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Research Article

Length – Weight Relationships, Meat Yield and Morphometric Indices of Five Commercial Bivalve Species Collected from the Çanakkale Strait (Türkiye)

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ABSTRACT

This study was conducted to determine the meat yield, morphometric characteristics, length–weight relationships (LWRs) and their correlations with environmental variables of five commercial bivalve species collected monthly between 2014 and 2015 from the coastal waters of the Çanakkale Strait. A total of 8588 individuals were examined, and different ranges for both shell length (9.00-108.50 mm) and total weight (0.30-234.20 g) were determined according to species. The highest meat yields from *Donax trunculus* (16.40-23.34%), *Mytilus galloprovincialis* (14.89-34.35%) and *Ostrea edulis* (5.91-26.24%) were determined in spring, while *Ruditapes philippinarum* (10.80-29.53%) and *Chamelea gallina* (12.26-18.92%) had maximum yield in late summer and early autumn ($p<0.05$). Elongation index (SH/SL), compactness index (SW/SL), convexity index (SW/SH), and density indexes (TW/SL) were significant ($p<0.05$) and had high correlation coefficients ($r=0.806$-0.975). The mean value of the allometry coefficient (b) was 3.257 ± 0.168, ranging from 2.291 to 4.058. Four species had negative allometries, namely *D. trunculus* (2.738), *C. gallina* (2.889), *M. galloprovincialis* (2.597) and *O. edulis* (2.728), while *R. philippinarum* (3.137) displayed positive allometry. The morphometric indices show high morphological resemblances. As a result, it is thought that the data obtained in this study can both provide data in the fields of biology and ecology for current scientific studies on these species, and can be used as a resource for the sustainable production of these commercial species.

Keywords: Meat yield, morphometric indices, bivalve species, Çanakkale Strait

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INTRODUCTION

Bivalves are unique organisms in terms of ecological impact in the marine environment and as a nutritional food in many countries (Wijsman et al., 2019). Their economic value is directly proportional to consumer demand, and demand can cause significant population reductions in regions where stock–supporting activities such as aquaculture are not carried out (Wijsman et al., 2019). Türkiye has significant bivalve production areas from the Aegean Sea to the Black Sea, where the primary production method is based on fishing.

Bivalve fishing has been performed using various methods (hydraulic and mechanical dredges, hand dredges, SCUBA diving) since the 1970s in Türkiye, and socio–economically contributes to coastal communities (Çolakoğlu & Palaz, 2015). In the coastal waters of the Marmara Sea and the Çanakkale Strait (0–20 m), there are various bivalve species with high economic value and extensive stocks, such as wedge clam (*Donax trunculus* Linnaeus, 1758), striped venus (*Chamelea gallina* Linnaeus, 1758), venerid clam (*Ruditapes philippinarum* Adams and Reeve, 1850), Mediterranean mussel (*Mytilus galloprovincialis* Lamarck, 1819) and flat oyster (*Ostrea edulis*). Among them, the most produced (fished) bivalve species along the coasts of Türkiye in 2020 were reported to be *Mytilus galloprovincialis* (~4000 tons) and *Chamelea gallina* (~30 000 tons) (Turkstat, 2021).

The length–weight relationship (LWRs) and morphometric characteristics are important for biology and fisheries in population dynamics (Gaspar et al., 2002). This information is useful especially for predicting current conditions and stock assessment, as well as morphological comparisons of bivalve species (Gaspar, Santos & Vasconcelos, 2001; Vasconcelos et al., 2018). In relative studies conducted worldwide, LWRs, relative growth and shell morphometric relationships were assessed for different bivalve species (Charef, Langar & Gharsallah, 2012; Gaspar et al., 2001; 2002; Petetta et al., 2019; Vasconcelos et al., 2018). In Türkiye, different bivalve species caught along the coastal areas between the Aegean and Black Seas were analysed in terms of morphometric and population characteristics (Çolakoğlu & Palaz, 2014; Çolakoğlu & Tokaç, 2014; Dalgıç, 2006; Deval, 2009). Also, several studies in the southern Marmara Sea and the Çanakkale Strait focused on diverse subjects such as fishing, population dynamics, aquaculture, chemical and biological contaminants (Çolakoğlu et al., 2011; Künili, Çolakoğlu & Çolakoğlu, 2021a; Künili et al., 2021b). However, there is a limited number of studies to determine the meat yields and morphometric characteristics of these commercial bivalve species and to compare them with environmental parameters in the South Marmara Sea and Çanakkale Strait, where one of the densest populations is found (Çolakoğlu, 2011). The present study was performed to determine and compare the meat yield, morphometric relationships (between shell length, height, width, and total weight), morphometric indices (elongation, compactness, convexity and density) and relative growth (isometry vs allometry) of *D. trunculus*, *M. galloprovincialis, O. edulis, R. philippinarum,* and *C. gallina* collected along the Çanakkale Strait coast in Türkiye.

MATERIALS AND METHODS

Material, study area and sampling

The research materials were *D. trunculus, M. galloprovincialis, O. edulis, R. philippinarum, and C. gallina* collected from coastal areas containing both hard substrate and sandy bottoms along the Çanakkale Strait in the west of the Marmara Sea (Figure 1). The sampling locations were selected according to current information on bivalve harvesting and from local fishermen. Due to the living habits of research materials, two sampling methods were used for the two predetermined sampling groups. In the first group, *D. trunculus*, *C. gallina,* and *R. philippinarrum* samples were collected from 1–8 m depths by using a mechanical dredge towed parallel to the shoreline for 5 min at a constant speed of 1–2 knots (length of dredge width and height: 55 and 30 cm; the number of teeth and length: 25 and 16 cm; mesh size: 5 mm). For the second group, *M. galloprovincialis* and *O. edulis* samples found at 1–12 m depths around sampling locations were collected by hand during SCUBA dives. All samples were collected between September 2014 and August 2015. Samples were firmly packed with wire meshes and transported to the laboratory via an ice–cooled insulated box within 1–2 hours.

Environmental parameters of the sampling areas, such as Sea Surface Temperature (SST) (°C), salinity (ppt), dissolved oxygen ($mg \cdot L^{-1}$), and pH, were measured in *situ* using a YSI 650 MDS multi–parameter water quality meter. Chlorophyll–a (Chl–a) concentrations in seawater samples obtained from the locations were determined according to the method described by the American Public Health Association (APHA, 1995).

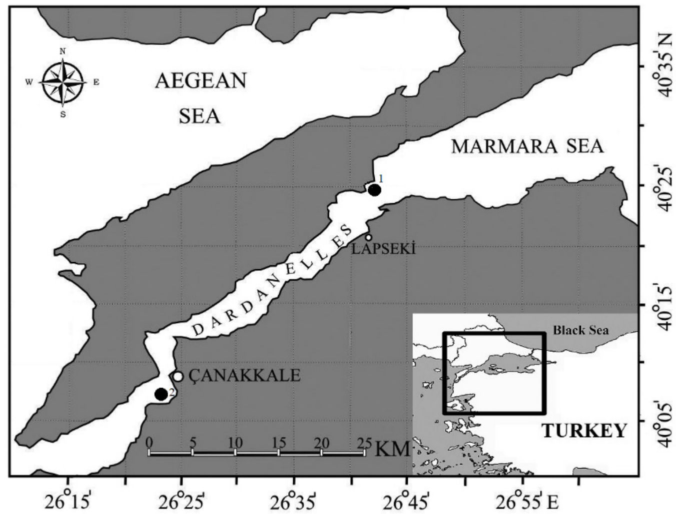

Figure 1. Map showing the study area along the Çanakkale Strait (Türkiye).

Data treatment and statistical analyses

The shell length (SL), shell height (SH), and shell width (SW) of individual specimens were measured using a digital vernier caliper (0.01 mm accuracy). The total wet weight (TW) and wet meat weight (MW) of each bivalve were measured using an electronic balance (d: 0.01 g, Max: 3100, Acculab, ALC-3100). Meat yield (MY) was calculated with the following equation: MY (%) = [(MW/TW) x 100]. Morphometric relationships were determined according to the allometric equation of Ricker (1973) $Y=a X^b$, where Y is SH, SW, or TW, X is the shell length (SL), *a* is the intercept, and *b* is the slope. The allometry coefficient is expressed by the exponent *b* in the linear regression equations. In these equations, in correlations between different types of variables and/or between different measuring units, the weight–length relationship reflects isometric growth when the exponent $b=3$ (Gaspar et al., 2002). To confirm whether the values of *b* obtained from linear regressions were significantly different from the isometric value ($b=3$) and described a negative ($b<3$) or positive ($b>3$) allometric relationship (Huxley & Teissier, 1936), the student t–test was applied with a confidence level of ±95% (Sokal & Rohlf, 1987).

Moreover, to characterize the morphology and growth shapes of bivalves, diverse morphometric indices including elongation index (SH/SL), compactness index (SW/SL), convexity index (SW/SH) and density index (TW/SL) were used (Vasconcelos et al., 2018; Caill–Milly et al., 2012, 2014). The significance for all statistical analyses was set at $P<0.05$ (Zar 1999).

RESULTS AND DISCUSSION

The present study evaluated the stock status of five commercial bivalve species from two stations in the Çanakkale Strait. Major environmental variables were measured and correlated with meat yield, as one of the most important economic properties, for complementary evaluation of the results. The results of the environmental parameters measured during the study period are summarized in Fig 2. The minimum and maximum values for SST (°C), salinity (ppt), DO (mg·L^{-1}), pH, and Chl–a (µg·L^{-1}) during the study period were determined as follows; 7.85 (Feb '15) – 23.85 (Jul '15) for SST, 22.00 (Aug '15)–26.00 (Mar '15) for salinity, 6.51 (Jul '15)–8.52 (Feb '15) for DO, 8.05 (Dec '14) – 8.40 (Mar '15) for pH, and 0.95 (Mar '15)–4.10 (Sep '14) for Chl–a, respectively.

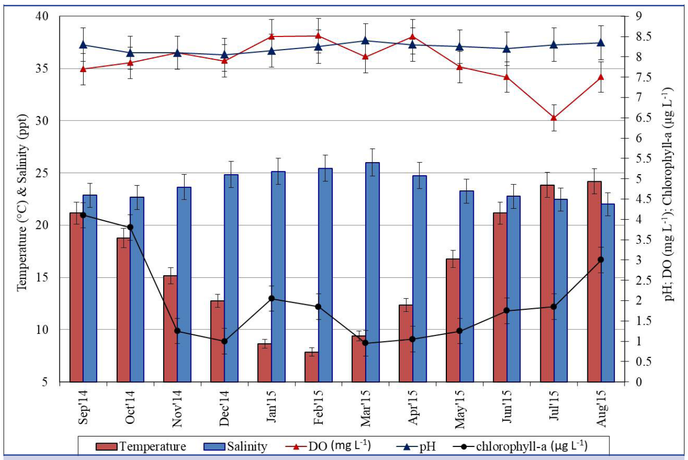

Figure 2. Summary of environmental variable data by months.

During the research period, 3394 individuals of *D. trunculus,* 2433 *C. gallina*, 1869 *R. philippinarum*, 580 *M. galloprovincialis* and 312 *O. edulis* were collected. The descriptive statistics and LWRs parameters of the samples are summarized in Table 1. The allometry coefficients (*b*) varied among species: *D. trunculus* =2.738, *C. gallina* =2.889, *R. philippinarum* =3.137; *M. galloprovincialis* =2.597 and *O. edulis* =2.728 (P<0.05). In general, regression analysis demonstrated a significant linear relationship for SH (range= 0.481–1.128) (P<0.05), SW (range=0.197–0.891) (P<0.05), and TW (range=0.323–2.159) (P<0.01) with SL. There were negative allometries (TW/SL) for four species *C. gallina* (*b*=2.889), *D. trunculus* (*b*=2.738), *M. galloprovincialis* (*b*=2.597) and *O. edulis* (*b*=2.728), while one bivalve species *R. philippinarum* (*b*=3.137) was observed to have positive allometries.

The morphometric indices, elongation (SH/SL), compactness (SW/SL), convexity (SW/SH), and density index (TW/SL) of the bivalve species studied are shown in Table 2. The morphometric indices of species were in the range 0.254–1.938 for SH/SL, 0.197–1.500 for SW/SL, 0.222–2.124 SW/SH, and 0.020–2.159 for TW/SL, respectively. In this study, four species had negative allometries, namely *D. trunculus* (2.738), *C. gallina* (2.889), *M. galloprovincialis* (2.597) and *O. edulis* (2.728), while *R. philippinarum* (3.137) displayed positive allometry.

According to the results, the lowest values were present for SH/SL in *M. galloprovincialis* and *O. edulis*; SW/SL in *O. edulis* and *D. trunculus*; SW/SH in *O. edulis* and *D. trunculus*, and TW/SL in *M. galloprovincialis* and *D. trunculus.* These values were found to be similar to those reported from Italian coasts for *M. galloprovincialis* (Orban et al., 2002), southern Black Sea for *D. trunculus* (Aydın, Tunca & Ersoy, 2020) and slightly different from the values from the Algarve coast, Portugal (Vasconcelos et al., 2018). In this study, mean values of SH/SL, SW/SL, SW/SH, and TW/SL were strongly correlated with SST and Chl–a (P<0.05). The morphology and physiology of bivalves are strongly influenced by fisheries and biomass (Gaspar et al., 2001, 2002), along with environmental conditions (Lucas et al., 1981) such as space competition for some species (Caill–Milly et al., 2014), differences in nutritional conditions and defence against predators (Caill–Milly et al., 2012; Tokeshi, Ota & Kawai, 2000; Watanabe & Katayama, 2010).

In comparison with previous reports, the allometric coefficient *b* (2.89) for *C. gallina* in this study was similar to values obtained from the Tyrrhenian Sea (2.74) and the Adriatic Sea (2.69) (Petetta et al., 2019), the West Marmara Sea (2.89) (Çolakoğlu & Tokaç, 2014), the North Sea (2.87) (Robinson et al., 2010), and the Algarve coast (Southern Portugal) (2.80) (Gaspar et al., 2001; Rufino et al., 2006), but higher than from the Mediterranean Sea (2.37) (Kasapoğlu & Düzgüneş, 2013). The *b* coefficient (2.74) value obtained for *D. trunculus* was similar to the values for the same species studied in the Tyrrhenian Sea (2.77) (Petetta et al., 2019) and

Table 1. Descriptive statistics, length–weight relationships and type of growth for five economic bivalves collected from the Çanakkale Strait (Türkiye).

Species	N	Length (mm)			Weight (g)			Morphometric relationship				Type of growth
		Min	Max	Mean±SD	Min	Max.	Mean±SD	a	b	SE (b)	r	
Dt	3394	13.00	40.50	28.78±0.07	0.36	7.69	2.93±0.02	0.0003	2.738	0.003	0.951	-A
Mg	580	15.05	84.00	59.02±0.39	0.30	50.17	16.06±0.28	0.0004	2.597	0.006	0.912	-A
Oe	312	53.00	108.50	75.73±0.54	17.30	234.20	72.52±1.78	0.0005	2.728	0.008	0.806	-A
Rp	1869	26.50	62.00	42.66±0.14	3.70	63.90	20.47±0.24	0.0001	3.137	0.003	0.932	+A
Cg	2433	9.00	38.00	23.65±0.11	0.30	17.76	4.67±0.07	0.0005	2.889	0.003	0.975	-A

Dt: Donax trunculus, Mg: Mytilus galloprovincialis, Oe: Ostrea edulis, Rp: Ruditapes philippinarum, Cg: Chamelea gallina, N:Number, SD: Standart Deviation, SE: Standart Error, a: Intercept, b: Slope, r: Correlation Coefficient;-A: Negative Allometry, +A: Positive Allometry the West Marmara Sea (2.69) (Çolakoğlu, 2014), and higher than in the Adriatic Sea (2.48) (Petetta et al., 2019) and the Algarve coast (Southern Portugal) (2.57) (Gaspar et al., 2001). The *b* value (3.14) for *R. philippinarum* was similar to exponential values obtained on the southern coast of the Marmara Sea (3.14) (Çolakoğlu & Palaz, 2014) and the Taehwa River, Ulsan (3.04) (Choi et al., 2011), but higher than for the coast of Yeongi in Tongyeong, Korea (2.99) (Cho, Jeong & Lee, 2008) and the Amurshy Bay, Sea of Japan (2.95) (Ponurovsky, 2008). The *b* (2.73) for *O. edulis* was lower than findings obtained in Mersin Bay, Aegean Sea (3.15) (Acarlı et al., 2011), but higher than in the Black Sea (2.46) (Aydın & Biltekin, 2020). The *b* value (2.60) for *M. galloprovincialis* was similar to the findings obtained in the Istanbul Bosporus (2.63) (Balcıoğlu & Gönülal, 2017) and Gökçeada Island, North Aegean Sea (2.73) (Keskin, Ekici & Serdar, 2020), but higher than in the Çanakkale Strait (2.33) (Balcıoğlu and Gönülal, 2017). Discrepancies in the value of *b* in LWRs could be affected by the fishing gear used and selectivity, and variations in environmental conditions such as ecological differences (water temperature, salinity, etc.) in the sampling areas, type of bottom and type of sediment, the intensity of predation, and lack or abundance of food (Gaspar et al., 2001; 2002; Çolakoğlu, 2020).

The meat yields of species were in the range of 16.40–23.34% for *D. trunculus*, 14.89–34.35% for *M. galloprovincialis*, 5.91–26.24% for *O. edulis*, 10.80–29.53% for *R. philippinarum*, and 12.26–18.92% *C. gallina*, respectively (Figure 3a). The highest meat yields for *D. trunculus*, *M. galloprovincialis* and *O. edulis* were determined in spring, while *C. gallina* and *R. philippinarum* had maximum yield in late summer and early autumn (P<0.05). The meat yields were found to be affected significantly by seasonal and species differences (P<0.05) (Figure 3a). The correlation of the meat yield with environmental variables and indexes is summarized in Figure 3b. The highest positive and negative correlations among meat yields of species and variables were observed as follows; *D. trunculus* had positive moderate correlations with salinity (r=0.598) and pH (r=0.630); *M. galloprovincialis* and *O. edulis* had strong–moderate positive correlations with Chl–a (r:0.827, r:0.597); and *C. gallina* and *R. philippinarum* had strong–moderate positive correlations with pH (r:0.545, r:0.731) (P<0.05). The highest negative strong correlations were observed as follows; *D. trunculus* with SST (r:–0.489); *M. galloprovincialis* with compactness index (C–I) (r:0.512), O. *edulis* with elongation index (E–I) (r:–0.518), *R. philippinarum* with DO (r:–0.356); and *C. gallina* with DO (r:–0.387) (P>0.05). The weakest correlations observed among species were determined as follows; *D. trunculus* with elongation index (E–I) (r:–0.069); *M. galloprovincialis* with density index (D–I) (r:0.014); *O. edulis* with density index (r:–0.077); *R. philippinarum* with salinity (r:0.062); and *C. gallina* with elongation index (E–I) (r:0.163, P>0.05).

In general, meat yield is an indicator of the condition status of bivalves which can change with seasons, reproduction period and food accessibility (Okumuş & Stirling, 1998; Orban et al., 2002). The highest meat yield of *D. trunculus, M. galloprovincialis*, and *O. edulis* were observed in the samples from the spring months, while it was at the highest level in the summer months for *R. philippinarum* and in the autumn months for *C. gallina*. Although the highest and lowest levels of meat yield slightly varied, the means of findings between months are similar to those reported in previous studies (Çolakoğlu & Tokaç, 2014; Vernocchi et al., 2007; Chen et al., 2020). Salinity was positively correlated with only *D. trunculus*, while pH was correlated with *D. trunculus, R. philippinarum* and *C. gallina* (P<0.05). A significant positive correlation for the most important parameter, Chl–a, was determined only for *M. galloprovincialis* and *O. edulis* (r:0.545–0.731; P<0.05). The living habits of both these bivalves (*M. galloprovincialis* and *O. edulis*) differs from other species (*D. trunculus*, *R. philippinarum*, and *C. gallina*) due to the requirements of hard substrates to adhere to in water columns (Wilcox & Jeffs, 2017; Potet et al., 2021). In seawater, the planktonic mass first increases in warmer months and then sedimentation and distribution occur to benthic and lower depths of the water column throughout seasons (Graf et al., 1982; Benedetti et al., 2019). This case may be an indicator that initially, meat yield increases in parallel with the planktonic bloom in the water column for *M. galloprovincialis* and *O. edulis*, then with the precipitation of the planktonic mass in late summer, other sub–benthic clams achieve higher meat yields. This is also most probably related to active feeding on these species from the spring to autumn as the Çanakkale Strait is characterized by SST and Chl-a level increases causing increased planktonic activity (Turkoglu, 2010), which is an important factor affecting food accessibility and growth of bivalves (Robinson et al., 2010). The information about meat yields in dif-

Table 2. Morphometric indices of five economic bivalves collected from the Çanakkale Strait (Türkiye)

Species	N	Elongation index (SH/SL)			Compactness index (SW/SL)			Convexity index			Density index (TW/SL)		
		Min	Max	Mean±SD	Min	Max	Mean±SD	(SW/SH)	Max	Mean±SD	Min	Max	Mean±SD
Dt	3394	0.71	0.50	0.59±0.001	0.42	0.27	0.33±0.001	0.78	0.36	0.56±0.001	0.20	0.03	0.10±0.001
Mg	580	1.94	0.25	0.37±0.003	1.50	0.37	0.52±0.003	2.12	0.42	1.45±0.006	0.60	0.02	0.26±0.004
Oe	312	1.13	0.48	0.81±0.006	0.89	0.20	0.34±0.004	0.96	0.22	0.43±0.006	3.99	3.14	3.58±0.008
Rp	1869	1.03	0.79	0.90±0.001	1.03	0.50	0.60±0.001	1.32	0.36	0.69±0.004	1.05	0.14	0.46±0.004
Cg	2433	1.07	0.77	0.92±0.001	0.59	0.39	0.51±0.001	0.67	0.42	0.56±0.001	0.48	0.03	0.19±0.002

Dt: Donax trunculus, Mg: Mytilus galloprovincialis, Oe: Ostrea edulis, Rp: Ruditapes philippinarum, Cg: Chamelea gallina, N:Number, SD: Standard Deviation, SL: Shell Length, SH: Shell Height, SW: Shell Width; TW: Total weight

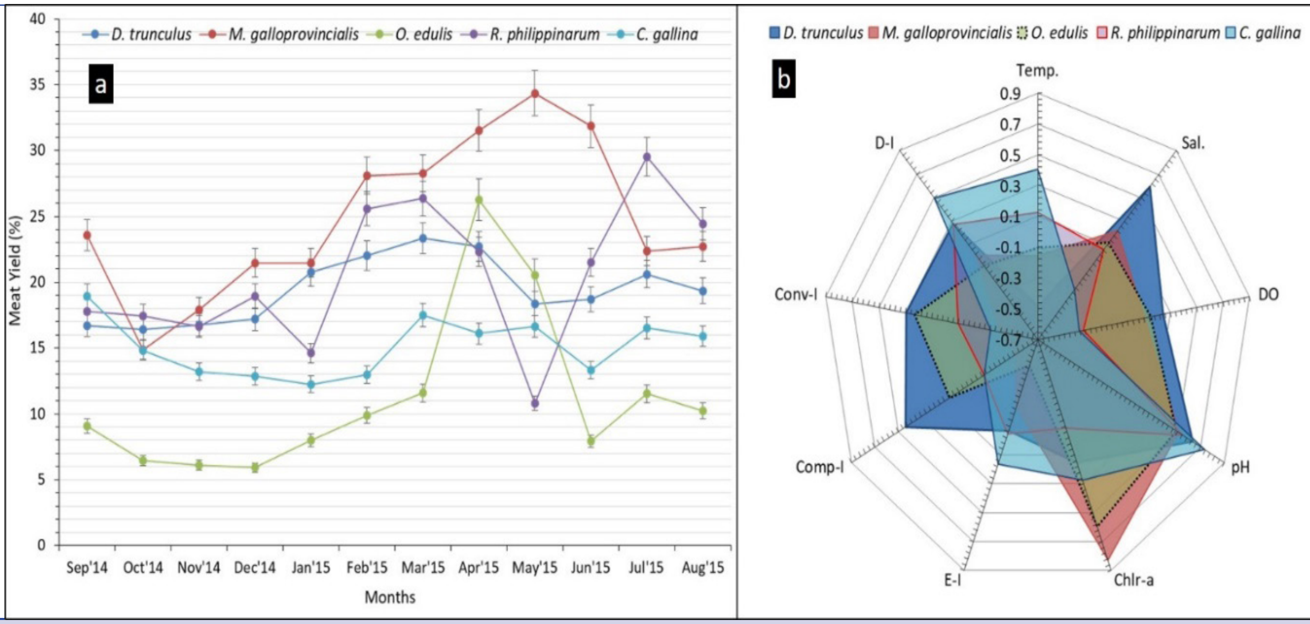

Figure 3. (a) Meat yields of bivalve species during study period (mean±SD); (b) correlations of meat yields with indexes and environmental variables.
Temp: SST, Sal: Salinity, DO: dissolved oxygen, Chlr–a: Chlorophyll–a, E–I: Elongation Index (SH/SL), Comp–I: Compactness Index (SW/SL), Conv–I: Convexity Index (SW/SH), D–I: Density Index (TW/SL).

ferent bivalves could be useful for maximizing catch and controlling the exploitation of bivalves in their natural beds in different geographical areas.

CONCLUSION

This study showed that condition, growth, and morphometric indices of *D. trunculus, C. gallina, R. philippinarum, M. galloprovincialis* and *O. edulis* could vary based on seasonal and environmental conditions. Although the LWRs, coefficient factors and morphometric indices showed good growth for the five species, the future of the populations of these species may be negatively affected since meat yield is one of the most important reasons for fishing due to consumer demand. The growth of species varied at a high rate with changing environmental factors, especially warmer seawater and planktonic abundance (Chl–a) by season. In further studies, commercial bivalve species should be monitored by including morphometric characteristics, growth, conditions indexes, as well as meat yield and environmental parameters, sustainability, and conservation of natural stocks in terms of fisheries management.

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