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Morphometric data and allometric relationships of the gorgonian *Eunicella singularis* (Esper, 1791) (Anthozoa Gorgoniidae) of Paloma Island, Algeria

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ABSTRACT The gorgonian *Eunicella singularis* (Esper, 1791) (Anthozoa Gorgoniidae) is abundant on rocky bottoms at Paloma Island (Algeria) in the south-western of the Mediterranean basin. In this study area, 150 gorgonian colonies of *E. singularis* were collected randomly using SCUBA diving and the following morphometric macro-features were measured (maximum height, maximum width, total branch length, rectangular surface area, height to width ratio and dry weight). Allometric growth was examined using the relationships between the dry weight and the five morphometric macro-features. The power equation of the simple allometry applied was $y=ax^b$ and the parameters of the linear regression a and b were estimated after the logarithmic transformation log (y)=log(a)+ b*log(x). The allometric relationships between the dry weight and the morphometric macro-features studied show that the growth of the gorgonian *E. singularis* in the study area is correlated positively and significantly with the five macro-features and that both the macro-features total branch length and the maximum width are the most appropriate parameter applied to the gorgonian *E. singularis* growth study.

KEY WORDS Biometric; *Eunicella singularis*; Morphometric Macrofeatures; Octocorallia; white gorgonian.

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INTRODUCTION

Coastal marine ecosystems support a high biological diversity and are among the most productive systems in the world (Costanza et al., 1993; Harvell et al., 1999). In the Mediterranean Sea, the gorgonians (Anthozoa Gorgoniidae) play a crucial ecological role in these marine habitats, maintaining biomass and structural complexity of hard bottom communities (Mills et al., 1993; Jones et al., 1994; Ballesteros, 2006; Ponti et al., 2014; Kipson et al., 2015; Otero et al., 2017). Gorgonians may develop singular facies of the highly diverse and valuable coralligenous outcrops (Ballesteros, 2006). Their attractive shape, impressive size and density contributes greatly to the Mediterranean underwater landscapes and to the success of several scuba diving spots (Harmelin & Marinopoulos, 1994, Coma et al., 2004). However, the Mediterranean populations of the gorgonians are strongly affected by diverse types of disturbances, in particular, destructive fishing practices, anchoring, over-frequent diving, mucilaginous algal aggregates, biological invasions and mass mortalities caused by anomalous seawater temperature increases (Harmelin & Marinopoulos, 1994; Mistri & Ceccherelli, 1996; Bavestrello et al., 1997; Coma et al., 2004; Garrabou et al., 2009; Cebrian et al., 2012; Cerrano et al., 2013).

In the Mediterranean Sea, the shallow benthic species are considered as the most vulnerable organisms to the water warming, in particular, the gorgonians are one of the most negatively impacted groups of the coralligenous communities (Cerrano et al., 2000, 2005). Several massive mortality events have drastically affected the gorgonian communities during the last three decades in several locations along the Mediterranean Sea (Harmelin, 1984; Cerrano et al., 2000; Pérez et al., 2000; Skoufas et al., 2000; Coma et al., 2006; Cigliano & Gambi 2007; Garrabou et al., 2009; Linares et al., 2012; Carella et al., 2014; Rivetti et al., 2014; Rubio-Portillo et al., 2016; Gambi et al., 2018; Turicchia et al., 2018). These events caused dramatic decreases in the gorgonian populations (Garrabou et al., 2009; Bo et al., 2014; Garrabou et al., 2017), which motivated their inclusion in different conservation frameworks at national and international levels (Otero et al., 2017). Several gorgonians are considered as key species of Mediterranean coralligenous assemblages with ecological, socio-economic and heritage values by the Barcelona Convention as part of the action plan for coralligenous assemblages (UN Environment/MAP 2017) and in the inventorying (UNEP-MAP-RAC/SPA, 2015).

Among gorgonian species in the Mediterranean Sea, five belong to the genus *Eunicella* Verrill, 1869: *E. cavolinii* (Koch, 1887), *E. verrucosa* (Pallas, 1766), *E. filiformis* Studer, 1901, *E. gazella* Studer, 1901, and *E. singularis* (Esper, 1791) (Rossi, 1959; Carpine & Grasshoff, 1975; Weinberg, 1976). The white gorgonian *E. singularis* is one of the most common and abundant species in the Western basin and Adriatic Sea, and is occasionally present in the eastern Mediterranean (Carpine & Grasshoff, 1975; Weinberg, 1976; Gori et al., 2012). In this context (Benabdi et al., 2019), report densities ranged between 44.5 and 117 gorgonians per m² in this study areas. In the Mediterranean Sea, *E. singularis* occurs mainly on horizontal and slightly sloping sediment-covered bottoms (Weinberg, 1979) while in the western Mediterranean Sea *E. singularis* is found at high densities on sublittoral rocky bottoms in shallow waters (Carpine & Grasshoff, 1975; Weinberg, 1976) and on coralligenous formations in deeper sublittoral waters characterized by high turbidity, at depths from 10 to 70 m (Gori et al., 2011a) and down to 100 m depth (Grinyó et al., 2016).

The studies of biology, ecology and distribution of gorgonian communities only concerned the northern part of the Mediterranean (e.g., Weinberg & Weinberg 1979; Skoufas et al., 2000; Sink et al., 2006; Skoufas et al., 2000; Virgilio et al., 2006; Ribes et al., 2007; Linares et al., 2008, 2012; Gori et al., 2011a, 2011b, 2012). Overall, the southern part of the Mediterranean basin has few informations on coralligenous habitat in general (Giakoumi et al., 2013) and an almost complete lack of information on gorgonians, except of the gorgonians inventory made by Ghanem et al. (2018) in Tunisian coast.

Several research works on biometrics of Anthozoa were carried out on both macroscopic characteristics (size, length, dry weight, etc.) and microscopic characteristics (shape and size of sclerites) (e.g., Grigg 1974; Velimirov, 1976; Russo, 1985, Lewis & Von Wallis, 1991; Skoufas et al., 2000, 2006; Gori et al., 2012). In fact, species biometrics can provide valuable information on different classes of a population from a monitoring perspective (Skoufas et al., 2000).

This study is the first work on the biometrics characteristics of *E. singularis* on the south-western Mediterranean Sea and aims to provide quantitative data of the morphometric macro-features that describe the growth of *E. singularis*. In addition, we examine the relationships between dry weight and five biometric parameters. The macro-features retained in this study can be used in the future for the estimation of biomass without resorting to destructive methods, especially during monitoring programs.

MATERIAL AND METHODS

Study area

Paloma Island lies in the western coast of Algeria (35.771069° - 0.901715°) in the south-west-

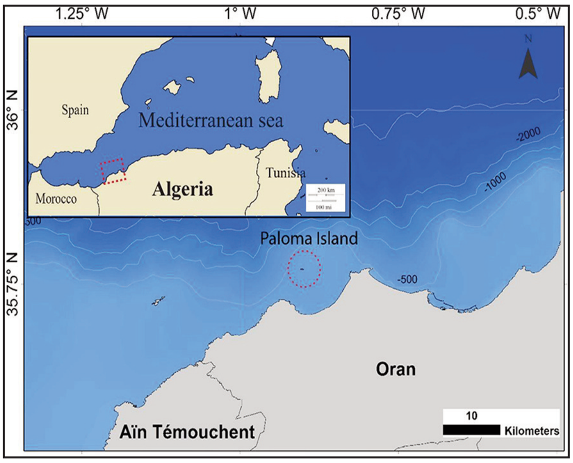

Figure 1. Location of the study area: Paloma Island, western Algerian coast.

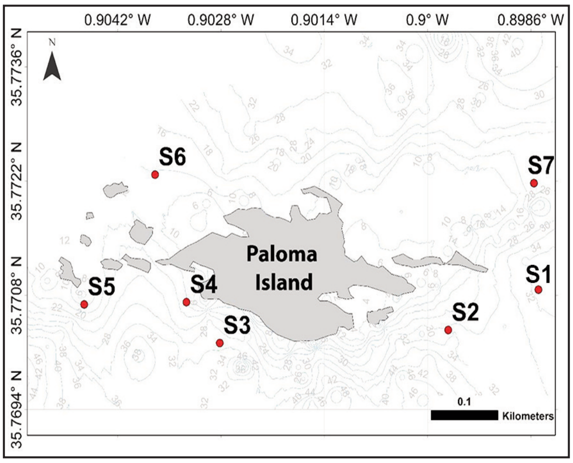

Figure 2. Location of the sampling stations (S) at Paloma Island, western Algerian coast.

Station	Latitude (dd .dd)	Longitude (dd .dd)	Depth (m)
1	35.770747°	-0.898000°	23-34
2	35.770411°	-0.899722°	11-26
3	35.770253°	-0.902794°	11-34
4	35.770750°	-0.903242°	11-24
5	35.770722°	-0.904617°	10-26
6	35.772300°	-0.903664°	10-20
7	35.772197°	-0.898569°	18-35

Table 1. Geographical coordinates (WGS84) and depth of sampling stations at Paloma Island, western Algerian coast.

ern of the Mediterranean basin, near the Alboran Sea (Fig. 1). The continental shelf in this area is among the smallest on the Algerian coast (Leclaire, 1972). Hydrographic conditions in this area are under Alboran Sea conditions and directly influenced by Atlantic current (Millot, 1999). The Paloma Island has been classified as marine protected area which is located 7 km from the coast. The seabed bordering this island, is dominated by large rocks strewn with reefs, flats, caves, rocky outcrops and surrounded by coastal detritic beds, followed by sandy bottoms.

Sampling method

Before the sampling, several survey dives were carried out between 5 to 50 m depth to characterize the *E. singularis* population's distribution in the investigated island. A total of seven sampling stations were selected to cover the entire perimeter of the rocky zone, within the bathymetric limits (0-35 m). For each sampling station, colonies were collected randomly using SCUBA diving. During two days, between April 4th and 5th, 2017, a total of 150 colonies were collected for all stations, with 30 colonies per 5m of depth from -10 m to -35 m depth (Fig. 2, Table 1). The collected samples are marked and kept in seawater until their treatment in the laboratory. After stabilization of colonies in the laboratory, the following macro-features were measured: Height (H, mm) defined as the greatest height of the colony from the base to the apex, Width (W, mm) defined as the greatest width of the colony perpendicular to the axis, Total Branch Length (TBL, mm) defined as the sum of the length of all the branches of the colony. Finally, the colonies were weighed (DW) with an electronic balance (accuracy 0.01g) after total drying in the open air shadowy (Skoufas, et al., 1996), the rectangular surface area (HxW, mm^2) and the ratio height by width (H/W) was calculed.

Data analysis

The data was analyzed in terms of descriptive statistics using mean and standard errors of macro-features and bathymetric levels subgroups. A non-parametric permutational analysis of variance (PERMANOVA; Anderson, 2001), based on square root transformed data and Euclidean distances, was used to test depth variability in the studied macro-features (Height, Width, Height/Width, Surface, Total Branch Length and Dry Weight) (one-way PERMANOVA with fixed factor 'Depht' n=5). Tests of significance were based on 9999 permutations.

Allometric growth was examined using the relationships between the dry weight and the various macro-features. The power equation of the simple allometry applied was $y=ax^b$ and the parameters of the linear regression a and b (Froese, 2006) were estimated after the logarithmic transformation $\log(y)=\log(a)+b*\log(x)$ to ease application of the results (Gould, 1966).

The type of allometry was evaluated by testing the allometric coefficient "b" and the isometric hypothesis (a=3 for metric macro-features or a=3/2 for surface macro-feature) was investigated using the Student t-test to verify whether the calculated "b" was significantly different from (3 or 3/2) as suggested by Dagnelie (1975).

All computations were performed using the PRIMER V.6 software program with the PERMANOVA+ add-on package (Clarke & Gorley, 2006; Anderson et al., 2008) and the package FSA (Ogle, 2016) under software R (R Core Team, 2017). We applied a non-parametric analysis because normality of the data for all macro-features was not achieved. An assumed significance level of 5% was used in all statistical analysis.

RESULTS

A total of seven sampling stations were examined in a study area with 150 colonies of *E. singularis*. For each colony, morphological macro-features were measured and recorded (Table 2).

PERMANOVA results suggest that a non-significant variability for all macro-features ($p > 0.05$) among depth range (Table 3), Thus, the all range depth of gorgonians were considered as same population.

Relationships between dry weight (DW) and the five macro-features Height (H), Width (W), Height/Width (H/W), Surface (HxL) and Total Branch Length (TBL) for the *E. singularis* population dwelling around Paloma Island were examined and the linear regressions between log (DW) and log of the five macro-features gave the following results:

$DW=a*H^b$

The investigation of the relationship between log (dry weight) and log (height) demonstrates that height was related to dry weight by a negative allometric relationship ($b<3$) (t-test, d.f.=144, t= -6.231908, $p<0.05$) (Fig. 3). This means that height (H) increases more than dry weight (DW).

$DW=a*W^b$

The relationship between log (dry weight) and log (width) demonstrates that width was related to dry weight by a negative allometric relationship ($b<3$) (t-test, d.f.= 144, t=-12.33891, $p>0.05$) (Fig. 4), which indicates that dry weight (Dw) increases less than width (W).

$DW=a*(LxW)^b$

The relationship between log (dry weight) and the rectangular surface area log (HxW) and the isometric hypothesis (a=3/2) have been examined (Fig. 5). Rectangular surface was related to dry weight (DW) with a negative allometric relationship ($a<3/2$) (t-test, d.f.= 148, t= -6.810824, $p>0.05$), which implies a faster increase of the rectangular surface in comparison with the dry weight.

$DW=a*(H/W)^b$

The allometric relationship between log (dry weight) and the ratio of height on width (H/W) was negative ($a<3$) (t-test, d.f.= 148, t= -16.86266, $p>0.05$), thus indicating a slower increase in dry weight compared to this ratio (Fig. 6).

$DW=a*(TBL)^b$

The linear regression between log (dry weight) and log (total branch length) (Fig. 7) demonstrates a negative isometry relationship between dry weight (DW) and total branch length (TBL) ($b<3$) (t-test, d.f.=148, t=-55.47496, $p<0.05$). This relationship is marked by a very strong correlation coefficient (r=0.9341) and a highly significant t-test.

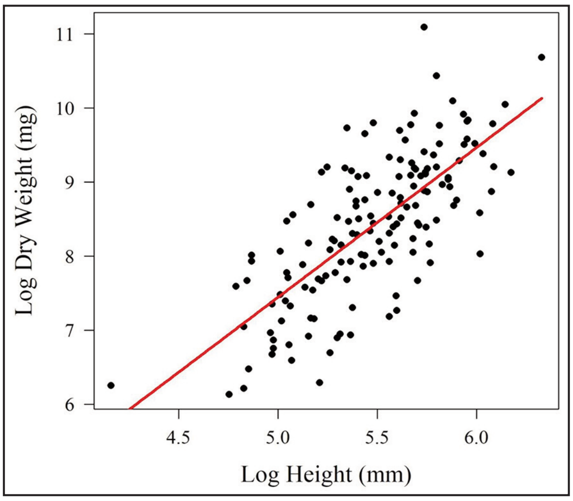

Figure 3. Linear regression between log (dry weight) and log (height) of *Eunicella singularis* colonies at Paloma Island (DW = 0.070* $H^{2.0209}$, n=150, r=0.7243, p<0.05<9).

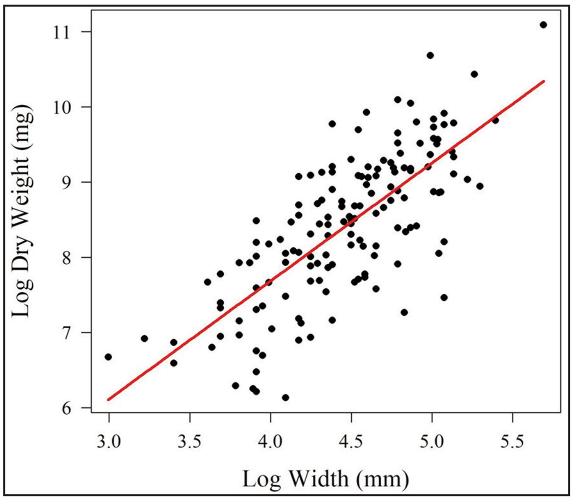

Figure 4. Linear regression between log (dry weight) and log (width) of *Eunicella singularis* colonies at Paloma Island (DW = 4.05* $H^{1.57}$, n=150, r=0.7420, p<0.05).

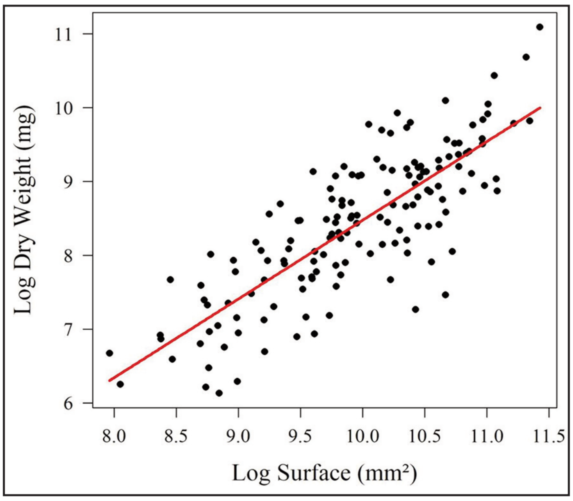

Figure 5. Linear regression between log (dry weight) and log (rectangular Surface) of *Eunicella singularis* colonies at Paloma Island (DW= 0.11* $H^{1.06}$, n=150, r=0.8075, p<0.05).

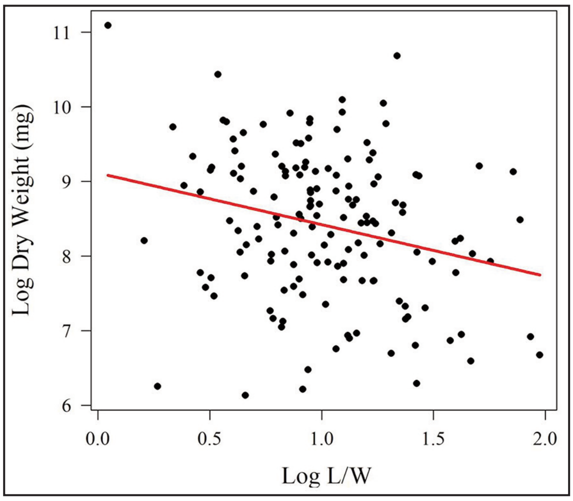

Figure 6. Linear regression between log (dry weight) and log (H/W) of *Eunicella singularis* colonies at Paloma Island (DW= 9045.29* $H^{-0.69}$, n=150, r=0.2386, p<0.05).

DISCUSSION

For the first time in the south-western Mediterranean coasts, this study provides quantitative data and understanding of the relationships between biomass and morphometric macro-features of the widespread gorgonian *E. singularis* population.

PERMANOVA test demonstrates that the morphometric characteristics studied do not vary significantly between -10 and -35 m of depth in the study area. This suggests that this bathymetric range is exposed to the same environmental conditions. In fact, these conditions may strongly influence the macro and microarchitectural features of gorgonians (Gori et al., 2012). Moreover, the population of *E. singularis* prospected shows the greatest height to width ratio as observed by Carpine & Grasshoff (1975), Weinberg (1976) and Weinbauer & Velimirov (1998) (i.e., the colony has a narrow width).

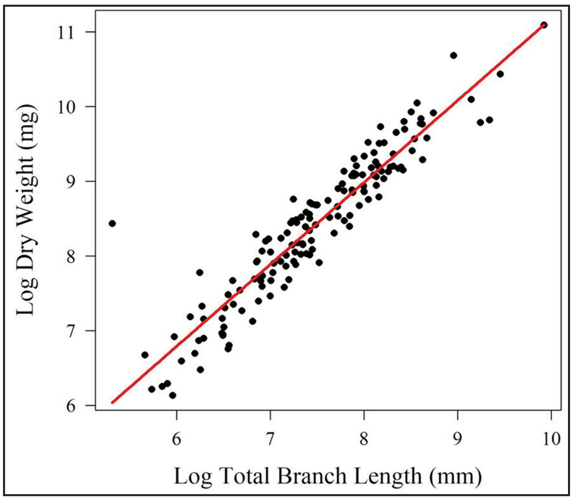

Figure 7. Linear regression between log (dry weight) and log (TLB) of *Eunicella singularis* colonies at Paloma Island (DW =1.23* $H^{1.09}$, n=150, r=0.9341, p<0.05).

Indeed, some species of gorgonian colonies, as *E. cavolinii* (Velimirov, 1976), have reduced surface area which enables them to resist to the water intensity. This situation can be explained by the geographical position of sites that are more or less exposed to the Atlantic current (Millot, 1999).

All the morphometric macro-features were related to dry weight with a negative allometric relationship. This involves a more fasting increasing of the all the studied morphometric macro-features values compared to the increasing dry weight. The present investigations demonstrate that the weight growth of the gorgonian *E. singularis* is correlated positively and significantly with the macro-features (TLB, W, rectangular surface and H) and isometry hypothesis relating dry weight (DW) to all macro-features studied present a negative allometric relationship which has been also demonstrated in the other cnidarian colonies (Migne & Davoult, 1993) and in *E. singularis* population studied in Greece by Skoufas et al. (2000).

Although the height of colonies is an easy parameter to measure, Weinberg & Weinberg (1979) indicate that the use of colony height is not an appropriate parameter to describe the gorgonian growth, because this biometric parameter could be affected by predation. The growth curve obtained by the use of rectangular surface area as suggested by Russo (1985) also exhibits significant negative allometric relationship, but it depends on the hydrodynamic properties of the area (Skoufas et al., 2000).

Width and total branch length are the other two more interesting biometric parameters, which are not influenced by the hydrodynamics (Skoufas et al., 2000). Otherwise, the fractal growth process proposed by several authors (Mandelbrot, 1982; Burlando et al., 1991; Mistri & Ceccherelli, 1993) suggest that the gorgonian width increases more regularly than the other biometric parameters. According to Velimirov (1976), Weinberg & Weinberg (1979), Skoufas et al. (2000), the total branch length (TLB) is considered as a relevant biometric parameter to the growth study. In addition, these biometric parameters are easily measurable in situ, especially by using photos (see Gori et al., 2012).

In fact, the width and total branch length as indicate by Skoufas et al. (2000) are the most appropriate parameter applied to the gorgonian *E. singularis* growth study. This parameters can also be tested as an indicator of the state of the marine environment due to the absence of influence of the hydrodynamic effects on these two parameters.

According to Migne & Davoult (1993), the indirect determination of biomass by size measurement can be extended to some colonial animals and the error made in this estimate remains low and the time and energy saved by the method justify its use. The use of the four biometric macro-features (height, width, rectangular surface and total branch length) in the monitoring of *E. singularis* populations in marine protected areas is very interesting. In fact, MPAs offer the possibility of installing fixed monitoring networks and periodically measuring these parameters without being under the influence of hydrodynamics due to the change of sites. The allometric relationships established in the present work will enable the use of the four biometric macro-features in the future through in situ measurements in the two marine protected areas of western Algerian coasts (Paloma and Habibas Islands) without the use of destructive sampling methods. These allometric relationships can be used in addition to the monitoring of gorgonian population dynamics to estimate biomasses. Finally, the biometric dataset for the *E. singularis* provided in this study can be used as a reference state for future comparisons in the study area.

	Source of variation						
Macrofeatures	Source	df	SS	MS	Pseudo-F	P(perm)	perms
Height	Depht	4	3.0788	0.7697	1.0398	0.3855	9948
Width	Depht	4	2.2527	0.56317	1.1917	0.3206	9953
Height/Width	Depht	4	0.23759	0.059399	0.6065	0.6581	9942
Surface	Depht	4	170.54	42.634	1.4472	0.2181	9943
Total Branch Length	Depht	4	1651.3	412.83	1.013	0.4056	9950
Dry weight	Depht	4	8.0676	2.0169	1.4385	0.2272	9946

Table 2. Averages of measured macro-features (mean ± standard error) of *Eunicella singularis* colonies at Paloma Island tabulated by depth.

	Depth 1 (10-15m)	Depth 2 (15-20m)	Depth 3 (20-25m)	Depth 4 (25-30m)	Depth 5 (30-35m)	Study area (All Depth)
N (Colonies)	30	30	30	30	30	150
Height (H,mm) ±SE	232.3±13.22	265±20.35	250.95±15.44	253.11±1.15	269.43±13.83	254.16±7.11
Width (W, mm) ±SE	85.37±5.57	99.2±10.17	90.17±6.80	99.33±9.64	106.60±6.25	96.13±3.57
Surface (HxL mm²) ±SE	21139.3±2521.55	30276.63±4533.18	24700.25±2970.76	27099.16±3557.55	30036.83±2634.17	26656.44±1493.46
H/W ±SE	3.58±0.16	3.57±0.19	3.44±0.19	3.265±0.20	3.18±0.20	3.41±0.08
Total Branch Length (TBL, mm) ±SE	2366.70±335.64	3245.933±569.46	2337.13±365.70	2668.6±667.48	1931.46±514.83	2509.97±207.63
Dry weight (DW, mg) ±SE	6662.00±818.53	9699.00±1843.99	7045.33±1241.56	7313.67±2151.97	4777.66±639.37	7099.53±656.70

Table 3. Summary of PERMANOVA results for Paloma Island *Eunicella singularis* population for the studied macro-features (Height, Width, Height/Width, Surface, Total Branch Length, Dry weight). *Statistically significant differences ($p<0.05$).

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