P	50%+50%
T_{12}	C×S×V	33.3%+33.3%+33.3%
T_{13}	C×S×P	33.3%+33.3%+33.3%
T_{14}	C×V×P	33.3%+33.3%+33.3%
T_{15}	S×V×P	33.3%+33.3%+33.3%
T_{16}	C×S×V×P	25%+25%+25%+25%

The harvested tubers were graded into four size classes using 5.0, 3.5, and 2.8 cm sieves: large (>5.0 cm), medium (3.5–5.0 cm), small (2.8–3.5 cm), and cull (<2.8 cm). Additionally, tubers with a diameter exceeding 35 mm were classified as marketable tubers. These graded tubers were first weighed individually to determine plot yields, which were then used to calculate the yield per hectare (t ha^{-1}) for each size category.

Furthermore, the weight-based proportions of these size-graded tubers within the total yield were determined and expressed as percentages (%).

Data were analyzed using the SPSS package (SPSS, Version 20.0, SPSS Inc, Chicago, IL, USA). When the F-test indicated statistical significance at the p=0.05 level, the protected least significant difference (Protected DUNCAN) was used to separate the means (Steel & Torrie, 1980).

3. Results

Marketable tuber yield (>3.8 cm), large tuber yield (>5.0 cm), medium tuber yield (3.5-5.0 cm), small tuber yield (2.8-3.5 cm), and cull tuber yield (<2.8 cm) were statistically significant at the p<0.01 level between years. The application of organic fertilizers, applied either individual or in combination, significantly affected (p<0.01) the yields of different tuber size classes, particularly marketable tuber yield, whereas no significant effect was observed on cull tuber yield. Furthermore, tuber size distribution was not significantly influenced by the organic fertilizer treatment × year interaction (Table 1).

3.1. Marketable tuber yield (>3,8 mm) and proportion of the total tuber yield

Marketable tuber yield was 24.2 t ha^{-1} in 2020, accounting for 92.3% of the total tuber yield; however, it declined to 11.1 t ha^{-1} in 2021, representing 66.5% of the total yield. The application of organic fertilizers, either alone or in combination, resulted in significant differences in marketable tuber yield and tuber size distribution in potato. Marketable tuber yields ranged from 12.8 to 22.0 t ha^{-1} across treatments, with combined organic fertilizer applications generally producing higher yields than individual applications. The highest marketable tuber yield was recorded in the T16 (C×S×V×P) treatment (22.0 t ha^{-1}), which also exhibited the greatest proportion of marketable tubers within the total yield (87.9%). This treatment was followed by T11 (V×P) (20.5 t ha^{-1}) and by T13 (C×S×P) and T12 (C×S×V), with yields ranging from 19.9 to 20.1 t ha^{-1}. The proportion of marketable tubers in these treatments varied between 82% and 85%, indicating that the combined use of different organic fertilizers positively influenced both tuber yield and marketable quality. Among the individual organic fertilizer treatments, T5 (P) resulted in a notable increase in marketable tuber yield (20.0 t ha^{-1}) compared with the control (13.9 t ha^{-1}). In contrast, cattle (T2), sheep (T3), and vermicompost (T4) applications produced moderate yields ranging from 17.2 to 18.3 t ha^{-1}. The lowest marketable tuber yields were observed in T8 (C×P) and the control treatment (T1), with 12.8 and 13.9 t ha^{-1}, respectively (Table 2, Figure 2).

3.2. Tuber yields across various size categories

Large tuber yield was 18.5 t ha^{-1} in 2020, accounting for 68.6% of the total tuber yield; however, it declined sharply to 2.9 t ha^{-1} in 2021, representing only 17.4% of the total yield. Significant differences were observed among organic fertilizer treatments and their combinations regarding large tuber yield. The highest large tuber yields were obtained from T13 (C×S×P) and T16 (C×S×V×P), with 14.3 and 13.5 t ha^{-1}, respectively. These treatments also exhibited the highest proportions within the total tuber yield at 60.7% and 53.9%. Treatments T5 (P), T6 (C×S), T10 (S×P), and T12 (C×S×V) provided moderate-to-high yields, with large tuber proportions ranging approximately between 49% and 54%. In contrast, the lowest large tuber yield was recorded in T8 (C×P) at 7.0 t ha^{-1} (41.5%). In the control treatment, large tuber yield was 8.4 t ha^{-1}, accounting for 47.2% of the total yield (Table 2, Figure 2). Overall, multi-organic fertilizer combinations enhanced both large tuber yield and its relative proportion compared to single applications.

Medium tuber yield (3.5–5.0 cm) was 6.4 t ha^{-1} in 2020, accounting for 23.8% of the total tuber yield, whereas it increased to 8.2 t ha^{-1} in 2021, representing 49.1% of the total yield. Among the organic fertilizer treatments, the highest medium tuber yield was recorded in T11 (V×P) (9.6 t ha^{-1}; 38.6%). This was followed by T4 (V), T2 (C), and T3 (S), with yields ranging from 8.1 to 8.4 t ha^{-1}. In contrast, relatively lower medium tuber yields were observed in T1 (Control) and T6 (C×S) (Table 1, Figure 2). Overall, the marked increase in the proportion of medium-sized tubers, particularly in the second year, suggests that medium tuber formation becomes more pronounced under environmental stress conditions that restrict tuber bulking.

Small tuber yield (2.8-3.5 cm) was 1.3 t ha^{-1} in 2020, accounting for 4.7% of the total tuber yield, whereas it increased to 4.2 t ha^{-1} in 2021, representing 26.6% of the total yield. When evaluated on a treatment basis, the highest small tuber yields and proportions were generally observed in T4 (V) and T8 (C×P), where marketable and large tuber yields were comparatively lower. In these treatments, small tuber yields were 3.7 and 2.9 t ha^{-1}, accounting for 16.9% and 17.7% of the total yield, respectively. In contrast, among the multiple organic fertilizer combinations, T15 (S×V×P) and T16 (C×S×V×P) produced lower yields of small tubers, ranging between 2.1 and 2.2 t ha^{-1}, with corresponding proportions of 10.1% and 8.68% of the total tuber yield (Table 2, Figure 2).

Table 2. Effects of different organic fertilizers and their combinations on marketable (>3.8 cm), large (>5.0 cm), medium (3.5-5.0 cm), small (2.8-3.5 cm), cull tuber yields (<2.8 cm), and the percentage distribution of tuber size classes within total tuber yield of potatoes

Treatments	Marketable tuber yield (>3.8 cm)		Large tuber yield (>5.0 cm)		Medium tuber yield (3.5-5.0 cm)		Small tuber yield (2.8-3.5 cm)		Cull tuber yield (>2.8 cm)	
	t ha^{-1}	%	t ha^{-1}	%	t ha^{-1}	%	t ha^{-1}	%	t ha^{-1}	%
Year										
2020	24.9 a	92.3	18.5 a	68.6	6.4 b	23.8	1.3 b	4.7	0.6 b	2.2
2021	11.1 b	66.5	2.9 b	17.4	8.2 a	49.1	4.2 a	26.6	1.7 a	9.9
Organic fertilizers and treatment combinations										
T_{1} (Control)	13.9 bc	78.3	8.4 ab	47.2	5.5 b	31.0	2.6 ab	14.8	1.2	6.9
T_{2} (Cattle, C)	18.3 ac	85.3	10.2 ab	47.4	8.1 ab	37.9	2.6 ab	12.0	1.2	5.7
T_{3} (Sheep, S)	17.5 ac	81.1	9.4 ab	43.4	8.1 ab	37.1	3.0 ab	13.9	1.1	5.3
T_{4} (Vermicompost, V)	17.2 ac	79.9	8.8 ab	41.1	8.4 ab	39.1	3.7 a	16.9	1.2	5.5
T_{5} (Poultry, P)	20.0 ac	84.4	12.6 ab	53.2	7.4 ab	31.1	3.0 ab	12.8	1.2	4.9
T_{6} (C×S)	17.5 ac	83.9	11.2 ab	54.2	6.2 b	29.9	2.5 ab	11.9	1.4	6.5
T_{7} (C×V)	18.1 ac	80.6	10.1 ab	44.9	8.0 ab	35.5	2.9 ab	13.3	1.2	6.3
T_{8} (C×P)	12.8 c	76.3	7.0 b	41.5	5.8 b	34.5	2.9 ab	17.7	1.1	6.3
T_{9} (S×V)	17.4 ac	75.7	10.2 ab	44.5	7.2 ab	31.3	2.8 ab	12.3	1.1	4.7
T_{10} (S×P)	19.0 ac	82.7	11.3 ab	48.7	7.8 ab	33.4	2.9 ab	12.9	1.1	4.7
T_{11} (V×P)	20.5 ab	82.1	10.9 ab	43.6	9.6 a	38.6	3.3 ab	13.1	1.2	4.7
T_{12} (C×S×V)	19.9 ac	84.5	11.9 ab	50.4	8.0 ab	33.9	2.7 ab	11.6	0.9	3.9
T_{13} (C×S×P)	20.1 ac	85.4	14.3 a	60.7	5.8 b	24.8	2.6 ab	10.9	1.3	5.4
T_{14} (C×V×P)	17.4 ac	83.7	11.3 ab	54.3	6.1 b	29.5	2.5 ab	12.2	0.9	4.1
T_{15} (S×V×P)	17.2 ac	84.8	10.5 ab	51.9	6.7 ab	33.0	2.1 b	10.1	1.0	5.0
T_{16} (C×S×V×P)	22.0 a	87.9	13.5 a	53.9	8.5 ab	33.8	2.2 b	8.68	0.9	3.6
Mean	18.1	82.3	10.7	48.8	7.3	32.8	2.8	12.8	1.2	5.3

Variation sources	*df*	Marketable tuber yield	Large tuber yield	Medium tuber yield	Small tuber yield	Cull tuber yield
Y	1	**	**	**	**	**
T	15	*	*	*	*	ns
Y×T	15	ns	ns	ns	ns	ns
Error	62					

Statistically significant at 5% (p<0.05) and 1% (p<0.01)**, ns: nonsignificant. Values followed by the same letter are insignificant.*

Cull tuber yield increased markedly between years; the values recorded in 2020 (0.6 t ha^{-1}, accounting for 2.2% of the total tuber yield) rose to 1.7 t ha^{-1} in 2021, representing 9.9% of the total yield. When evaluated in terms of organic fertilizer treatments, the lowest cull tuber yields and proportions were observed in T12 (C×S×V), T14 (C×V×P), and T16 (C×S×V×P). In these treatments, the cull tuber yield was 0.9 t ha^{-1}, with proportions ranging from 3.9% to 4.1% of the total yield. In contrast, the proportion of cull tuber was found to be higher in the T6 (C×S) and T1 (Control) treatments (Table 2, Figure 2).

4. Discussion

The variations observed in marketable and different tuber size yields between years can be largely attributed to the adverse ecological conditions prevailing during the second experimental year. In the first year, more favorable temperature and moisture conditions during the tuber growth and development likely enhanced the mineralization of nutrients derived from organic fertilizers, resulting in higher proportions of marketable and large-sized tubers. Conversely, high temperatures and low humidity in June and July of the second year likely increased respiratory losses, thereby limiting tuber bulking and reducing the proportions of marketable and large tubers. Under these stress conditions, limited translocation of photosynthates to the tubers may have contributed to the increased proportions of small and cull tubers. Furthermore, the reduced mineralization rate of nutrients from organic sources under hot and dry conditions may have delayed nutrient availability and uptake, thereby adversely affecting tuber size distribution. Although rainfall increased and temperatures declined in August, these changes were insufficient to adequately stimulate mineralization processes (Figure 1). Overall, these findings indicate that the effectiveness of organic fertilizer applications on marketable tuber yield is strongly dependent on climatic conditions. Similarly, previous studies have reported that climatic factors may exert a more decisive influence on potato yield and tuber size distribution than fertilizer type (Honeycutt, 1997; Warman & Havard, 1998; Kjellenberg & Granstedt, 1998).

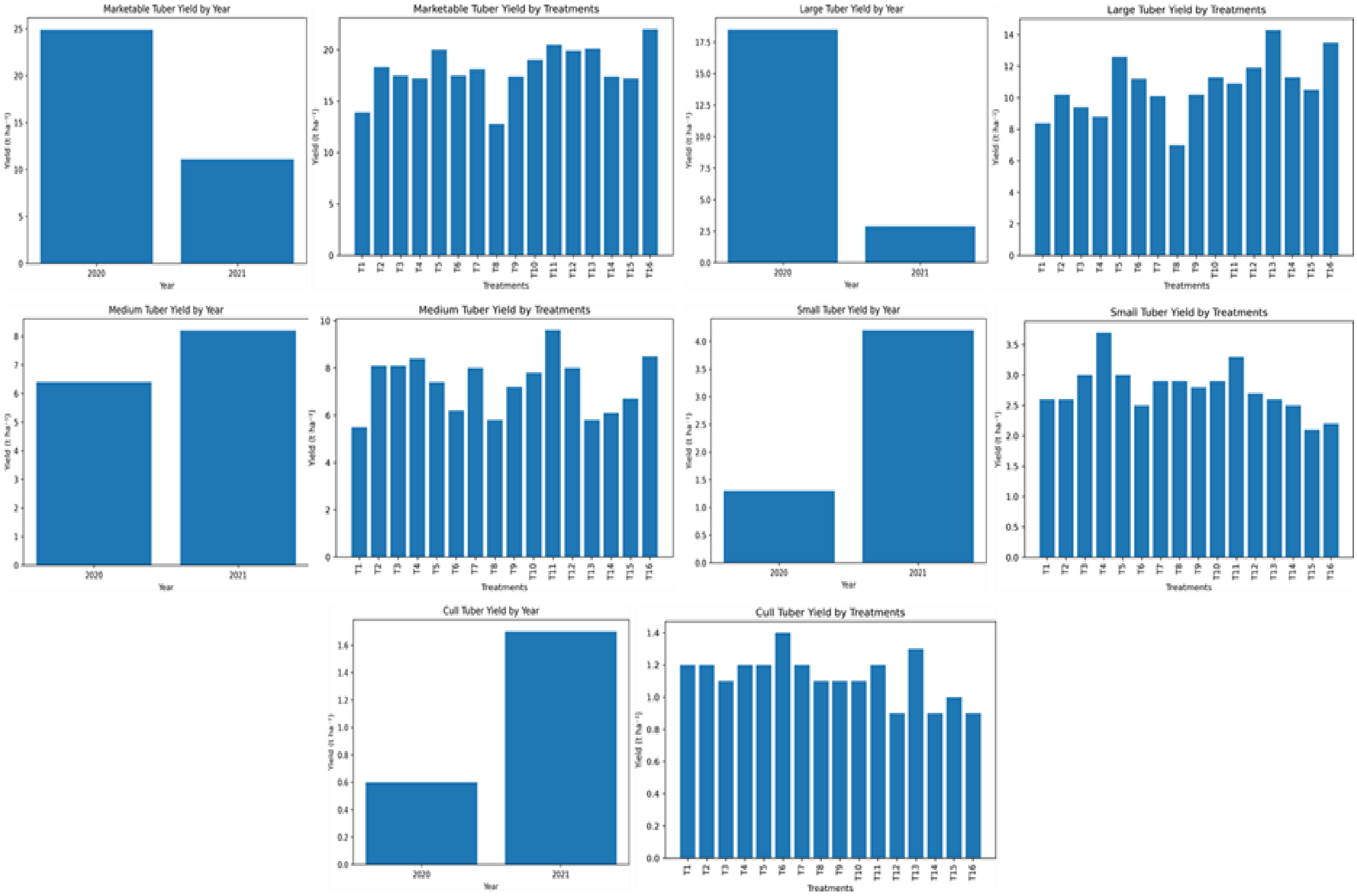

Figure 2. Effects of year and organic fertilizer treatments on marketable (>3.8 cm), large (>5.0 cm), medium (3.5-5.0 cm), small (2.8-3.5 cm), and cull (<2.8 cm) tuber yield

The growth and tuber quality enhanced by organic fertilizer applications are associated with increases in soil organic matter content, cation exchange capacity (CEC), and mineral nutrient levels. Furthermore, these fertilizers contribute to meeting crop requirements and supporting production by increasing the availability of macro and micro nutrients in the soil (Mirdad, 2010). These findings are consistent with the results of Shahein et al. (2014), Amara et al. (2015), and Bilkis et al. (2018), who reported that organic fertilizer applications significantly improve yield and crop characteristics in potato as well as other crops such as eggplant, cowpea, and watermelon. Numerous studies have demonstrated that, compared to the application of chemical fertilizers alone, the use of organic fertilizers can significantly improve soil quality, thereby playing a crucial role in enhancing crop yields (Zhou et al., 2022; Liu et al., 2023). It is widely recognized that fertilizers such as manure and straw provide a more comprehensive nutrient profile and a greater overall input of organic matter than commercial organic fertilizers, thereby ensuring a more adequate and sustained nutrient supply for optimal potato growth (Lin et al., 2023; Qiao et al., 2024).

The results of the study indicated that, rather than the sole application of individual fertilizers, the application of recommended doses in specific combinations generally produced better results in obtaining tubers of different sizes (Table 2). On the other hand, the application of 100% of the same nutrient source alone was not found to be highly effective in producing tubers of varying sizes. This situation may be attributed to nutrient losses under single-fertilizer use, resulting in insufficient nutrient availability during the tuber growth period (Keisham et al., 2015). It has been reported that the application of recommended fertilizer doses in combination increases the production of tubers of different sizes (Kumar et al., 2008; Das et al., 2009).

The increased quantity of marketable and large tubers through co-application of organic fertilizers is thought to result from improved soil friability, which creates a more conducive environment for tuber expansion. Furthermore, the likely reason for the increase in marketable yield is the enhanced availability of soil nutrients for vegetative growth, subsequently leading to higher production of photosynthates (photo assimilates). It has been demonstrated that organic fertilizer treatments lead to a significant increase in marketable yield compared to the control (Kahlel, 2014). Al-Sahaf and Atee (2007) reported that organic compounds and amino acids formed during the decomposition of organic fertilizers promote vegetative growth, positively reflecting on total and marketable yields. These results align with findings reported by Mohamed et al. (1999), Al-Zahawi (2007), Al-Zubi et al. (2007), Abdul-Rasol et al. (2009) and Al-Qaesi (2009). Ahmed et al. (2019) also noted that organic fertilizer types influence the formation of different tuber sizes and increase large tuber yield. Similar studies have reported significant differences between different cultivars (Bhardwaj et al., 2008) and treatments (Banjare et al., 2014; Chilephake & Trautz, 2014) regarding tuber yields of different sizes. In addition, the combined application of specific organic fertilizer doses reduced small tuber yield. This effect may be explained by the more balanced and growth-promoting nutrient supply provided through combined applications (Grappelli et al., 1985; Tomati et al., 1990). Indeed, the combined use of organic fertilizers has been reported to enhance soil nutrient availability and biological activity (Pengthamkeerati et al., 2011). As a consequence of improved plant growth, tuber volume increased, leading to a proportional reduction in the proportion of small tubers.

In this study, marketable tuber yield and size distribution were significantly influenced by organic fertilizer type, application method, and inter-annual climatic variations. Favorable climate conditions in the first year enhanced the mineralization of nutrients, increasing marketable and large tuber ratios. However, high temperatures and low humidity in the second year restricted tuber bulking, resulting in higher proportions of small and cull tubers.

5. Conclusion

Overall, the results clearly indicate that increasing the number of organic fertilizers applied in combination improved not only total yield but also the proportion of marketable and large tubers, while reducing the proportions of small and cull tubers. The results indicated that fertilizer treatments significantly affected total yield, marketable yield, and tuber size distribution in both years. Generally, combined applications outperformed individual applications. Specifically, the highest marketable tuber yield (22.0 t ha^{-1}) and marketable tuber proportion (87.9%) were obtained from the T16 treatment. While the highest large tuber yields were recorded in T13 (14.3 t ha^{-1}) and T16 (13.5 t ha^{-1}) treatments, the maximum medium and small tuber yields were found in T11 (9.6 t ha^{-1}) and T4 (3.7 t ha^{-1}) treatments, respectively. The positive response of potato to the combined application of organic fertilizers may be attributed to their different solubility and mineralization rates, which enable a gradual and balanced supply of nutrients throughout the growing period. The application of cattle, sheep, vermicompost, and poultry manures at 25% each of their recommended doses (T16 - C×S×V×P) provided the highest marketable yield and the most balanced size distribution compared to individual applications. These findings suggest that in high-altitude ecological conditions, the complementary use of diverse organic fertilizers with different characteristics instead of a single fertilizer source is a sustainable and effective method for both yield and market quality.

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Conflict of interest

The authors declare no conflict of interest.

Ethical Approval

This arcticle does not require ethics committee approval.

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Length-weight relationship and condition factor of the glasshead grenadier *Hymenocephalus italicus* (Gadiformes: Macrouridae) from Gökçeada Island (Northern Aegean Sea, Türkiye)

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Abstract

This study investigated the length-weight relationship (LWR) and condition factors of the glasshead grenadier *Hymenocephalus italicus* (Giglioli, 1884) from the deep waters surrounding Gökçeada Island in the northern Aegean Sea (Türkiye). Fish specimens were collected between March 2015 and April 2017 during commercial bottom trawl operations at depths ranging from 109.7 to 332.8 m. A total of 245 individuals were analyzed. Total length (*TL*) ranged from 4.10 to 14.10 cm (mean: 11.20±0.10 cm), while total weight (*W*) ranged from 0.41 to 5.45 g (mean: 2.62±0.05 g). The LWR was described by the equation $W = 0.0577 \cdot TL^{1.5667}$, corresponding to the logarithmic form $\log(W)=-1.2388+1.5667\cdot\log(TL)$. The regression model was statistically significant ($p<0.001$) and explained a moderate proportion of the variance ($R^2=0.545$). The estimated growth coefficient ($b=1.5667$; 95% CI: 1.386-1.748) was significantly lower than the theoretical isometric value of 3, indicating negative allometric growth. Mean Fulton's condition factor (*K*) and relative condition factor (K_n) were 0.194±0.005 and 0.171±0.005, respectively. This investigation provides foundational biological data for *H. italicus* in the northern Aegean Sea. It underscores the importance of standardized morphometric protocols, particularly the use of pre-anal length (PAL), in future studies of deep demersal ichthyofauna.

Keywords: LWR, Trawl, Discard, Condition factor, Macrourid species, Deep-sea fish

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1. Introduction

Deep-sea demersal fishes constitute a key structural and functional element of continental slope ecosystems, making significant contributions to biomass, trophic connectivity, and benthopelagic energy flow (D'Onghia et al., 2000). Within this group, macrourid (grenadiers or rattails) fishes are particularly notable due to their broad bathymetric distribution, high abundance in slope assemblages, and ecological role as intermediate and upper-level consumers in deep-sea food webs (Cohen et al., 1990; D'Onghia et al., 2000). Although most macrourids have little direct commercial value, they are frequently represented in trawl catches and are considered informative components of deep demersal ecosystem structure and functioning (Massutí et al., 1995; D'Onghia et al., 2000).

The glasshead grenadier (*Hymenocephalus italicus* Giglioli, 1884) is a small benthopelagic macrourid widely distributed in the Mediterranean Sea and adjacent Atlantic-influenced regions. The species is generally associated with the upper and middle continental slope, where it is a recurrent component of deep demersal fish communities (Cohen et al., 1990; Massutí et al., 1995). Previous studies have shown that *H. italicus* is typically most abundant between 400 and 600 m depth, while its abundance progressively declines below this range and may become very low or disappear near 900 m in some Mediterranean sectors (Massutí et al., 1995). Comparable bathymetric patterns have been reported from the Catalan Sea (Massutí et al., 1995), the western Ionian Sea (D'Onghia et al., 2000), and the Iberian Mediterranean margin (Moranta et al., 2007; Cartes et al., 2021), indicating a relatively consistent depth-related ecological distribution across the Mediterranean (Schwarzhans, 2014).

In addition to its bathymetric distribution, *H. italicus* is ecologically relevant because of its trophic role in deep-sea food webs. General faunistic and taxonomic syntheses indicate that the species occurs predominantly at depths shallower than approximately 500 m and feeds mainly on pelagic copepods, followed by euphausiids, amphipods, shrimps, ostracods, cumaceans, and other small crustaceans, with occasional ingestion of small fishes (Cohen et al., 1990). Although *H. italicus* has negligible direct commercial value due to its small body size and commonly discarded in demersal fisheries, its recurrent occurrence and numerical abundance indicate a potentially important role in energy transfer between pelagic and benthic compartments in slope environments. This ecological relevance is further reflected in its conservation status, as the species is currently classified as Least Concern on the IUCN Red List (Iwamoto, 2015).

Despite its ecological relevance (D'Onghia et al., 2000, García-Ruiz et al., 2019; D'Iglio et al., 2025), *H. italicus* remains comparatively underrepresented in the fisheries and fish biology literature of the northern Aegean Sea, especially with respect to species-specific morphometric and condition-based analyses (Filiz & Taskavak, 2008). In the broader Mediterranean, previous studies have mainly focused on distribution (Massutí et al., 1995; García-Ruiz et al., 2019), assemblage structure (Labropoulou et al., 2000; Politou et al., 2008), population biology, and growth-related characteristics of macrourids (D'Onghia et al., 2000; Sion et al., 2012) rather than on local-scale biometric assessment of this species. In the northern Aegean, *H. italicus* has been recorded in demersal trawl surveys and fish assemblage studies, confirming its presence as a regular component of deeper fish communities (Karakulak & Keskin, 2007). However, to the best of our knowledge, no previous study has specifically described the length-weight relationship (LWR) and condition factors of *H. italicus* from the waters surrounding Gökçeada Island. This gap is important because LWRs are among the most widely used descriptors in fisheries biology. They provide essential information for estimating biomass from length-frequency data, comparing growth patterns among populations, converting length-based observations into weight-based models, and evaluating deviations from isometric growth (Ricker, 1975; Froese, 2006). Deviations from isometry may reflect ontogenetic changes, body shape, reproductive condition, food availability, habitat-specific environmental conditions, and sampling structure (Ricker, 1975; Froese, 2006). Therefore, region-specific LWR estimates are essential for robust biological interpretation and meaningful comparison among populations.

In deep-water macrourids, however, the interpretation of LWRs may be further complicated by morphological constraints related to body form. Many species in this family possess a strongly elongated, tapering, and fragile posterior body region, which can reduce the precision and repeatability of total length (*TL*) measurements. This issue is particularly relevant for *H. italicus*, whose delicate caudal extremity is highly susceptible to bending, breakage, or distortion during capture and handling. In fact, previous morphometric studies on macrourids have often preferred pre-anal length (*PAL*) rather than *TL* because *PAL* provides a more stable and biologically meaningful measure of body size in elongate slope fishes (Massutí et al., 1995). Consequently, local LWR studies on *H. italicus* are important not only for documenting biological variation, but also for evaluating the methodological implications of morphometric choice in deep-sea fishes.

The length-weight relationships of various fish species in the northern Aegean Sea have been thoroughly examined by numerous researchers (Lamprakis et al., 2003; Filiz & Bilge, 2004; Karakulak et al., 2006; Cengiz, 2012, 2013a, 2013b, 2019, 2021a, 2021b, 2022a, 2022b, 2022c, 2022d; Altın et al., 2015; Gonulal, 2017; Ayyildiz & Altin, 2018; Ayyildiz et al., 2019; Cengiz et al., 2019a, 2019b, 2019c; Adamidou et al., 2020; Cengiz & Paruğ, 2021, 2022). In contrast, studies focusing on bycatch and discarded species within commercial trawl fisheries in the same region remain relatively scarce (Soykan et al., 2016, 2019). Furthermore, Soykan and Kınacıgil (2021) investigated the length-weight relationships of certain discarded fish species in the central Aegean Sea.

The northern Aegean coast of Türkiye is commonly divided into several sub-regions, including the Edremit and Saros Bays, the Bozcaada and Gökçeada Islands, and the Gallipoli Peninsula (Cengiz & Paruğ, 2020). Gökçeada Island, the westernmost and largest island of

Türkiye, is located at the entrance of Saros Bay (Cengiz, 2023) and offers a particularly valuable setting for such an assessment. The island lies within a hydrographically dynamic sector influenced by the Çanakkale Strait, Black Sea-derived nutrient-rich waters, and regional circulation patterns. These oceanographic characteristics contribute to relatively high productivity and habitat heterogeneity compared with the more oligotrophic sectors of the eastern Mediterranean. In addition, fisheries constitute an important economic activity in the region (Cengiz, 2020). Previous studies conducted around Gökçeada have highlighted the ecological importance of the area for fish diversity, coastal habitats, and trawl-associated assemblages (Kale et al., 2014a, 2014b, 2015a, 2015b, 2021; Altın et al., 2015, 2020; Acarli et al., 2018, 2022a, 2022b). However, most existing work from the area has focused on coastal biodiversity, shallow-water fish communities, or multi-species bycatch/discard assemblages, while species-specific biological information for deep demersal fishes remains scarce.

The present study addresses a clear local and taxon-specific knowledge gap by providing the first detailed assessment of the length-weight relationship, growth type, and condition factors of *H. italicus* from the deep waters surrounding Gökçeada Island. Based on the species' deep-water ecology, elongated macrourid morphology, and the known sensitivity of length-based morphometrics in such fishes, we hypothesized that the Gökçeada population of *H. italicus* would exhibit non-isometric growth, potentially differing from the more conventional scaling patterns commonly reported for many shelf-associated teleosts. By addressing this hypothesis, the present study was designed with three main objectives: (i) to estimate the LWR parameters of the species, (ii) to determine whether growth deviates significantly from isometry, and (iii) to assess the general physiological status of the sampled population using Fulton's condition factor (K) and Le Cren's relative condition factor (K_n).

2. Material and Method

2.1. Study area and sampling

Fish specimens were obtained from the coastal waters of Gökçeada Island in the northern Aegean Sea between March 2015 and April 2017 (Figure 1). Sampling was conducted during the commercial trawl fishing season using a standard commercial trawl net fitted with a codend having a 44 mm opening mesh size as defined by the Turkish fisheries regulation (Communiqué No. 6/1). Bottom trawl surveys covered a bathymetric range from 109.7 m to 332.8 m. Following the MEDITS program guidelines (Bertrand et al., 1997), all hauls were conducted during daytime hours to ensure consistency.

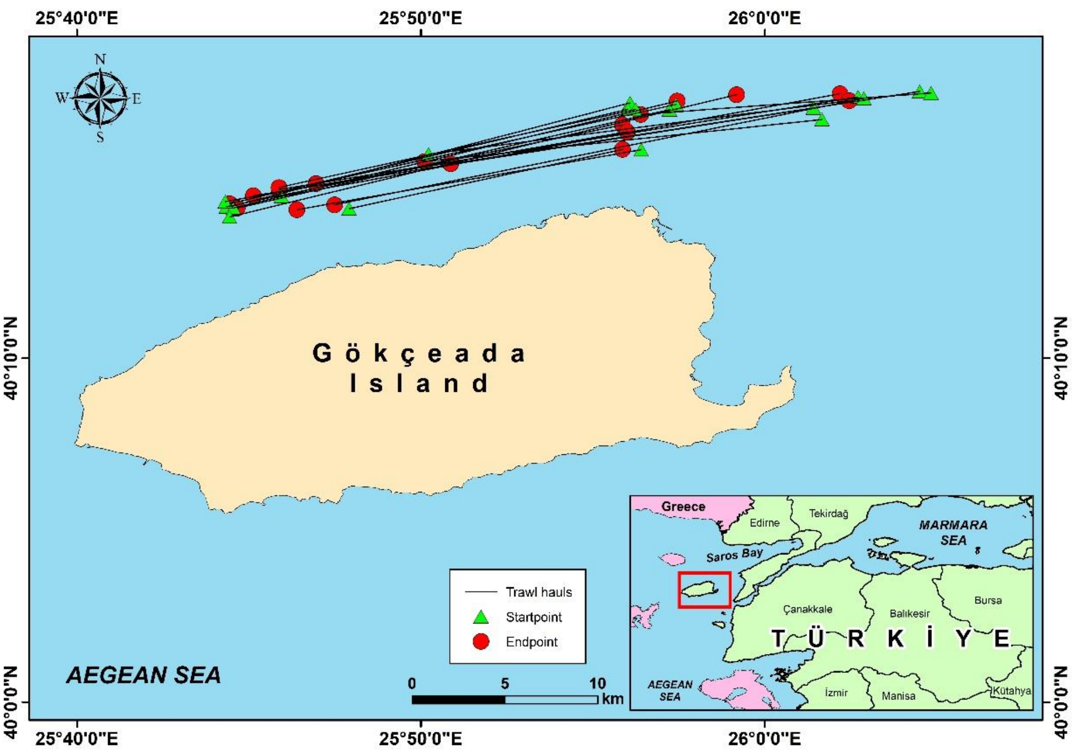

Figure 1. Study area and samplings

2.2. Statistical analyses

The total length (TL) of each individual was measured to the nearest 0.1 cm, and the total weight (W) was recorded to the nearest 0.01 g. The length-weight relationship (LWR) was determined using the power function (Eq. 1) (Ricker, 1975).

$$W = aL^b \tag{1}$$

where a is the intercept and b is the allometric growth coefficient. To facilitate linear regression, the equation was log-transformed (Eq. 2):

$$\log(W) = \log(a) + b\log(L) \tag{2}$$

The physiological status of the population was assessed using Fulton's (1904) condition factor (K) (Eq. 3) and Le Cren's (1951) relative condition factor (K_n) (Eq. 4):

$$K = 100\frac{W}{L^3} \tag{3}$$

In this equation, K is the condition factor, L is the total length (cm) and W is the total weight (g).

$$K_n = \frac{W}{aL^b} \tag{4}$$

In this equation, K_n is the relative condition factor, L is the length (cm) and W is the total weight (g) of individuals, a is the intercept and b is the slope obtained from the LWR estimation.

To determine whether growth significantly deviated from isometry (b=3), a Student's t-test (Zar, 1984) was performed using the formula given below (Eq. 5):

$$t = \frac{b-3}{SE(b)} \tag{5}$$

Growth was classified as isometric (b=3), positive allometric (b>3), or negative allometric (b<3) based on the calculated slope (Froese, 2006). Descriptive statistics, including mean, standard error, skewness, and kurtosis, were calculated for all parameters.

3. Results

A total of 245 individuals of *H. italicus* were analyzed. The frequency distributions of total length and total weight for *H. italicus* are presented in Figure 2. The sampled individuals exhibited a relatively concentrated size structure, with most specimens clustering around the intermediate size classes. Total length of the sampled individuals ranged from 4.10 to 14.10 cm with a mean of 11.20±0.10 cm, while total weight ranged from 0.41 to 5.45 g with a mean of 2.62±0.05 g. In both distributions, the majority of individuals were concentrated around the central classes, while relatively few specimens were represented at the smallest and largest size intervals. The fitted normal curves indicate that both length and weight distributions generally followed a unimodal pattern, although slight asymmetry was evident, particularly in the lower size and weight classes due to the presence of a limited number of small individuals. Descriptive statistics for the total length, weight, and condition factors are provided in Table 1.

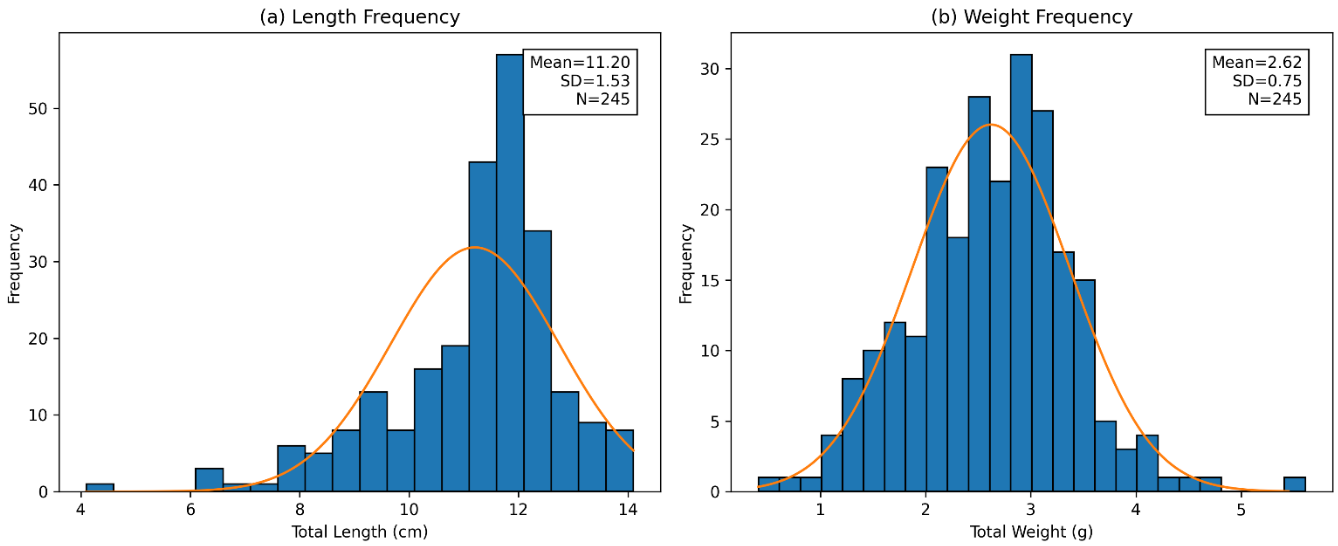

Figure 2. Frequency distributions of total length (a) and total weight (b) of *Hymenocephalus italicus* collected from Gökçeada Island (northern Aegean Sea). Solid lines represent fitted normal distribution curves. Mean, standard deviation (SD), and sample size (N) are shown within each panel

Table 1. Descriptive statistics of the total length, weight, Fulton's condition factor (K) and Le Cren's relative condition factor (K_n) for the glasshead grenadier (*Hymenocephalus italicus*) from Gökçeada Island, northern Aegean Sea (sample size: 245)

Values	Total Length	Weight	K (Fulton)	K_n (Le Cren)
Mean	11.20	2.62	0.19	0.17
Standard Error	0.10	0.05	0.005	0.005
Skewness	-1.19	0.04	2.19	2.69
Kurtosis	2.25	0.60	6.02	9.95
Minimum	4.10	0.41	0.10	0.08
Maximum	14.10	5.45	0.59	0.67

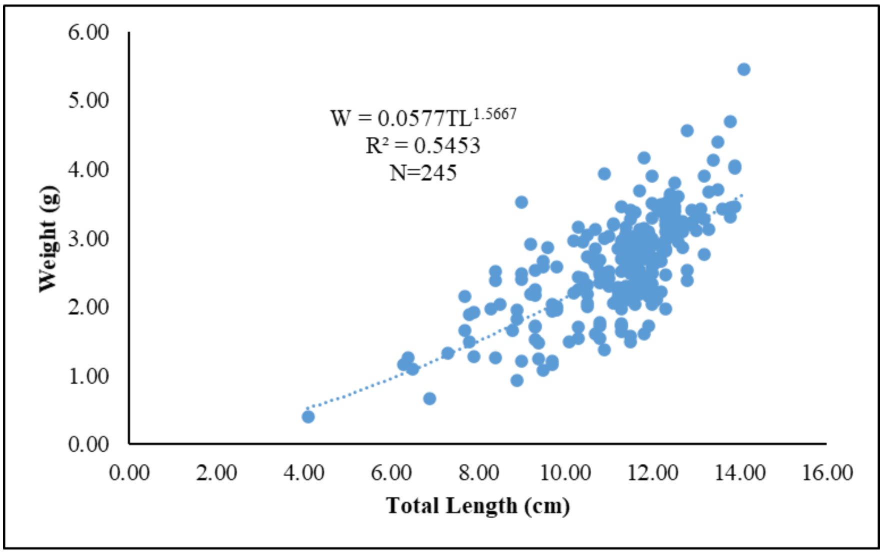

Figure 3. Length-weight relationship of *Hymenocephalus italicus* from Gökçeada Island (northern Aegean Sea)

The length-weight relationship was estimated using the power equation $W = aL^b$. The derived regression equation for the Gökçeada population was $W = 0.0577 \cdot TL^{1.5667}$ or in logarithmic form $\log(W) = -1.2388 + 1.5667\log(TL)$. The model was statistically significant (p<0.001) and explained a moderate proportion of the variance (R^2=0.545). The length-weight relationship of *H. italicus* is presented in Figure 3.

The estimated growth coefficient was b=1.5667 with a 95% confidence interval of 1.386-1.748. This was significantly lower than the theoretical isometric value of 3 (t-test, p<0.001), indicating negative allometric growth in the studied population.

The mean condition factor values were 0.194±0.005 for Fulton's condition factor (K) and 0.171±0.005 for the relative condition factor (K_n). Fulton's K ranged between 0.098 and 0.595, while K_n ranged between 0.083 and 0.667.

4. Discussion

The present study contributes new information on the length-weight relationship (LWR) and condition status of *H. italicus* inhabiting the deep continental shelf and upper slope waters around Gökçeada Island in the northern Aegean Sea. Macrourid fishes are recognized as one of the most important components of deep demersal assemblages in the Mediterranean, contributing significantly to biomass and trophic functioning despite their low commercial value (Sion et al., 2012). In this context, the present results contribute valuable biological data for a species that is both ecologically relevant and still relatively underrepresented in regional fisheries studies.

The estimated LWR revealed a growth coefficient of b=1.5667, indicating negative allometric growth. Although deviations from isometry are common in fishes, the observed value is clearly lower than the range generally reported for Mediterranean teleosts. Previous studies on macrourids from the eastern Aegean Sea reported b values ranging between 2.51 and 3.49, including negative, isometric, and positive allometric growth depending on species (Filiz & Taskavak, 2008). Therefore, the markedly low b value observed in the present study suggests that either species-specific traits or environmental and methodological factors play a significant role in shaping the growth pattern of *H. italicus* in the Gökçeada region.

Table 2. Published length-weight relationship (LWR) parameters for *Hymenocephalus italicus* reported from different geographic regions using total length (*TL*) and pre-anal length (*PAL*) measurements

N	*a*	*b*	R^2	*G*	*L*	Location	References
245	0.0577	1.5667	0.545	-A	TL (4.10-14.10 cm)	Gökçeada Island, northern Aegean Sea, Türkiye	Present study
98	0.0069	2.510	0.880	-A	TL (6.70-16.80 cm)	Sığacık Bay, eastern Aegean Sea, Türkiye	Filiz and Taskavak (2008)
76	0.0077	2.450	0.771	NA	TL (8.2-15.5 cm)	Antalya Bay, Mediterranean, Türkiye	Deval et al. (2014)
91	0.0034	2.891	0.860	-A	TL (7.4-14.9 cm)	Southeast Aegean Sea, Türkiye	Yapici et al. (2015)
117	0.0027	2.504	0.958	+A	TL (7.1-16.0 cm)	Northeastern Mediterranean	Başusta et al. (2025)
60 (♀)	0.0024	2.632	0.958	+A	TL (8.30-16.0 cm)	Northeastern Mediterranean	Başusta et al. (2025)
57 (♂)	0.0033	2.575	0.959	+A	TL (7.10-14.50 cm)	Northeastern Mediterranean	Başusta et al. (2025)
69	0.1277	2.7964	0.965	-A	PAL (2.2-5.1 cm)*	Western Mediterranean	Morey et al. (2003)

Note: Only studies explicitly reporting LWR parameters in the form $W = aL^b$ were included in the main comparison. *N*: sample size; NA: Not applicable; ♀: female individuals; ♂: male individuals; *a* and *b*: parameters derived from the LWR; R^2: coefficient of determination; *G*: growth type (-A: negative allometric; +A: positive allometric); *L*: length type (*TL*: total length; *PAL*: pre-anal length).
*Although one study used pre-anal length (*PAL*) instead of total length (*TL*), it was included due to the limited number of published length-weight relationship studies available for *H. italicus*. However, direct comparison between *PAL*-based and *TL*-based LWR parameters should be interpreted with caution because the two morphometric measurements are not directly equivalent.

Comparison of LWR results with previously published papers was presented in Table 2. The currently available literature indicates that published LWR data for *H. italicus* are still limited, but the few available studies provide important comparative context for the present findings. In particular, Başusta et al. (2025) reported the first large-scale LWR estimates for *H. italicus* from the northeastern Mediterranean, with the relationship for all individuals expressed as $W = 0.0027 \cdot TL^{2.504}$ (R^2=0.958, SE(b)=0.051), while sex-specific analyses yielded $W = 0.0024 \cdot TL^{2.632}$ for females (R^2=0.958, SE(b)=0.072) and $W = 0.0033 \cdot TL^{2.575}$ for males (R^2=0.959, SE(b)=0.072). Likewise, Filiz and Taskavak (2008) reported *b*=2.51 for the eastern Aegean Sea, while Morey et al. (2003) reported *b*=2.7964 for the western Mediterranean. In contrast, the present study yielded *b*=1.5667, indicating a much stronger departure from isometric growth. These estimates are substantially higher than the *b*=1.5667 obtained in the present study, indicating a much stronger weight increase with length in the northeastern Mediterranean population. Taken together, these results suggest that the b value obtained in the present study is the lowest so far reported for the species, clearly deviating from the more moderate allometric scaling documented elsewhere in the Mediterranean.

Several explanations may account for this discrepancy. First, regional ecological variability may play a role, as slope fish populations are known to respond to local differences in food availability, hydrography, and bathymetric habitat structure. Second, sample composition, including sex ratio, maturity stage, and seasonal pooling, may strongly influence the estimated allometric coefficient. This is particularly relevant because Başusta et al. (2025) showed that even within the same regional population, females and males produced slightly different LWR parameters. Third, and perhaps most importantly in the case of *H. italicus*, morphometric methodology may significantly affect the outcome. Macrourid fishes possess an extremely elongated, tapering, and fragile caudal region, making total length (TL) measurements particularly sensitive to handling-related distortion and measurement error. Some studies were not included in the main LWR comparison (Table 2) because they do not provide directly comparable $W = aL^b$ parameters. In this respect, Massutí et al. (1995) demonstrated a strong morphometric relationship based on pre-anal length (PAL) ($HL = 0.0674 + 0.5872 \cdot PAL$; *n*=154; R^2=0.92), supporting the use of PAL as a more stable size descriptor in this species. Likewise, D’Onghia et al. (2000) reported significant population-level morphometric relationships for large Mediterranean samples (*n*=6353), supporting the view that body-size estimation in this species is strongly influenced by the choice of morphometric variable. Therefore, the unusually low b value estimated here should be interpreted not only as a biological pattern, but also as a likely consequence of using TL in a species for which PAL may provide a more reliable morphometric basis. Future studies should prioritize PAL-based LWR estimation to improve comparability and reduce measurement-related uncertainty.

From a biological perspective, the observed negative allometry may be partly explained by the ontogenetic structure of the sampled population. Previous studies on macrourid fishes have demonstrated that size-frequency distributions often exhibit multimodal patterns and that population structure is influenced by depth-related variation, seasonal dynamics, and recruitment processes (D'Onghia et al., 2000). In particular, *H. italicus* exhibits prolonged recruitment and slow growth, with individuals of different life stages co-occurring within the same depth range (D'Onghia et al., 2000). When such heterogeneous size groups are analyzed together, deviations from isometric growth are expected, as body proportions and tissue allocation change throughout ontogeny.

Another important factor is the bathymetric and ecological context of the study area. Macrourids are dominant components of slope ecosystems, typically inhabiting depths between 200 and 2000 m and playing key roles in benthopelagic food webs (Massutí et al., 1995). In the Mediterranean, deep-sea environments are characterized by relatively stable physical conditions but limited and variable food supply, which strongly influences fish growth and energy allocation (Sarda et al., 2004). *H. italicus* in particular is known to feed mainly on suprabenthic and benthopelagic prey, with feeding intensity and diet composition varying temporally (Madurell & Cartes, 2006). Such trophic flexibility, combined with patchy prey availability, can lead to substantial variability in body mass relative to length and may contribute to reduced weight gain with increasing size.

At the assemblage level, deep demersal fish communities in the Mediterranean are strongly influenced by food availability, seasonal dynamics, and trophic interactions (Madurell et al., 2004). Long-term studies have shown that shifts in benthopelagic food webs can alter species composition, biomass, and trophic structure (Cartes et al., 2009). Since *H. italicus* is a benthopelagic feeder linking pelagic and benthic trophic pathways, its growth pattern is likely sensitive to such ecosystem-level variability. Therefore, the low b value observed here may reflect not only individual growth dynamics but also broader ecological processes operating in the Gökçeada slope ecosystem.

The bathymetric distribution of macrourids further supports this interpretation. Previous studies have shown that *H. italicus* abundance and biomass generally decrease below certain depths, while mean body size tends to increase with depth (Massutí et al., 1995). Similarly, large-scale analyses across the Mediterranean have revealed spatial and depth-related variability in abundance and size structure of macrourid populations (García-Ruiz et al., 2019). Such patterns indicate that growth and body form are closely linked to habitat use and environmental gradients, reinforcing the idea that the observed allometry is ecologically driven.

Condition factors (K and K_n) are widely used bio-indicators for assessing the nutritional and physiological status of fish populations within their habitats (Morey et al., 2003; Kale et al., 2021). The condition factor results obtained in the present study are consistent with the observed growth pattern of *H. italicus*. The moderate mean values of Fulton's condition factor (K) and relative condition factor (K_n), together with their relatively wide ranges, indicate inter-individual variability in physiological condition. Such variability is expected in deep-sea species, where feeding opportunities are irregular and energy intake is closely associated with the episodic availability of prey resources. In general, higher condition factor values are associated with favorable environmental and nutritional conditions, whereas lower values may reflect poorer physiological status or growth limitations. For the relative condition factor, values close to 1 indicate that individuals conform to the expected weight predicted from the population length-weight relationship, while deviations from 1 may suggest differences in individual condition relative to the population average (Kale et al., 2021; Acarli et al., 2022a). However, in elongated and slender-bodied species such as macrourids, relatively low Fulton's K values may naturally occur due to species-specific body morphology. Moreover, since Fulton's K assumes isometric growth, its applicability may be limited in species exhibiting strong allometry. In contrast, K_n is considered more appropriate under such conditions because it is directly derived from the empirical LWR.

A further methodological issue that should be considered when interpreting the present LWR results is the morphological peculiarity of the species, particularly the structure of the caudal region. *H. italicus* exhibits a highly elongated, fragile, and tapering tail, which is characteristic of many macrourid fishes and is associated with their benthopelagic lifestyle and locomotion. Such morphology can introduce significant uncertainty in total length (*TL*) measurements, especially if the caudal extremity is damaged, curved, or inconsistently positioned. In fact, morphometric studies on macrourids frequently rely on pre-anal length (*PAL*) as a more stable and biologically meaningful metric, particularly in growth and maturity analyses (Massutí et al., 1995). Since *TL* was used in the present study, part of the deviation observed in the LWR, especially the low b value, may reflect measurement-related bias associated with tail morphology. Therefore, future studies on *H. italicus* are strongly recommended to incorporate *PAL*-based analyses alongside *TL* measurements in order to reduce measurement error and obtain more reliable growth estimates.

The Gökçeada region itself provides an ecologically meaningful framework for interpreting these findings. The northern Aegean Sea is characterized by heterogeneous hydrographic conditions, complex circulation patterns, and variable productivity, all of which can influence deep benthic and demersal communities (Puerta et al., 2025). Such environmental variability may affect prey availability, habitat use, and energy allocation in slope-dwelling fishes, thereby influencing growth patterns and condition indices. Consequently, the observed growth characteristics of *H. italicus* may represent a combined effect of species-specific biology and local environmental conditions rather than a universal trait.

Despite these insights, the present study has some limitations that should be acknowledged. The LWR parameters were derived from pooled samples covering different seasons and depth ranges, and therefore represent population-level averages rather than fixed biological constants. Given the known influence of sex, maturity stage, season, and depth on growth patterns in macrourids, future studies should aim to stratify samples accordingly to better resolve intra-population variability.

In conclusion, the low b value observed in the present study should be interpreted as the result of multiple interacting factors, including ontogenetic variability, trophic ecology, deep-sea environmental conditions, and measurement sensitivity related to body morphology. Rather than representing a statistical anomaly, it likely reflects the adaptive growth strategy of *H. italicus* within the deep demersal ecosystem of the northern Aegean Sea. From a broader perspective, improving the understanding of growth patterns and condition in deep-sea fishes is essential for interpreting energy flow, trophic connectivity, and ecosystem functioning in slope environments. Such knowledge is also increasingly relevant in the context of expanding deep-sea exploitation and environmental change. Therefore, future research integrating standardized morphometric approaches (e.g., *PAL*), seasonal sampling, and bathymetric stratification will be critical for enhancing the ecological interpretation and management of deep demersal fish communities in the Mediterranean.

5. Conclusion

The present study provides the first detailed assessment of the length-weight relationship and condition factors of *H. italicus* from the deep waters surrounding Gökçeada Island in the northern Aegean Sea. The species exhibited a negative allometric growth pattern, with an estimated growth coefficient significantly lower than the theoretical isometric value. The condition indices obtained in this study suggest moderate but variable body condition among individuals, which is consistent with the ecological variability expected in deep demersal environments. The relatively low b value observed here likely reflects the combined influence of population structure, deep-water ecological conditions, and morphological measurement sensitivity, particularly due to the elongated and fragile caudal region of the species. In this respect, the use of pre-anal length (*PAL*) instead of total length (*TL*) may provide more robust morphometric estimates in future studies. The results presented here contribute valuable baseline biological information for *H. italicus* in the northern Aegean Sea. Such information is crucial for advancing knowledge of the species' growth dynamics, ecological role, and population-level variability within Mediterranean deep demersal ecosystems. Future research incorporating seasonal sampling, depth-stratified approaches, and *PAL*-based morphometric analyses will be valuable for refining biological assessments and strengthening ecosystem-based evaluations of deep-sea fish assemblages in the region.

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Conflict of interest

The authors declare that there is not any conflict of interest regarding the publication of this manuscript.

Ethical Approval

This article does not require ethics committee approval.

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Growth of mastic tree (*Pistacia lentiscus* var. *chia* Duham.) seedlings and the presence of arbuscular mycorrhizal fungi in V-shaped microcatchments

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Abstract

Afforestation success in semi-arid Mediterranean regions is increasingly constrained by water scarcity and climate change. Conventional planting techniques often fail to provide sufficient soil moisture for optimal seedling establishment and growth, highlighting the need for effective water management strategies. Rainwater harvesting (RWH) techniques, combined with plant-supportive treatments, offer a promising approach to overcome these limitations. This study aimed to evaluate the effects of V-shaped microcatchment systems and plant-supportive applications, including polymer, osmoprotectant, and mycorrhiza, on the early growth performance of *Pistacia lentiscus* seedlings. The experiment was conducted under semi-arid Mediterranean conditions using a randomized complete block design. At the end of the fourth growing season, root collar diameter and shoot height were measured. The sturdiness index was calculated, and mycorrhizal spores were counted. The results revealed that the terrace control (C-A) consistently produced the lowest growth values, indicating the inadequacy of conventional methods under water-limited conditions. In contrast, all microcatchment treatments significantly improved seedling performance and mycorrhizal spore counts. Overall, microcatchment systems increased soil moisture availability and promoted significant improvements in both height and diameter growth compared to the control. In conclusion, water availability was identified as the primary limiting factor for afforestation success. The integration of V-shaped microcatchment systems with plant-supportive treatments provides an effective and sustainable strategy to enhance seedling establishment and growth under semi-arid conditions.

Keywords: *Pistacia lentiscus* var. *chia*, Rainwater harvesting, V-shaped microcatchments, Semi-arid afforestation

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1. Introduction

Paleoclimatic studies indicate that climate systems have always undergone continuous change. However, while these changes were historically driven by natural processes, they are now predominantly influenced by anthropogenic activities (Türkeş, 2013). In particular, energy production, industrialization, urban expansion, and improper land-use practices have led to a significant increase in greenhouse gas concentrations in the atmosphere, thereby accelerating global warming and rendering climate change a critical issue at both global and national scales (Desonie, 2008; Erdönmez et al., 2023). Consequently, climate change manifests through a range of environmental impacts, including decreasing and irregular precipitation patterns, increased frequency of drought events, intensified forest fires, plant exposure to water stress, and progressive desertification (Öner et al., 2010; Örs et al., 2011).

One of the most critical consequences of climate change is the growing pressure on water resources. Declining and irregular precipitation, particularly in semi-arid and arid regions, significantly increases the risk of water scarcity and directly affects agricultural and forestry systems (Örs et al., 2011). Elevated temperatures combined with reduced rainfall intensify plant water stress, adversely affecting plant growth and development and ultimately resulting in yield losses. Furthermore, the progressive transition of semi-arid regions into arid zones exacerbates plant survival challenges. Therefore, enhancing plant tolerance to water stress has become a central focus in recent research efforts.

Among the strategies developed to mitigate these challenges, water harvesting techniques have emerged as effective approaches for improving water availability. Water harvesting involves capturing and storing rainfall at the point of occurrence, thereby reducing surface runoff, minimizing soil erosion, and promoting water retention within the soil profile (Tarı & Çakır, 2009; Örs et al., 2011). These techniques, which date back to ancient times, have regained considerable importance, particularly in arid and semi-arid environments (Oweis et al., 2001). Practices such as Negarim systems, semi-circular bunds, and contour-based structures effectively reduce runoff losses and support plant water requirements (Geremu et al., 2016). Nevertheless, these approaches alone are often insufficient, highlighting the need for complementary plant-based strategies.

In this context, biological approaches that enhance plant water and nutrient acquisition have gained increasing attention. Mycorrhizal fungi establish symbiotic associations with plant roots, significantly improving the efficiency of water and nutrient uptake. In this mutualistic relationship, fungi facilitate the absorption of water and mineral nutrients from the soil, while plants supply the fungi with photosynthetically derived organic compounds (Smith & Read, 2008; Dighton, 2009). These associations enhance plant tolerance to drought stress and sustain plant growth even under limited water availability (Cooper, 1984; Perry et al., 1987).

Mycorrhizal fungi are classified into different types depending on plant species, soil characteristics, and environmental conditions. Among these, endomycorrhiza and ectomycorrhiza are particularly significant for agricultural and forestry applications (Erzurumlu & Kara, 2014; Yılmaz, 2019). In endomycorrhizal associations, fungi colonize the cortical tissues of plant roots and facilitate nutrient exchange through specialized structures known as arbuscules. In contrast, ectomycorrhizal fungi develop between root cells and form extensive external mycelial networks, substantially increasing the plant's capacity to absorb water and nutrients (Anonymous, 2014). This enhanced absorption capacity provides a critical advantage for plant survival, particularly under arid and semi-arid conditions.

The benefits of mycorrhizal fungi extend beyond improved water and nutrient uptake. These fungi also promote plant growth, enhance root development, and increase resistance to plant pathogens (Erzurumlu & Kara, 2014; Altuntaş et al., 2015; Rafique & Ortas, 2018). Additionally, mycorrhizal associations contribute to soil structure improvement and play a vital role in maintaining ecosystem sustainability (Palta et al., 2010; Ataklı et al., 2021). Empirical studies conducted in arid and semi-arid regions have demonstrated that mycorrhizal inoculation significantly improves seedling establishment success and enhances plant resistance to water stress (Perry et al., 1987; Sanchez, 1994).

Within this framework, the mastic tree (*Pistacia lentiscus*), an economically and ecologically valuable species, holds particular importance. This species is naturally distributed only in the Çeşme Peninsula and Chios Island, making these regions key production centers. Mastic is widely utilized in various sectors, particularly in the food, cosmetic, and pharmaceutical industries, and constitutes a significant source of income for local communities. However, despite the ecological suitability of regions such as the Çeşme Peninsula, commercial production remains largely confined to Chios Island. This highlights the need to expand cultivation efforts through large-scale seedling production and plantation initiatives.

Given the increasing severity of climate change and associated water stress conditions, the successful establishment and growth of mastic seedlings in semi-arid environments remain a significant challenge. Therefore, integrating water harvesting techniques with mycorrhizal applications represents a promising approach to enhance plant survival and growth under drought conditions. Such integrated strategies may contribute significantly to sustainable forestry and agricultural practices, particularly in regions vulnerable to climate change.

2. Material and Method

2.1. Site description

The study was conducted in the Mediterranean Basin, where the adverse effects of climate change have recently become increasingly evident and are expected to intensify further. The research was carried out in three different sites located within the jurisdiction of the İzmir Regional Directorate of Forestry in Türkiye: one site in Çeşme (38°25′01″N, 26°31′16″E) and two sites in Urla (38°26′53″N, 26°30′13″E; 38°26′43″N, 26°30′12″E) (Figure 1).

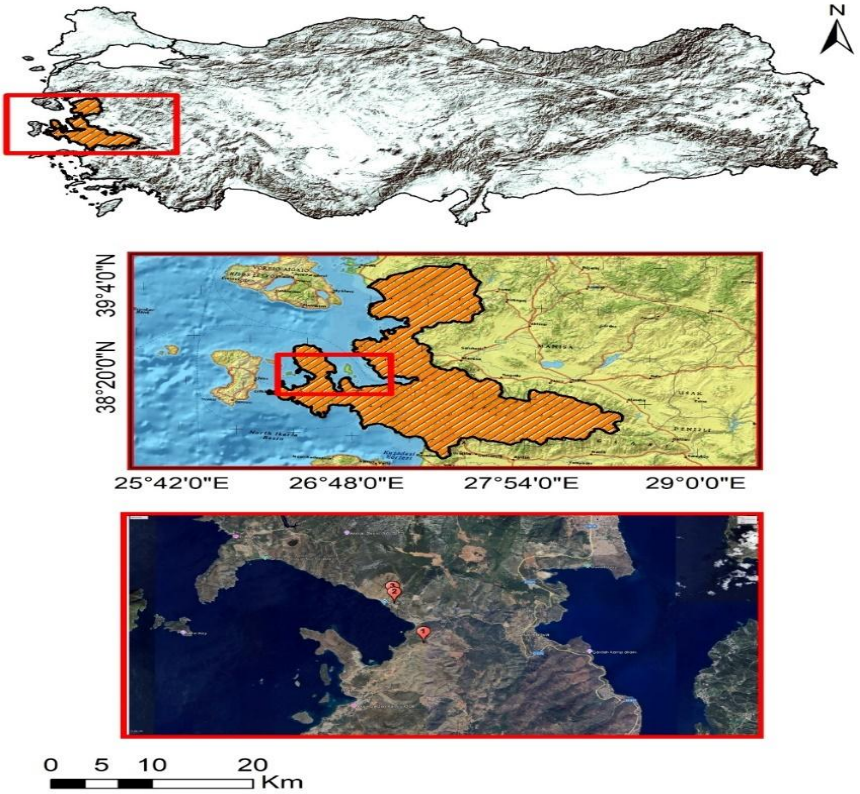

Figure 1. Location of the study sites

The treatments were applied over a total area of approximately 1.5 ha across the three sites. A randomized block design with three replicates (each site representing one "block") was employed in the study. The dominant parent material across the sites is limestone. The study area is characterized by an average slope of 20% and a mean elevation of approximately 150 m above sea level.

2.2. Climatic conditions

Long-term meteorological records spanning more than 80 years were utilized to characterize the climate of the study area. Thornthwaite potential evapotranspiration analyses indicate a substantial water deficit during the growing season, particularly from April to October (Figure 2). Additionally, analysis of the regional precipitation regime shows that approximately 80% of the total annual rainfall occurs outside the main growing season, when soil moisture availability is relatively high.

Recent data derived from the Copernicus/ECMWF ERA5 dataset (Hersbach et al., 2020) indicate that precipitation patterns in the region have become increasingly variable, while temperature and precipitation anomalies have become more frequent. These climatic changes are likely to exacerbate water scarcity and increase the vulnerability of afforestation areas to the impacts of climate change.

2.3. Growth measurements and statistical analysis

At the end of the fourth growing season, root collar diameter and shoot height were measured. The sturdiness index (SI), calculated as the ratio of shoot height to root collar diameter (SI = Shoot Height / Root Collar Diameter), was determined for each seedling, and mycorrhizal spores were counted and mycorrhizal spores were counted. Data were analysed according to the randomised complete block design, with blocks representing site-level differences in climatic water deficit. Treatment effects on growth were evaluated by analysis of variance (ANOVA). Normality and homogeneity of variances were tested using the Shapiro–Wilk and Levene tests, respectively. When treatment effects were significant, means were compared using Tukey's honestly significant difference (HSD) test at $\alpha = 0.05$. All analyses were performed using SAS software (SAS Institute Inc., Cary, NC, USA).

2.4. Plant species

Seedlings of *Pistacia lentiscus* var. *chia* obtained through air layering were used in the study (Figure 3). The mastic tree (*Pistacia lentiscus*) is one of the plant species native to the Mediterranean Basin and is naturally distributed particularly along the coastal regions of Greece, Türkiye, Italy, and Spain. This species is one of approximately 14 known species belonging to the genus *Pistacia* within the family Anacardiaceae.

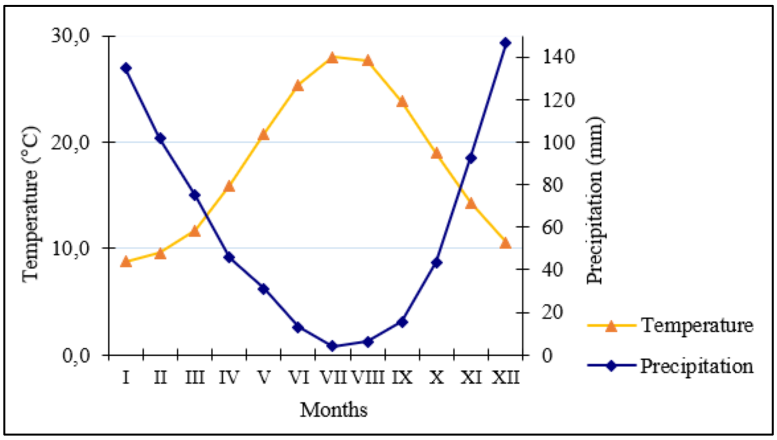

Figure 2. Diagram illustrating seasonal temperature and precipitation patterns at the study sites

Figure 3. Mastic seedling in the experimental area

2.5. Experimental design

The experiment was established using a randomized complete block design (RCBD) with three replications across three afforestation sites characterized by differing levels of seasonal water deficit (Koyuncu, 2024; Figure 4). Following the removal of vegetation, V-shaped microcatchments were constructed with their arms aligned parallel to contour lines. Conventional terracing was included as a reference treatment representing standard afforestation practices.

Across each block, six experimental units were established, four of which consisted of V-shaped microcatchments. Within these units, four treatments were applied: mycorrhiza (M), polymer (P), osmoprotectant (O), and polymer + osmoprotectant (P+O). In addition, an untreated microcatchment control (C-V) and a terraced control (C-A) were included. The C-A treatment represented conventional afforestation practice and received no plant-supportive treatments, as the primary objective was to compare V-shaped microcatchments against traditional terracing rather than to assess the interaction between catchment type and soil amendments. In total, 18 experimental units were established across the three sites, comprising 360 seedlings.

A commercial mycorrhizal mixture (RhizoMyx®, Novozymes) containing arbuscular mycorrhizal fungi and growth-enhancing components (i.e., humic acids, amino acids, vitamins, and organic extracts; Table 1) was used for mycorrhizal treatments. For application, 1 g of the mycorrhizal mixture was dissolved in 500 mL of water and applied to each seedling at the time of planting. For osmoprotectant treatments, a commercial product containing glycine betaine as the active ingredient was used. A 0.5% glycine betaine solution was applied as a foliar spray four times during the growing season (June, July, August, and September) using a backpack sprayer. For polymer treatments, a straw-based superabsorbent polymer (Natural Aquatic®) was applied at planting. The polymer, produced through the modification and acrylic polymerization of straw, has the capacity to absorb 200–300 times its volume in water and nutrients. Each seedling received 50 g of polymer, which was placed directly into the planting hole.

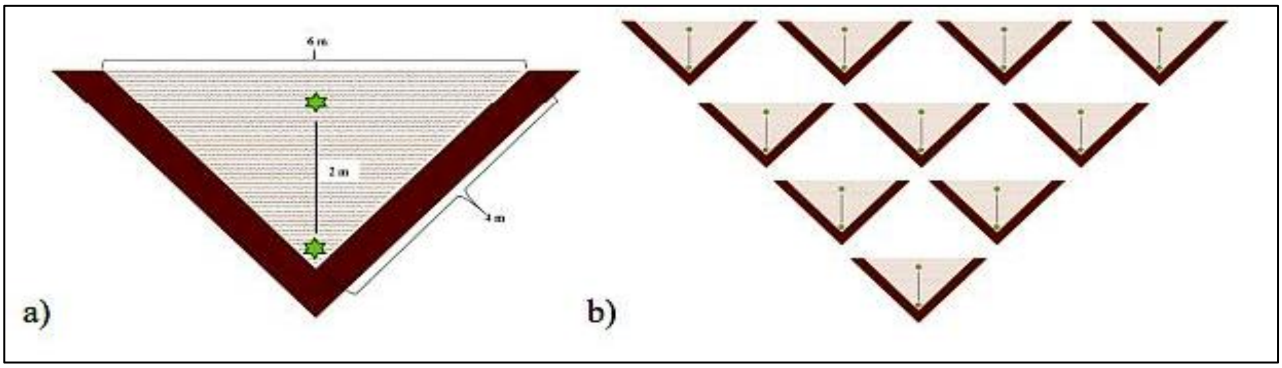

Figure 4. V-shaped microcatchment (a) and the appearance of V-shaped microcatchments in the experimental units (b)

Table 1. Composition of mycorrhizal mixture [RhizoMyx®(Novozymes)]

Arbuscular Mycorrhiza	(propagule g^{-1})	Inert Ingredients	%
Rhizophagus irregularis	25	Humic acids	28.70
Funneliformis mosseae	24	Cold-water kelp extracts	18.00
Glomus aggregatum	24	Ascorbic acid	12.00
Rhizophagus clarus	1	Amino acids	6.00
Glomus monosporum	1	Myo-inositol	2.50
Glomus deserticola	1	Surfactant	2.50
Glomus brasilianum	1	Thiamine	1.75
Glomus etunicatum	1	Alpha-tocopherol	1.00
Gigaspora margarita	1		

2.6. Determination of mycorrhizal spore density in soil

Mycorrhizal spore density in soil was determined using the wet sieving method (Gerdemann & Nicolson, 1963). For this purpose, 10 g of soil sample collected from each sampling area was mixed with an adequate amount of water and allowed to stand for 1–2 minutes. The soil–water suspension was then thoroughly homogenized, left to settle again for 1–2 minutes, and subsequently passed through a series of sieves with mesh sizes of 750, 250, 125, and 50 µm. This procedure was repeated until the filtrate became clear.

The material retained on the sieves was transferred into 100 mL centrifuge tubes and subjected to centrifugation. After centrifugation, the supernatant was discarded, and a 60% glucose solution was added to the remaining sediment, followed by a second centrifugation step. The sugar solution was then decanted, and distilled water was added to the samples. The resulting samples were examined under a light microscope at 40× magnification, and mycorrhizal spores were counted (Gerdemann & Nicolson, 1963). Spore density was calculated as the number of spores per unit weight of soil using the following equation (Mahulette et al., 2022).

3. Results

3.1. Effects of treatments on root collar diameter

Root collar diameter (RCD) values for 2025 are presented in Figure 5. A statistically significant difference was detected among treatments (p=0.0165). While no significant differences were found among the V-shaped microcatchment treatments (C-V, M, P, O, and P+O), their mean RCD was approximately 60.4% higher than that of the C-A treatment.

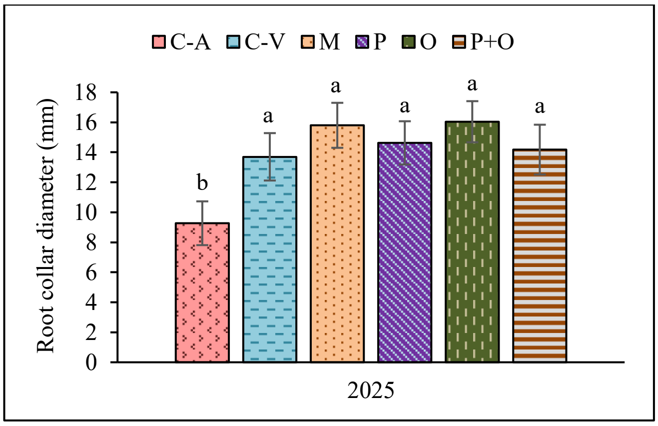

Figure 5. Effects of different treatments on root collar diameter (RCD) of *Pistacia lentiscus* seedlings in 2025

3.2. Effects of treatments on seedling height

Seedling height values for 2025 are presented in Figure 6. A statistically significant difference was detected among treatments (p=0.0004). While no significant differences were found among the V-shaped microcatchment treatments (C-V, M, P, O, and P+O), their mean seedling height was approximately 77.9% higher than that of the C-A treatment.

3.3. Effects of treatments on seedling sturdiness index

Seedling sturdiness index (SI) values for 2025 are presented in Figure 7. A statistically significant difference was detected among treatments (p<0.0001). The P treatment exhibited approximately 41% higher values than the C-V and P+O treatments, and about 115% higher than the C-A treatment. The mean SI values of the M, P+O, O, and C-V treatments were approximately 66.4% higher than that of the C-A treatment. In addition, the highest SI value was observed in the P treatment, whereas the lowest value was recorded in the C-A treatment. However, no statistically significant differences were found between the P treatment and the M and O treatments.

3.4. Effects of treatments on mycorrhizal spore density

Mycorrhizal spore counts for June and September are presented in Figure 8. A statistically significant difference was detected among treatments in both sampling periods (p<0.0001). In June, in terms of mycorrhizal spore density, the M treatment exhibited the highest value among all treatments. The M treatment was approximately 16.3 times higher than C-A, and 157.9%, 58.1%, 145.0%, and 133.3% higher than C-V, P, O, and P+O, respectively. The P treatment was approximately 10.3 times higher than C-A, and 63.2%, 55.0%, and 47.6% higher than C-V, O, and P+O, respectively. In addition, the mean value of the P+O, O, and C-V treatments was approximately 6.7 times (about 566.7%) higher than that of the C-A treatment.

In September, the M treatment exhibited the highest mycorrhizal spore density among all treatments, being 288.9% higher than C-A, 52.2% higher than C-V, 34.6% higher than P, 66.7% higher than O, and 45.8% higher than P+O. The P treatment also showed higher values than C-A, C-V, and O, being 188.9% higher than C-A, 13.0% higher than C-V, and 23.8% higher than O. In addition, the P+O, C-V, and O treatments were approximately 2.52 times (about 151.9%) higher than the C-A treatment.

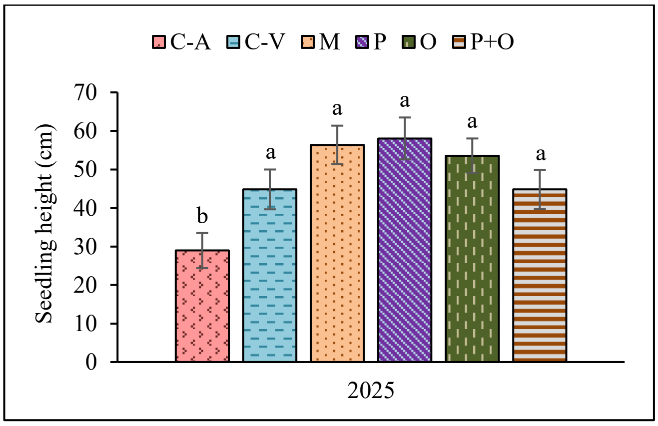

Figure 6. Effects of different treatments on seedling height of *Pistacia lentiscus* seedlings in 2025

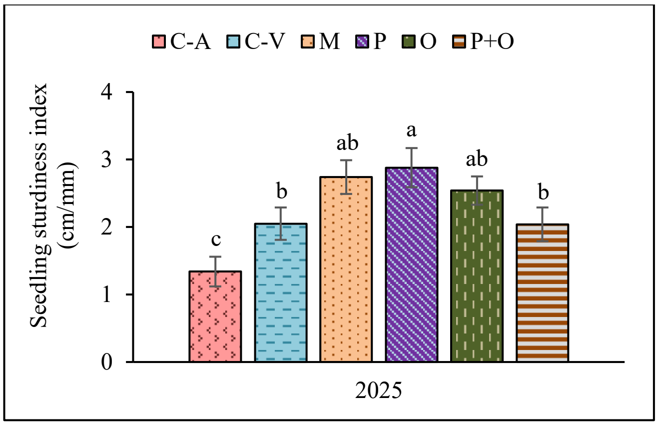

Figure 7. Effects of different treatments on seedling sturdiness index of *Pistacia lentiscus* seedlings in 2025

4. Discussion

The findings of this study clearly demonstrate that V-shaped microcatchment techniques, combined with plant-supportive treatments, play a decisive role in improving seedling performance under semi-arid Mediterranean conditions. The consistently lower values observed in all growth parameters under C-A treatment indicate that conventional afforestation practices are insufficient to sustain optimal seedling development in water-limited environments. Similar limitations of traditional methods under drought conditions have been reported in previous studies, where low soil moisture availability resulted in reduced growth and survival rates (Omer & Ahmed, 2021).

In contrast, all microcatchment-based treatments, including C-V treatment, exhibited superior growth performance compared to the terrace control. This highlights the effectiveness of V-shaped microcatchment systems in enhancing soil moisture availability within the root zone. Microcatchment structures reduce surface runoff and promote water infiltration, thereby increasing plant-available water.

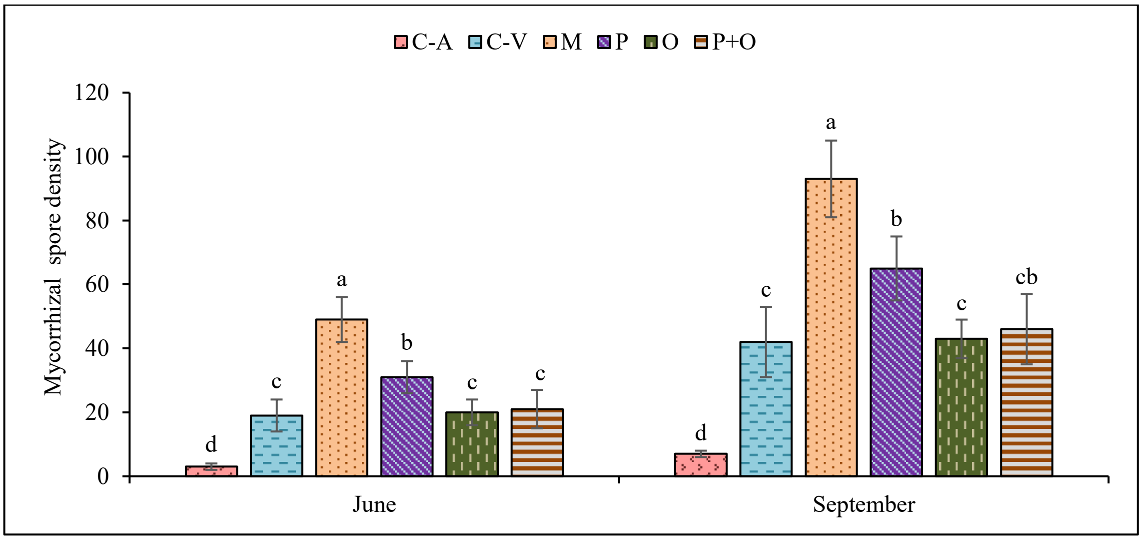

Figure 8. Effects of different treatments on mycorrhizal spore density in June and September

These findings are consistent with previous studies demonstrating that microcatchment techniques significantly improve soil moisture and seedling growth (Karaşin et al., 2024; Ma et al., 2024; Aydın et al., 2025). Moreover, studies conducted in different ecosystems have shown that rainwater harvesting systems can substantially enhance plant height and root collar diameter (Singh et al., 2013; Feng et al., 2024).

The increased growth observed in microcatchment treatments is also supported by the findings of Siyum et al. (2019), who reported that moisture harvesting structures significantly improved seedling height, root collar diameter, and crown width compared to control treatments. Similarly, in a study conducted under Mediterranean conditions, crescent-shaped rainwater harvesting structures significantly enhanced the growth performance of *Pistacia lentiscus* seedlings (Kamer et al., 2026).

When the treatments are evaluated, the relatively higher seedling height and sturdiness index observed under the P treatment indicate the important role of water-retentive materials in mitigating water stress under semi-arid conditions. Superabsorbent polymers enhance soil water-holding capacity and provide a gradual water supply to plants during dry periods, thereby supporting growth performance. These findings are consistent with previous studies showing that polymer applications improve plant growth and drought tolerance (Ünlü et al., 2025). Furthermore, when combined with microcatchment systems, these materials contribute to prolonged moisture retention in the root zone, indirectly supporting plant development (Karaşin et al., 2026).

Similarly, the relatively greater root collar diameter observed under the O treatment indicates that physiological stress mitigation mechanisms may influence plant development under drought conditions. Osmoprotectants help maintain cellular osmotic balance and improve plant tolerance to water stress, allowing growth processes to continue more steadily (Ünlü et al., 2025). In this context, the integration of structural water management approaches with physiological support may create a complementary effect in enhancing plant growth performance.

The positive effects of M treatment applications are also supported by previous research. Mycorrhizal fungi enhance water and nutrient uptake by increasing the effective root surface area, thereby improving plant performance under drought stress. In this context, the findings of this study are consistent with those of Ma et al. (2024), who reported that rainwater harvesting systems improve plant hydraulic conductivity and root-related traits.

The absence of significant differences among microcatchment treatments, despite their clear superiority over C-A treatment, suggests that water availability is the primary limiting factor in this ecosystem. Once sufficient soil moisture is provided through microcatchment systems, additional treatments such as polymer, osmoprotectant, and mycorrhiza contribute to growth through complementary mechanisms.

Overall, the results indicate that rainwater harvesting techniques, particularly V-shaped microcatchment systems, play a critical role in enhancing afforestation success under semi-arid conditions. The integration of these systems with plant-supportive applications such as polymers, osmoprotectants, and mycorrhiza offers an effective and sustainable strategy for improving seedling establishment and growth in water-limited environments. These findings emphasize the importance of integrated water management approaches for afforestation under increasing climate change-induced drought conditions.

5. Conclusion

The findings of this study clearly show that V-shaped microcatchment techniques play a significant role in improving the growth performance of *Pistacia lentiscus* seedlings under semi-arid Mediterranean conditions. The low growth values observed in C-A highlight the limitations of conventional afforestation practices in water-limited environments. In contrast, C-V proved to be highly effective in enhancing soil moisture availability, leading to noticeable improvements in both seedling height and root collar diameter.

Overall, the results clearly indicate that water availability is the main limiting factor for afforestation success in semi-arid environments. The study clearly demonstrated the positive effects of the micro-catchment when combined with supportive treatments such as polymers, osmoprotectants, and mycorrhiza.

In conclusion, the combined use of V-shaped microcatchment systems with plant-supportive treatments offers an effective and practical approach to improving seedling performance under water-limited conditions. These findings contribute to the development of more sustainable afforestation strategies, particularly in regions increasingly affected by climate change..

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This article is derived from the master's thesis of the first author.

Conflict of interest

The authors declare no conflict of interest.

Ethical Approval

This article does not require ethics committee approval.

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Morphometric and biochemical composition of blue crabs (*Callinectes sapidus* Rathbun, 1896) collected from the Saros Bay (Çanakkale, Türkiye)

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Abstract

In this study, the morphometric characteristics, and biochemical composition of the blue crab (*Callinectes sapidus* Rathbun, 1896) population found in the Saros Bay (Çanakkale, Türkiye) were evaluated. Carapace width and length-weight relationships (CWiWR and CLWR), as well as protein, lipid, ash, and moisture contents, were examined in the sampled crabs. It was observed that female crabs (72%) predominated in the population. The average carapace width of female crabs was found to be greater than that of male individuals. In this study, carapace length-weight relationship (CLWR) and carapace width-weight relationship (CWiWR) in blue crab individuals demonstrated different growth patterns between sexes. Female crabs exhibited negative allometric growth in both CLWR (b=1.809) and CWiWR (b=1.773) relationships, indicating that body dimensions increased at a faster rate than body weight. In contrast, male crabs showed an isometric growth pattern in the CLWR relationship (b=3.008), suggesting a proportional increase between carapace length and body weight during growth. However, the CWiWR relationship in males (b=2.525) indicated negative allometric growth. In addition, the relatively higher b values observed in males compared to females suggest that males tend to gain more body mass during development. The blue crab is an important species in terms of nutritional value due to its high protein content. It is believed that the species' physiological characteristics, energy storage strategies, and reproductive cycle influence the variations in protein, lipid, and ash content among tissues.

Keywords: Carapace length/width-weight relationship, Meat yield, Biochemical composition

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1. Introduction

One of the most commonly caught crab species in the waters of Türkiye is *Callinectes sapidus*. The blue crab is native to the northwestern Atlantic (Yağlıoğlu et al., 2014; Bilgin, 2019). The blue crab, which can easily enter lagoons, river mouths, and occasionally rivers, has a high tolerance for salinity and temperature; it is known to be able to survive in both highly saline and very low-salinity waters (Mancinelli et al., 2017; Bilgin, 2019). It was first observed in Türkiye in the Gulf of Iskenderun (Hatay) (Holthuis, 1961). It has been reported to be distributed from the Gulf of Iskenderun throughout the entire Mediterranean coast and lagoons, extending as far as the Menderes Lagoon in the Aegean, and is also present in the Sea of Marmara (Enzenrob et al., 1997). Saros Bay constitutes an important habitat for numerous marine species due to its unique oceanographic characteristics, and high biological diversity (Öztürk & Öztürk, 1996). Furthermore, the extensive coastal lagoon systems, muddy-sandy substrate structure, and rich benthic organism diversity of Saros Bay provide suitable feeding, sheltering, and breeding grounds for blue crabs. These ecological characteristics may contribute significantly to the growth performance, population structure, and physiological development of the species (Öztürk & Öztürk, 1996).

Information on the nutritional composition of blue crabs is necessary to simplify their processing, consumption, and marketing. Blue crabs have a wide dietary range consisting of both plant and animal organisms, whether live or dead. Although they are known as scavengers, they prefer live and fresh food. Their diet includes bivalves, fish, crustaceans, gastropods, and plant matter. They catch small fish and use their crushing chelipeds to consume young oysters and bivalves (Türeli, 1999).

Blue crabs, which are among luxury food products and have the potential to generate foreign exchange for our country through exports, are not currently farmed in Türkiye. There is also an imbalance in the quantities obtained through fishing. In this study, the aim was to evaluate the relationships between length-weight, meat yield, and biochemical composition of blue crabs.

2. Material and Method

2.1. Study area and sample preparation

In this study, blue crabs were collected in April 2022 from the Saros Bay (Çanakkale, Türkiye). The crab specimens brought to the laboratory were separated into female and male groups based on their sex (Figure 1). Their weights were measured using a scale with a precision (AND GF 6100) of 0.01 g. Morphological measurements were also carried out on 58 female and 22 male blue crabs (Figure 2). Carapace length, carapace depth, carapace width, cheliped length, cheliped width, and cheliped depth were measured to the nearest 0.01 cm using a vernier caliper (MITUTOYO 500-203-30). Carapace width (CWi) was defined as the linear distance between the apices of the posterior-most lateral carapace spines. Carapace length (CL) was measured dorsally along the median axis, extending from the frontal notch to the posterior edge of the carapace (Josileen, 2011). Subsequently, the basic statistical data of the measurement values were calculated, and the relationships among them were determined (Paul & Haefner, 1985; Türeli, 1999).

2.2. Meat yield and condition factor

The following formula were used to determine meat yield (*MY*) (Freeman, 1974).

$$MY = \frac{Wet\ meat\ weight\ (g)}{Total\ weight\ (g)} 100 \quad (1)$$

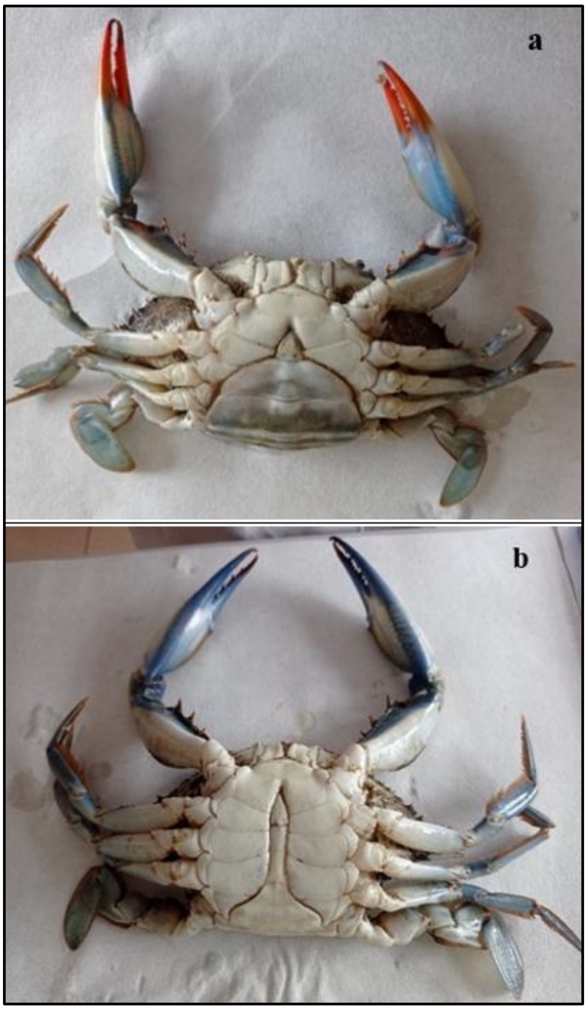

Figure 1. Ventral view of (a) female and (b) male blue crabs. In males, the tail flap is characterized by a narrow triangular apron, whereas in females it exhibits a comparatively broader morphology.

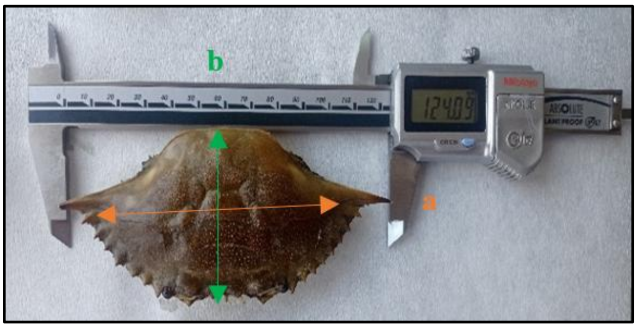

Figure 2. Morphometric measurements of blue crab (a: Carapace width, b: Carapace length)

2.3. Biochemical composition

Freeze-dried meat samples were analyzed to determine their proximate composition. Crude protein content (%) was measured using the Kjeldahl method with a nitrogen conversion factor of 6.25 (N×6.25). Total lipid content was determined by extraction with a chloroform–methanol mixture following the method of

Erickson (1993). Ash content was obtained by incineration in a muffle furnace according to AOAC (2000). Moisture content was determined gravimetrically in accordance with AOAC (2000). Carbohydrate content was calculated by difference as described by Çelik et al. (2014).

$$Moisture(\%) = \frac{wet\ meat\ weight(g) - dry\ meat\ weight(g)}{wet\ meat\ weight(g)} 100 \qquad (2)$$

$$Carbohydrate(\%) = 100 - [Lipid(\%) + Protein(\%) + Ash(\%)] \qquad (3)$$

2.4. Morphometric relationship

The morphometric measurements are expressed as mean ± standard deviation (SD). The carapace length–weight relationship (CLWR) and carapace width–weight relationship (CWiWR) were estimated using the following exponential equations (Ricker, 1975).

$$W = aL^b \qquad (4)$$

$$W = aCWi^b \qquad (5)$$

In these equations;
W: Total weight (g),
L: Carapace length (cm),
CWi: Carapace width (cm),
a: Intercept,
b: Slope of the regression curve.

The exponential equations were transformed to following logarithmic equations.

$$\log W = \log a + b \log L \qquad (6)$$

$$\log W = \log a + b \log CWi \qquad (7)$$

The statistical significance of the b value was evaluated using a t-test. Growth was considered isometric when b=3, positive allometric when b>3, and negative allometric when b<3 (Pauly, 1984). The significance level was determined as p<0.05. The Kolmogorov-Smirnov test was utilized to assess the normality of the data distribution. The relationship between the morphometric parameters and biochemical compositions of blue crabs was examined using Spearman correlation analysis. The SPSS 27 software for Windows was used to conduct all statistical analyses.

3. Results

A total of 80 blue crabs were collected. The population examined was found to consist of 28% male and 72% female individuals.

Morphometric measurements of female blue crabs are given in Table 1. The average carapace length, width, weight of female blue crabs was 6.42±0.8 cm, 14.57±2.06 cm, 142.77±38.95 g, respectively. Morphometric measurements of male blue crabs are given in Table 2. The weight of male blue crabs was measured at 158.98±49.06 g, and carapace length at 10.91±1.13 cm.

Table 1. Biometric characteristics of female blue crabs

	Weight (g)	Carapace Length (cm)	Carapace Depth (cm)	Carapace Width (cm)	Carapace Weight (g)	Carapace Meat Yield (%)
Min	57.36	8.08	2.53	9.82	38.51	12.70
Max	215.66	13.22	4.11	18	149.58	33.35
Mean±SD	142.77±38.95	11.12±1.21	3.53±0.34	14.57±2.06	95.47±26.99	25.09±4.75
	Right Cheliped Weight (g)	Right Cheliped Length (cm)	Right Cheliped Depth (cm)	Right Cheliped Width (cm)	Right Cheliped Meat Yield (%)	
Min	2.32	4.56	1.16	0.97	14.36	
Max	12.90	8.09	2.17	2.15	70.16	
Mean±SD	6.95±2.40	6.60±0.78	1.74±0.23	1.39±0.21	48.92±8.26	
	Left Cheliped Weight (g)	Left Cheliped Length (cm)	Left Cheliped Depth (cm)	Left Cheliped Width (cm)	Left Cheliped Meat Yield (%)	
Min	2.76	4.88	1.26	0.98	8.33	
Max	12.67	7.92	2.21	2.04	90.27	
Mean±SD	6.90±2.32	6.51±0.70	1.75±0.21	1.41±0.21	49.48±12.45	

Table 2. Biometric characteristics of male blue crabs

	Weight (g)	Carapace Length (cm)	Carapace Depth (cm)	Carapace Width (cm)	Carapace Weight (g)	Carapace Meat Yield (%)
Min	80.08	8.59	2.86	10.36	53.52	24.65
Max	236.25	12.62	3.95	16.14	141.20	44.97
Mean±SD	158.98±49.06	10.91±1.13	3.53±0.31	13.43±1.58	93.45±25.82	32.79±4.37
	Right Cheliped Weight (g)	Right Cheliped Length (cm)	Right Cheliped Depth (cm)	Right Cheliped Width (cm)	Right Cheliped Meat Yield (%)	
Min	4.45	5.69	1.55	1.06	22.70	
Max	17.58	8.91	2.31	1.94	55.87	
Mean±SD	10.92±3.90	7.59±0.99	1.98±0.24	1.62±0.24	46.13±8.35	
	Left Cheliped Weight (g)	Left Cheliped Length (cm)	Left Cheliped Depth (cm)	Left Cheliped Width (cm)	Left Cheliped Meat Yield (%)	
Min	4.15	5.66	1.46	1.15	33.44	
Max	16.3	9.23	2.30	1.99	57.11	
Mean±SD	9.96±3.96	7.56±1.03	1.90±0.25	1.58±0.24	47.88±5.88	

Table 3. Allometric relationships of blue crab between morphometric components (carapace length and carapace width) and total weight

Relationship	Sex	*N*	*a*	*b*	R^2	Relationship (*t*-test)
CLWR	Female	58	0.682	1.809	0.657	- allometry
	Male	22	-0.281	3.008	0.918	isometry
CWiWR	Female	58	0.082	1.773	0.777	- allometry
	Male	22	-0.660	2.525	0.857	- allometry

Statistical description of the parameters including sample size (*N*) (number of specimens observed), length-weight relationship parameters ‘*a*’ and ‘*b*’ with 95% confidence limits, and coefficient of determination (R^2) for blue crabs are shown in Table 3.

When analyzing the nutritional composition of blue crabs, in female blue crabs, protein content was highest in the carapace meat (77.39±1.88%), followed by the right cheliped, left cheliped, gonad, carapace shell, right cheliped shell, and left cheliped shell; lipid content was highest in the gonad (23.83±1.75%); carbohydrate content was highest in the carapace shell (30.54±5.42%); moisture content was highest in the carapace meat (80.45±3.47%); and ash content was highest in the right cheliped shell (70.18±1.70%). In male blue crabs, similar to females, the highest protein content was found in carapace meat (78.89±3.24%), lipids in sperm (15.33±1.15%), carbohydrates in carapace shell (25.34±2.85%), and moisture in carapace meat (80.90±3.25%). However, the highest ash content was observed in the left cheliped shell (70.53±1.07%) (Table 4).

According to the Spearman correlation analysis (Table 5), significant relationships were identified among the biochemical parameters of the blue crab. Protein content showed strong positive correlations with lipid (r=0.702, p<0.01) and moisture content (r=0.947, p<0.01), whereas significant negative correlations were observed with carbohydrate (r=-0.662, p<0.01), ash (r=-0.693, p<0.01), and tissue type (r=-0.898, p<0.01). These findings indicate that protein-rich tissues are also characterized by high moisture content, while containing lower levels of carbohydrates and mineral substances. Lipid content was positively correlated with moisture (r=0.787, p<0.01) and negatively correlated with ash content and tissue type, suggesting that lipid accumulation is greater in softer edible tissues than in mineralized structures. Carbohydrate content exhibited positive correlations with ash (r=0.578, p<0.01) and tissue type (r=0.741, p<0.01), indicating that carbohydrates are relatively more abundant in mineral-rich shell tissues. In addition, the negative correlation detected between moisture and ash content (r=-0.624, p<0.01) suggests that increasing water content is associated with reduced mineral density. No significant correlations were found between sex and the examined biochemical parameters, indicating that biochemical composition is influenced primarily by tissue type rather than sex. Overall, these results demonstrate that the biochemical composition of blue crab varies substantially according to the physiological and structural characteristics of different tissues.

Table 4. Biochemical composition of blue crab freeze-dried tissue (meat, gonad, sperm) and shell (%) (Mean±SD)

	Sex	Protein	Lipid	Carbohydrate	Moisture	Ash
Carapace Meat	Female	77.39±1.88	12.67±2.31	2.71±0.15	80.45±3.47	7.23±1.06
	Male	78.89±3.24	14.00±2.00	3.15±2.81	80.90 ±3.25	3.96±1.71
Right Cheliped Meat	Female	75.52±0.49	11.33±3.06	5.22±2.90	80.71±5.55	7.92±1.04
	Male	76.26±4.40	12.00±2.00	3.76±2.38	79.96±10.99	7.98±1.03
Left Cheliped Meat	Female	77.15±0.39	10.67±1.15	5.08±0.73	80.15±10.52	7.10±2.03
	Male	79.11±0.65	10.67±4.16	3.93±2.62	82.10±6.06	6.30±2.88
Gonad	Female	54.43±0.83	23.83±1.75	19.09±1.95	71.76±6.50	2.65±2.30
Sperm	Male	70.79±1.20	15.33±1.15	7.60±2.00	71.76±6.50	6.27±1.15
Carapace Shell	Female	13.00±0.62	2.97±0.96	30.54±5.42	37.55±4.77	53.49±4.09
	Male	13.26±0.35	3.32±2.32	25.34±2.85	35.06±4.76	58.08±0.70
Right Cheliped Shell	Female	10.42±0.99	2.00±0.00	17.40±2.65	26.44±8.71	70.18±1.70
	Male	9.43±0.80	4.60±1.11	15.77±1.32	26.43±8.50	70.20±1.00
Left Cheliped Shell	Female	9.44±0.28	3.31±1.13	18.07±1.31	26.09±6.59	69.18±0.37
	Male	9.30±0.08	2.00±3.46	18.17±4.07	25.37±7.41	70.53±1.07

Table 5. Spearman correlation of protein, lipid, carbohydrate, moisture, ash, sex (female and male) and tissue (Carapace meat, right cheliped meat, left cheliped meat, gonad, sperm, carapace shell, right cheliped shell and left cheliped shell)

Spearman	Protein	Lipid	Carbohydrate	Moisture	Ash	Sex	Tissue
Protein	1						
Lipid	0.702*	1					
Carbohydrate	-0.662*	-0.439*	1				
Moisture	0.947*	0.787*	-0.566*	1			
Ash	-0.693*	-0.735*	0.578*	-0.624*	1		
Sex	0.051	0.049	-0.132	-0.002	0.033	1	
Tissue	-0.898*	-0.688*	0.741*	-0.863*	0.764*	0.018	1

**Correlation is significant at the 0.01 level.*

4. Discussion

In the present study, the proportion of female blue crabs (72%) was found to be considerably higher than that of males (28%). It is well established that sex ratios in crab populations are not constant and may vary depending on sampling period, environmental conditions, migration behavior, and reproductive cycles (Permatahati et al., 2025). Similarly, Türeli (1999) reported that females constituted 68.8% of the blue crab population in the Gulf of Iskenderun. This pattern may be explained by the tendency of females to aggregate in specific habitats during reproductive periods, whereas males generally exhibit a broader spatial distribution (Permatahati et al., 2025).

Morphometric analyses revealed that the mean carapace width of female individuals was greater than that of males. This finding may be associated with reproductive adaptations related to egg-carrying capacity in females. However, several studies have reported that male crabs may attain larger body sizes (Iveša et al., 2025). Türeli (1999) reported a mean carapace width of 12.69±2.33 cm in adult females, while Enzenrob et al. (1997) documented carapace widths ranging between 10.8 and 15.1 cm. In addition, Prager et al. (1990) reported an average carapace width of 14.7 cm in ovigerous females. These findings indicate that the morphometric values obtained in the present study are generally consistent with the existing literature.

Regression analyses of the length–weight relationships demonstrated distinct growth patterns between female and male individuals. In the CLWR, females exhibited negative allometric growth (b=1.809), whereas males showed an isometric growth pattern, with the b value being very close to 3 (b=3.008). This result indicates that body weight increased proportionally with carapace length in males. In contrast, the predominance of length increase over weight gain in females may be associated with energy allocation toward reproductive activities and metabolic processes (Hartnoll, 1983; Atar & Seçer, 2003).

The CWiWR revealed negative allometric growth in both sexes. Nevertheless, the relatively higher b value and high coefficient of determination (R^2=0.857) observed in males indicated that body weight increased more rapidly with increasing carapace width. This pattern may be related to enhanced muscle development and pronounced cheliped enlargement in males. In brachyuran crabs, chelipeds are functionally important structures involved in prey capture, defense, territorial competition, and mate acquisition, and they are generally more developed in males (Lee & Seed, 1992; Mariappan et al., 2000). In the present study, the larger right cheliped measurements observed in males support the existence of functional asymmetry associated with dominant claw usage. Similarly, the relatively larger right cheliped measurements in females suggest that bilateral morphological asymmetry may also occur in female individuals.

In length–weight analyses, *b* values lower than 3 indicate negative allometric growth, suggesting that body dimensions increase at a faster rate than body weight. Negative allometric growth is generally associated with food limitation, population density, environmental stress, and developmental stages of individuals (Sahu et al., 2026). Furthermore, length–weight relationships are influenced by several biological factors including sex, sexual maturity, molting stage, and carapace morphology (Olmi & Bishop, 1983). Therefore, the growth differences identified in this study may be associated with the environmental conditions and population structure of Saros Bay (Çanakkale, Türkiye).

The high R^2 values obtained from the regression analyses demonstrated strong relationships between carapace measurements and body weight, indicating that the models explained the variability in the data to a considerable extent. These findings suggest that both carapace length and carapace width are reliable morphometric parameters for biomass estimation and population assessments. Similarly, Atar and Seçer (2003) reported that width/length–weight relationships exhibit high correlation and provide a reliable method for population evaluation.

Biochemical analyses revealed that blue crab represents an important nutritional resource due to its high protein content. The protein values determined in this study were generally consistent with those reported in the literature, indicating that the nutritional quality of the species may exhibit similar characteristics across different geographical regions. The biochemical composition of different body parts varied considerably depending on tissue type and sex. The highest protein content was detected in the carapace meat of male individuals (78.89±3.24%), while similarly high protein levels were also recorded in the carapace and cheliped meat of females. Lipid content was particularly high in gonadal tissues (23.83±1.75%), indicating substantial energy storage associated with reproductive activity. Carbohydrate levels were generally low in all tissues, although relatively higher values were observed in shell tissues. Moisture content ranged between 71% and 81% in edible tissues, confirming the high water content characteristic of blue crab meat. In contrast, ash content was markedly higher in shell tissues (53–70%), reflecting their mineral-rich composition.

The generally higher protein levels observed in males may be associated with stronger muscle development and increased metabolic activity. Türeli et al. (2000) reported 18.93% protein, 22.43% moisture, and 2.34% crude ash in the carapace meat of male blue crabs and emphasized that blue crab meat constitutes a protein-rich food source. Furthermore, biochemical composition is influenced not only by species-specific characteristics but also by tissue type and seasonal variation. Türeli et al. (2002) reported that the distribution of protein, lipid, and ash in cheliped and carapace meat varies according to seasonal changes.

5. Conclusion

The findings of this study revealed that female individuals were dominant in the studied population and that the sex ratio could vary depending on environmental and biological factors.

Morphometric analyses revealed that female individuals had a larger carapace width than male individuals, and negative allometric growth was detected in the length-weight relationship. This indicates that height increase occurs faster than weight increase, and that the growth pattern can be influenced by environmental conditions. Furthermore, the strong correlation between carapace measurements and weight demonstrates that these parameters are reliable indicators in population analyses.

Biochemical analyses have revealed that the blue crab is a highly nutritious species with a high protein content. The variation in protein, lipid, and ash components among tissues is thought to be related to the species' physiological structure, energy storage strategies, and reproductive processes. This suggests that biochemical composition can vary not only depending on species characteristics but also on environmental conditions and seasonal changes.

Overall, the blue crab population in this area has been determined to have significant potential in terms of both morphometric and biochemical aspects. However, due to the sensitivity of its growth characteristics and population structure to environmental factors, regular monitoring studies, seasonal assessments, and the development of appropriate fishing strategies are of great importance for the sustainable management of the species.

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Conflict of interest

The authors declare that there is not any conflict of interest regarding the publication of this manuscript.

Ethical Approval

This article does not require ethics committee approval.

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