Population structure of Aequiyoldia eightsii (Jay, 1839) (Protobranchia, Sareptidae) in the shallow water zone of an Antarctic Specially Managed Area (Admiralty Bay, King George Island, Antarctic Peninsula)

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Research Article

Abstract

The protobranch *Aequiyoldia eightsii* is one of the most common bivalves in Antarctica and for the first time, its population structure was studied in Admiralty Bay, an Antarctic Specially Managed Area (ASMA), to establish a baseline for future monitoring. Density, size structure, length-weight relationship, condition index, and shell morphometry were evaluated at the shallow coastal zone of the bay. High abundance values of *A. eightsii* were related to sites with greater contributions of mud particles and total organic carbon contents in the sediment, while the condition indexes were higher in Martel Inlet, possibly due to higher food availability. Individuals obtained from gravel-rich sediments were significantly larger than compressed, while rounded forms were observed in sandy and muddy bottoms of the bay. Positive allometric growth was reported in most sites, except Botany Point, where specimens presented an isometric growth. The results demonstrated that the sediment composition and its organic content influence the population structure of *A. eightsi* as well as biological factors such as predation and recruitment rates. It is also worth noting that the phenotypic shell plasticity observed for this protobranch species in geographically close sites (hundreds of meters) highlights the importance of local-scale heterogeneity to be considered in future monitoring programmes for Antarctic marine ecosystems.

Introduction

The bivalve mollusks correspond to one of the most important benthic groups in terms of abundance and biomass in the Antarctic and Subantarctic shallow waters (Arnaud et al. 1986; Jażdżeski et al. 1986; Sáiz-Salinas et al. 1997; Absher and Feijó 1998; Echeverría et al. 2005; Siciński et al. 2011). Among these organisms, the sareptid protobranch *Aequiyoldia eightsii* (Jay, 1839), previously known as *Yoldia eightsii*, is a common species of soft-bottom communities, reaching densities up to 796 ind.m⁻² at Potter Cove in King George Island (Kowalke and Abele 1998). This bivalve is usually a dominant member of the macrofauna of muddy bottoms over a wide range of depths (from *ca*.5 m to 824 m), although it is most frequently found in waters shallower than 100 m (Davenport 1988; Dell 1990). *Aequiyoldia eightsii* is widespread around the Antarctic continent with a circumpolar distribution but can also be found in Subantarctic habitats such as the Magellan Strait (Dell 1990; González-Wevar et al. 2012).

Aequiyoldia eightsii has both suspension and deposit feeding behaviours, consuming suspended particles from the water column, or derived from the microphytobenthic biofilm as well as macroalgal detritus (Corbisier et al. 2004). This bivalve can feed on mud surface layers through palp proboscides extension outside the partially buried shell, but it commonly feeds while completely buried in the sediment (Davenport 1988). This species is further an important agent of bioturbation, promoting the mixing of the subsurface layers of the sediment and increasing pore-water transport and nutrient fluxes (Shull 2009), not only when feeding, but also during its horizontal movement when the shell acts like a plough (Davenport 1988). Given its high abundance and faster burrowing rates (Peck et al. 2004), A. *eightsii* widely contributes to sediment reworking compared to other Antarctic bivalves.

In terms of reproduction, *A. eightsii* is a dioecious species, which exhibits continuous oogenesis and asynchrony between females (Lau et al. 2018). Its elevated reproductive intensity and spawning have been observed to occur during austral winter (April and May) in Rothera Station (Lau et al. 2018). Recently, the species' biochemical composition and energy content have been studied at the West Antarctic Peninsula (WAP) (Bascur et al. 2021). High variability in the nutritional condition of populations from distant localities among the WAP was observed, and it was associated with differences in somatic and gametogenesis growth rhythms, as well as contrasting environmental conditions. These findings appear to be consistent with a multi-year-long reproductive cycle, related to the portioning of energetic resources between somatic and reproductive investments (Román-González et al. 2017b).

That species may also be considered as a sclerochronological archive for Antarctic coastal waters (Román-González et al. 2017a, b). Its relatively high longevity (> 60 years) (Davenport 1989; Peck and Bullough 1993) in comparison with other Antarctic bivalves allows the construction of longer chronologies (Román-González et al. 2017b). In addition, *A. eightsii* has been suggested as a good indicator species useful for modelling the effects of the sea acidification impacts and climate changes due to its high abundance, low shell dissolution resistance, and elevated thermal tolerance (McClintock et al. 2009; Clark et al. 2016; Morley et al. 2019). Therefore, *A. eightsii* has an important potential not only to deepen the understanding of climatic environmental processes of the Southern Ocean but also to contribute to explaining ecological issues through comparison with other Antarctic bivalves, such as *Laternula elliptica* (Román-González et al. 2017a).

Considered one of the key-species in Antarctic shallow water benthic ecosystems (Cattaneo-Vietti et al. 1999), A. *eightsii* has been the subject of studies about growth patterns, shell increments, and reproductive aspects (Nolan and Clarke 1993; Peck and Bullough 1993; Peck et al. 2000; Román-González et al. 2017a, b; Lau et al. 2018). Its population structure has been investigated at Factory Cove, Signy Island, where iceberg scouring was shown to be a factor limiting the maximum size of that bivalve species (Peck and Bullough 1993). Since most of those biological studies was carried out at the very shallow waters of Signy Island (≤ 9 m), the natural variation of its population structure is still incipient for other Antarctic regions and bathymetric ranges.

Situated in one of the fastest warming regions on the planet (Turner and Marshall 2011), Admiralty Bay is an ecologically important area, serving as a nursery ground for birds, mammals, and fishes. It was designated as an Antarctic Specially Managed Area (ASMA) by the Antarctic Treaty System Consultative Meeting in 1996 to minimize the cumulative impact of human activities, including those from research stations, and to optimize efforts to obtain scientific data (Weber and Montone 2006; Verde and di Prisco 2012). The present study aimed to analyse the spatial distribution of *A. eightsii* in Admiralty Bay evaluating its abundance, biomass, morphometry, condition index, and its relationships with sediment structure. In this context, it contributes with original information about the population structure of the species considering the biological features in the Antarctic Peninsula region. The data presented here improve the knowledge about *A. eightsii* populations from shallow-water Antarctic environments, as it

serves as a baseline for future studies about the ecological role of this protobranch in the Antarctic benthic communities and monitoring programmes.

Materials And Methods

Study area

Admiralty Bay is located at King George Island (South Shetland Islands, Antarctic Peninsula) and encompasses three main Inlets (Ezcurra, Martel, and Mackellar), comprising a total surface area of 122 km² with a wide opening (8.25 km width) to the Bransfield Strait (Kruszewski 2002) (Fig. 1). Waters entering the bay from the Bransfield Strait originate from either the adjacent Weddell Sea or Bellingshausen Sea, depending on the regional water circulation, winds, and seasonal regime (Tokarczyk 1987). The influence of the Bellingshausen Sea water, warmer and less saline (2.3°C and 33.5), is usually pronounced in summer. In winter, the colder and more saline Weddell Sea waters, (0.81°C and 34.4) prevail (Tokarczyk 1987). The bay has a maximum depth of 600 m and its bottom is composed of sediments spanning all size ranges, from clay to coarse gravel, with intermixed pebbles of various sizes and shapes (Siciński et al. 2011), providing substrate for sessile benthic organisms, which, in turn, form complex habitats for several other invertebrates (Pabis et al. 2011).

Sampling And Processing Methods

Benthic surveys were conducted during the austral summer (January to February 2011) in four sampling stations in Admiralty Bay: Ferraz Station (FS), Ullmann Point (UP), Botany Point (BP), and Refuge 2 (REF2) (Table 1; Fig. 1). The first three stations are located in Martel Inlet while the latter is located in Mackellar Inlet. The sampling sites were previously established according to a long-term environmental monitoring program proposal (Corbisier et al. 2010; Montone et al. 2013). The Ferraz Station is under the direct anthropogenic influence of the Brazilian research station and the others are used as reference areas. Specimens were collected using an Agassiz Trawl dredge with an opening of 56 x 36 cm, a bottom sac of 60 cm long, and a 4-cm mesh size. Three trawls were performed at a constant speed of 1.5 knots between 20 and 35 m. Samples were washed through a 2-mm-mesh sieve, fixed in a 4% borax-buffered formaldehyde solution, and the sorted organisms were preserved in 70% alcohol.

Table 1

Geographic coordinates of the sampling stations and mean contributions (%) of grain-size fractions, CaCO$_3$ and total organic carbon (TOC) (± SE) in the sediment surface layer (0−2 cm). Ferraz Station (FS), Ullmann Point (UP), Botany Point (BP) and Refuge 2 (REF2)

	FS	UP	BP	REF2
Latitude	62°05'7.90" S	62°05'1.40" S	62°05'48.90" S	62°04'24.40" S
Longitude	58°23'19.40" W	58°20'54.20" W	58°20'13.40" W	58°25'17.60" W
Depth (m)	23 ± 10	25 ± 7	29 ± 2	34 ± 2
Gravel (%)	10.56 ± 7.22	31.71 ± 17.25	6.22 ± 2.52	19.99 ± 11.49
Sand (%)	53.04 ± 2.22	39.74 ± 10.98	42.24 ± 3.22	20.26 ± 6.60
Mud (%)	36.40 ± 4.99	28.55 ± 6.27	51.54 ± 0.70	59.75 ± 18.09
CaCO$_3$ (%)	12.47 ± 0.20	16.19 ± 0.42	18.81 ± 2.75	17.72 ± 0.04
TOC (%)	0.49 ± 0.15	0.34 ± 0.01	0.32 ± 0.01	0.45 ± 0.07

The shell morphometry was obtained for all *A. eightsii* specimens using digital callipers to measure length, width, and height (accuracy of 0.01 mm). Then the soft tissue mass was separated from the shell using a scalpel. Total wet weight and tissue mass wet weight were obtained by weighing on an analytical balance (accuracy of 0.01 g) after being blotted dry on absorbent paper to remove external water. All animals with a shell length of 20 mm or higher were considered fully mature reproductive adults, as already reported for this species (Peck et al. 2000).

Grain size, CaCO$_3$, and total organic carbon (TOC) data were obtained from previously collected sediment samples (February 2010) using a small box-corer (30 x 30 x 55 cm) in the same sites and bathymetric ranges that fauna samples (Table 1). The dried sediment was treated with hydrogen peroxide (10%) and 1 M HCl to eliminate organic matter and carbonate, respectively. Grain size was determined in a Malvern 2000 analyser on decarbonated samples. The grain size classification of Wentworth (1922) and statistical parameters of Folk and Ward (1957) were used to describe sediment textural characteristics. CaCO$_3$ was determined by measurement of weight loss after acidification (Carver 1971) and TOC was measured with an elemental Costech Instruments Elemental Combustion System coupled with a Thermo Scientific Delta V Advantage Isotope Ratio Mass Spectrometer (EA-IRMS).

Data analysis

A one-way ANOVA was used to test for differences in density, biomass, shell size, total wet weight, and condition index of *A. eightsii* between sampling stations. The Tukey test was applied *a posteriori* for multiple pairwise comparisons. The Cochran test was used to check the homogeneity of variances, and total abundance values were log-transformed, when necessary. The Kolmogorov-Smirnov test was used to compare size distributions between sites. The Condition Index (CI) was calculated from the following

equation: CI = (tissue mass wet weight/total wet weight) x 100 (Zeng and Yang 2021). This equation was chosen because it is a direct measure of body proportions which reflects changes in the condition/size relationship and allows the evaluation of spatial changes of the bivalves' growth (Hickman and Illingworth 1980). The relationships between shell dimensions were estimated by linear regressions of shell length, height, and width. The coefficient of determination (R^2) was used as an indicator of how well the regression model fits the observed data. The length-weight relationship was derived by applying the equation $W = a.L^b$, where a and b are the coefficients calculated by the least-squares regression analysis (Bayne and Warroll 1980). Difference between the estimated b from 3 (isometric growth) for total wet weight was tested using a Student t-test with a Bonferroni correction (Cohen et al. 2003). All univariate analyses were done using Statistica for Windows v.7 by Statsoft Inc. (2004).

Results

Sediment characteristics

In Martel Inlet, the sediment of Ferraz and Botany Point presented a higher contribution of fine particles than Ullmann Point, where sand and gravel were predominant (Table 1). On the other hand, Refuge 2 (Mackellar Inlet) was characterized by thinner sediment particles, with the highest proportion of mud (> 59%). Mean percent values of $CaCO_3$ were very similar among the sampling stations but slightly lower in Ferraz. Total organic matter contents were similar between Ferraz and Refuge 2. Ullmann Point and Botany Point, at the inner reaches of the Martel Inlet, presented similar TOC concentrations, which were lower than those found at Ferraz Station.

Density And Biomass

A total of 845 specimens of *A. eightsii* were collected between 20 and 35 m depth range regarding all sampling stations. The lowest mean density of *A. eightsii* occurred in Ullmann Point (0.54 ind.m^{-2} ± 0.44). In contrast, the highest mean density value was observed in Refuge 2 (4.77 ind.m^{-2} ± 2.75). Although no significant spatial density differences were found (F = 1.412; p = 0.309), a tendency of decreasing abundance was observed in Ullmann Point compared to Refuge 2 (Fig. 2a). The biomass presented a similar pattern, and no significant differences were found among stations (F = 1.563; p = 0.272) (Fig. 2b).

Wet Weight And Condition Index

Significant differences were found in the individual total weight means of *A. eightsii* among the sampling stations (Fig. 3a, b). Individuals from Botany Point were heavier (1.74 g WW ± 0.05; F = 20.789; p < 0.0001) in comparison with the other stations. Regarding the condition index, significant differences between Martel and Mackellar Inlets were found (Fig. 3b). Botany Point also presented the highest mean values

for this parameter (44.33% ± 0.34), while Refuge 2 showed the lowest mean values (37.44% ± 0.38) (F = 47.820; p < 0.0001).

Size-frequency Distributions

The size-distribution patterns at the sampling stations were markedly different (Fig. 4). At Ullmann Point, there was a bimodal distribution, with the second mode between 17 and 20 mm. Most of the population was composed of small and juvenile individuals (59.52%), and no individuals larger than 29 mm were found. At Ferraz Station, the largest individual sampled in this study was found with a shell length of 36.03 mm. At this station, adult individuals occurred in greater abundance, representing 55% of the total. The size distribution at Botany Point was significantly different from those present at the other sampling stations (Table 2; Fig. 4c). Only adult individuals (> 20 mm in length) were found at this station, and most of them ranged from 23 to 29 mm in length (70.35%). A bimodal data distribution was also observed at Refuge 2, with the modes corresponding to 17–20 and 29–32 mm length intervals. Although this station was the only one to present individuals smaller than 5 mm, most of its population was composed of adults (53.64%).

Table 2
Kolmogorov-Smirnov results based on size (shell length) of *Aequiyoldia eightsii* at four sampling stations in Admiralty Bay. Ferraz Station (FS), Ullmann Point (UP), Botany Point (BP) and Refuge 2 (REF2). Significant results ($p < 0.001$)

Comparisons	d	p
BP x FS	0.545	< 0.001
BP x UP	0.709	< 0.001
BP x REF2	0.536	< 0.001
FS x UP	0.194	> 0.100
FS x REF2	0.086	> 0.100
UP x REF2	0.195	> 0.100

Length-weight Relationships

Aequiyoldia eightsii showed a positive allometric relationship between shell length and total wet weight at Ferraz Station, Ullmann Point, and Refuge 2 (Fig. 5). However, no allometry was observed at Botany Point, where an isometric growth of the population was verified. The allometric coefficients (*b*) at Ferraz Station and Ullmann Point were significantly different from those observed at Botany Point and Refuge 2 (Table 3).

Table 3

Student's t test with Bonferroni correction for parameter b of the length-weight relationships (Total wet weight = a.Shell length^{b}) of *Aequiyoldia eightsii*. Ferraz Station (FS), Ullmann Point (UP), Botany Point (BP) and Refuge 2 (REF2). Significant results for $p < 0.008$

Comparisons	t	p
BP x FS	3.861	0.0001
BP x UP	3.582	0.0004
BP x REF2	1.364	0.1730
FS x UP	1.323	0.1869
FS x REF2	6.039	< 0.0001
UP x REF2	3.346	0.0009

Table 4

Morphological parameters from linear regressions for *Aequiyoldia eightsii* at four sampling stations in Admiralty Bay. Number of individuals (N), Shell length (L), Shell height (H), Shell width (W), Ferraz Station (FS), Ullmann Point (UP), Botany Point (BP) and Refuge 2 (REF2). All R^2 values are significant ($p < 0.05$)

	FS	UP	BP	REF2
N	258	40	170	364
L x H	-1.3970 + 1.6470x	-2.2258 + 1.7441x	-3.4812 + 1.8008x	-1.8434 + 1.6653x
R² (L x H)	0.991	0.984	0.957	0.989
L x W	3.5840 + 2.9658x	4.3082 + 2.6163x	7.4762 + 2.5664x	3.8179 + 2.9788x
R² (L x W)	0.977	0.930	0.860	0.957

Shell Morphology

Significant differences among areas were found for all morphometric variables (Fig. 6). Specimens from Botany Point showed the highest means for shell length (26 mm ± 0.23; F = 39.860; p < 0.0001), height (16.37 mm ± 0.13; F = 35.300; p < 0.0001), and width (7.22 mm ± 0.08; F = 26.93; p < 0.0001). Those specimens also had the highest mean length/height ratio (1.59 ± 0.003), being significantly more elongated than the specimens from the other sites (F = 64.120; p < 0.0001). The Ullmann Point individuals presented the lowest mean length/width ratio (3.50 ± 0.06) and therefore were comparatively wider than long (F = 10.530; p < 0.0001). On the other hand, Refuge 2 bivalves had the highest mean length/width

and the lowest mean length/height ratios (3.76 ± 0.02 and 1.52 ± 0.003, respectively), indicating individuals comparatively slimmer and more rounded.

Discussion

Mean densities of *A. eightsii* varied from *ca.* 1 to 5 ind.m⁻² in the shallow zone (20-35m depth) of Admiralty Bay. Those abundance values are much lower than those observed by Peck and Bullough (1993) at Signy Island in the 9-meter isobath, where mean densities ranged from 361 to 669 ind.m⁻². A previous study on the benthic communities of Admiralty Bay (Echeverría et al. 2005), using van Veen grab samples, reported a variation in depth preference for *A. eightsii*, which presented high densities at 12 m (210 ind.m⁻²) and significantly lower values at 25 m (10 ind.m⁻²) near Ferraz Station during austral winter. Similar patterns of depth distribution were also observed for other bivalves at Ezcurra Inlet (King George Island) and Signy Island, where the highest abundances were verified in shallow waters of up to 15 m deep (Hardy 1972; Jażdżeski et al. 1986). In summer periods, there are considerable ice impacts in Admiralty Bay coastal waters mainly due to the formation of icebergs and ice scouring activity (Nonato et al. 2000). These impacts form a special topography in the marine bottom, with depressions and crests of up to 2 m in height. The benthic fauna inhabiting these scours are mainly motile forms and the bivalve *L. elliptica*, which buries deeper in the sediment than *A. eightsii*. Since the bulk of the impacts occur in the 20-meter-isobath, it is probable that they represent a factor limiting the occurrence of *A. eightsii* in this depth zone.

Another possible explanation for the higher densities found at Signy Island by Peck and Bullough (1993) can be related to differences in sampling methodology. These authors used an airlift suction device with a 1-mm-mesh bag to collect specimens, which allowed collecting even smaller specimens. In fact, the great majority of the population sampled at Signy Island (80%) was composed of very small individuals (≤ 5 mm), which can explain the higher density values found at that Island. As benthic fauna abundance estimates are strongly influenced by differences in sampling devices and mesh-sieve sizes, it is urgent to establish the same sampling protocol for benthic sampling around Antarctica if *A. eightsii* is used as a biomonitor species.

The spatial density distribution of *A. eightsii* was not significantly different among sites at the 20–35 m depth range and may have been affected not only by the small number of samples but also by the high heterogeneity at small spatial scale (replicates). However, benthic invertebrate densities often reflect substrate preferences, since sediment grain size is usually an important factor influencing protobranch distributions (Zardus 2002). The lowest density values for *A. eightsii* were obtained at Ullmann Point, where sediment samples presented the highest proportion of gravel. In addition, macroalgae beds were already reported for this site (Lanna et al. 2012), indicating the presence of hard substrata at the studied depth range. On the other hand, the highest density values were obtained at Refuge 2, where a muddy bottom with higher values of TOC predominates. Those differences can be related to the lower speed of the tidal currents in Mackellar (~ 0.02 m.s⁻¹) in comparison to Martel Inlet (~ 0.10 m.s⁻¹), which explains the higher content of finer particles at the last (Weber and Montone 2006).

Higher densities of *A. eightsii* were also found in Ferraz Station (FS). The sediment samples from this site indicated a greater proportion of TOC in comparison with the others. As FS is located near a seaweed bed (Zieliński 1990), this site receives a high contribution of algae debris especially in the summer, when macroalgae thalli tend to be deposited on the beaches as drifting algae (Colepicolo et al. 2014). Moreover, the sampling site of Ferraz is situated in front of the Brazilian research station (Weber and Montone 2006) and is susceptible to an additional input of organic matter through organic sewage and nutrients (Martins et al. 2005; Nakayama et al. 2011). Those results reinforce the preference of *A. eightsii* for fine and organically enriched sediments, as previously reported for this species at Terra Nova Bay, Ross Sea (Fabiano et al. 1999), and for other nuculanid protobranchs from the north of the Atlantic Ocean such as *Yoldia limatula* and *Nucula proxima* (Sanders 1960; Rhoads and Young 1970).

Spatial differences in species size and weight seem to be mainly related to variations in food availability since growth rates can increase as a function of food quantity (Sebens 1987; Saxby 2002). The highest condition indexes for *A. eightsii* were found in Martel Inlet, and they may be attributed to different environmental conditions. In the summer of 2011, significant spatial variability was observed in phytoplankton samples from Martel and Mackellar Inlets (Tenório et al. 2012). Botany Point samples presented chlorophyll *a* biomass twice as high as the other stations, coinciding with the highest condition index value reported in our study. Therefore, the greater tissue mass observed in this site can be related to the contribution of phytoplankton biomass as a primary food source during summer periods, when filter feeding is known to be more effective (Davenport 1988). On the other hand, endogenous factors can also play an important role in the metabolism and growth of the species (Román-González et al. 2017a; Lau et al. 2018). Bascur et al. (2021) reported a strong variability in terms of the nutritional condition within *A. eightsii* populations from distant localities (hundreds of kilometers) of the West Antarctic Peninsula (WAP). The differences observed in terms of lipids, proteins, fatty acids, and energy contents from the north, middle, and south populations were related to oceanographic factors, food quantity and quality, growth, and reproductive cycles. In marine invertebrates, the biochemical reserves, and consequently, gonad size and weight, tend to increase before spawning due to the production of gametes (Li et al. 2011). In the present work, we did not analyse individual gonadal stages and maturity. However, we cannot eliminate the possibility of asynchrony in terms of energy flow for somatic or tissue growth between the populations of Admiralty Bay. In this context, it is possible that specimens from Martel Inlet invest more in reproduction than in somatic growth, in comparison with Mackellar specimens. Besides, it is also worth noting that *A. eightsii* populations show significant variability patterns not only between geographically distant areas (Bascur et al. 2021) but also within sites of close proximity (< 1 Km), as it is observed in our study.

A positive allometric relationship between shell length and total wet weight reported here for *A. eightsii* in most of the sites of Admiralty Bay reveals the presence of heavier specimens than expected to a certain size. These results are consistent with the allometric growth already reported for other Antarctic mollusks, such as the gastropod *Nacella concinna* (Figueiredo and Lavrado 2012) and the bivalves *Adamussium colbecki* (Stockton 1984) and *Yoldiella ecaudata* (Reed et al. 2013). Studies regarding bivalve relative growth revealed that several different species from temperate waters present gradual morphologic

changes throughout their ontogeny (Rabaoui et al. 2011; Vasconcelos et al. 2018). In the present work, an isometric growth was only verified for Botany Point specimens. The length-weight relationship at Botany Point was exclusively based on individuals larger than 20 mm in length (adults), which could indicate an ontogenetic shift in allometry for the species. It is possible that *A. eightsii* grows allometrically at younger stages but changes to isometric growth at sexual maturity, a pattern also observed in marine gastropods (Hollander et al. 2006). Additionally, *A. eightsii* presents ontogenetic growth cycles which reflect trade-offs between somatic and reproductive investment (Román-González et al. 2017b). Therefore, the energy allocation towards somatic and shell growth would be related to a positive allometry in juveniles, while the allocation of resources towards gametogenesis would be related to an isometric growth in adults.

Considering the size-frequency distributions, similar patterns were encountered at all studied sites, with exception of Botany Point, where no juveniles were found. In the summer of 2011, the ophiuroid *Ophionotus victoriae* was observed at high densities between 20–30 m depth range at Botany Point, consisting of about 99% of the echinoderms (Lanna et al. 2012). *Ophionotus victoriae* is a dominant and opportunistic species in Admiralty Bay and intensively feeds on bivalves, being able to prey on small-sized individuals (Fratt and Dearborn 1984). Since *A. eightsii* was shown to be one of its most frequent prey, it appears that the absence of small organisms in Botany Point can be related to prey size selection by the ophiuroid. Another reason would be a density-dependent control of its recruitment, as already observed for *A. eightsii* populations from Signy Island (Peck and Bullough 1993). Those authors found that high adult densities can inhibit recruitment or survival of young stages by consuming larvae as they begin to settle or by eating recently settled individuals along with the sediment. This control, associated with low adult mortality, has also been considered to explain population distributions in gastropods which are dominated by large individuals (Peck and Culley 1990).

Morphological variations in mollusks are often attributed to the environmental physical conditions to which they are exposed to (Reed et al. 2014). *Aequiyoldia eightsii* shows reasonable constancy in the length/height ratio, but the variations of shell inflation can be correlated with the increase of grain size (Rabarts and Whybrow 1979). The specimens with the most obese and inflated shells were observed at Ullmann Point, where the highest percentages of coarse sediments were found. *Aequiyoldia eightsii* individuals from gravelly bottoms are known for being superficially distinct from the more compressed arcuate forms found in fine sand and mud (Rabarts and Whybrow 1979). However, this difference alone does not explain all the morphological differences between *A. eightsii* populations. Specimens from muddy (Refuge 2) and sandy (Ferraz Station) bottoms, presented more slim and rounded shells, as expected, but Botany Point individuals were more elongated, although this station was characterized by fine sediments. In bivalves, shell growth patterns may also vary considering different life stages (Gaspar et al. 2002). These ontogenetic changes are generally related to the distinct lifestyles between juveniles, usually active burrowers, and adults, more sedentary and inhabiting deeper on the bottom. Peck et al. (2004) observed that smaller individuals of *A. eightsii* (11 mm shell length) can borrow up to 10 times faster than larger individuals (26 mm shell length). Therefore, it is suggested that shell morphometric parameters of *A. eightsii* can change with age, since the higher mean length/height ratios from Botany Point specimens were obtained from adults only.

In general, the population structure of *A. eightsii* in Admiralty Bay was spatially heterogeneous, reflecting the presence of different habitats in the bay. Those spatial differences were probably related to the species response to the sediment characteristics, food availability, and to biotic factors such as predation and recruitment rates. Moreover, the phenotypic shell plasticity of *A. eightsii* between populations of geographically close areas highlights the importance of local-scale variation for ecological analysis. No single mechanism can explain the macrobenthic infauna distribution patterns observed in different environments (Snelgrove and Butman 1994). Thus, determining how many interacting variables contribute to the spatial distribution of *A. eightsii* can only be achieved by controlled experimentation and greater sampling effort. Future investigations should focus on ontogenetic shifts between different life stages, as well as on the analysis of intra and interspecific ecological relationships, in order to further clarify their effects on the structure of *A. eightsii* populations. Only by understanding those aspects will it be possible to distinguish long-term effects of climate change or anthropogenic impacts from natural changes on populations of that bivalve species.

Declarations

Conflicts of interest/Competing interests: The authors certify that the research was conducted in the absence of any commercial, financial, or non-financial relationships that could be construed as a potential conflict of interest.

Ethics approval: This study was conducted according to the regulations of the Brazilian Antarctic Program and the Antarctic Treaty. Samplings were authorized by the Brazilian Ministry of Environment.

Consent for publication: All authors consent to the publication of this manuscript.

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Code availability: Not applicable.

Author's contributions: HPL and AGD contributed to conception study design, field sampling, and discussion. IBA performed the sampling processing, the statistical analysis, and wrote the first draft of the manuscript. All authors contributed to manuscript writing, revision, and approved the submitted version.

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Figures
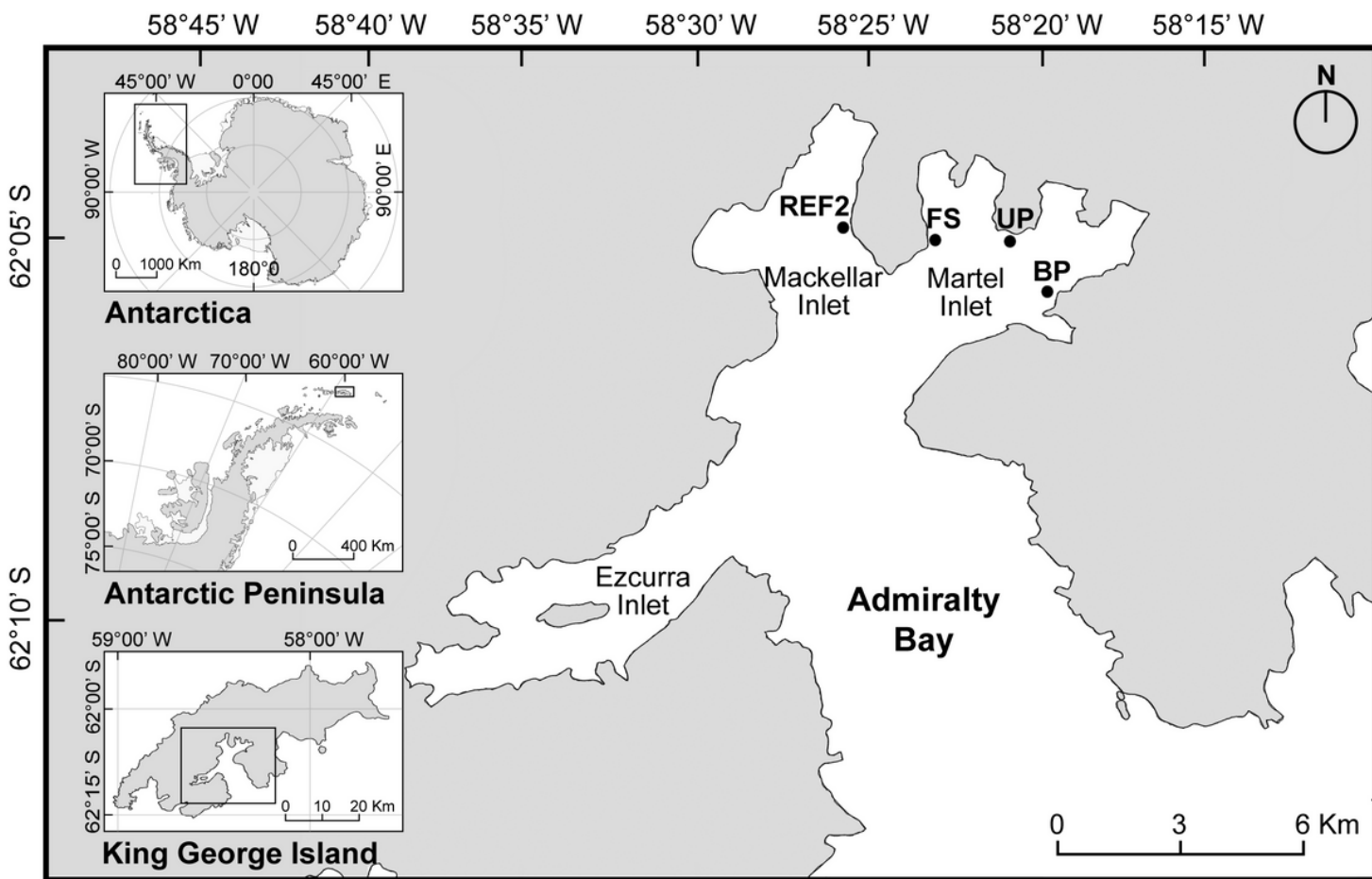
Figure 1

Admiralty Bay (King George Island, Antarctic Peninsula). The points represent the sampling stations: Refuge 2 (REF2), Ferraz Station (FS), Ullmann Point (UP) and Botany Point (BP)

a

b
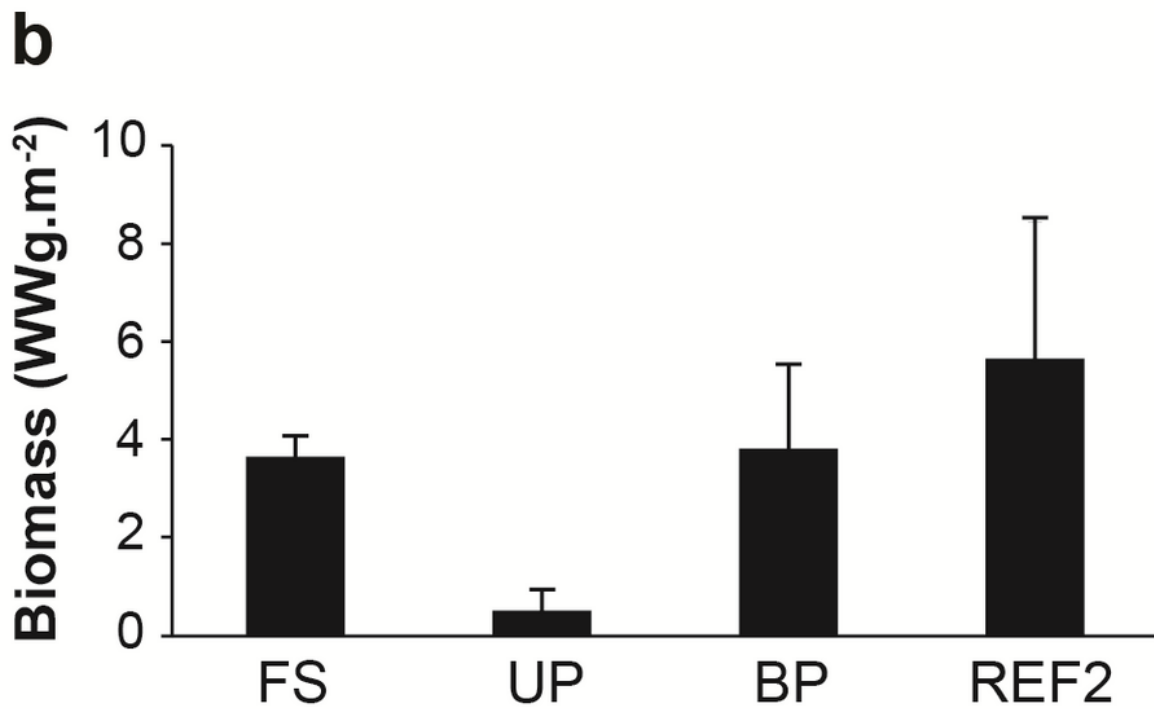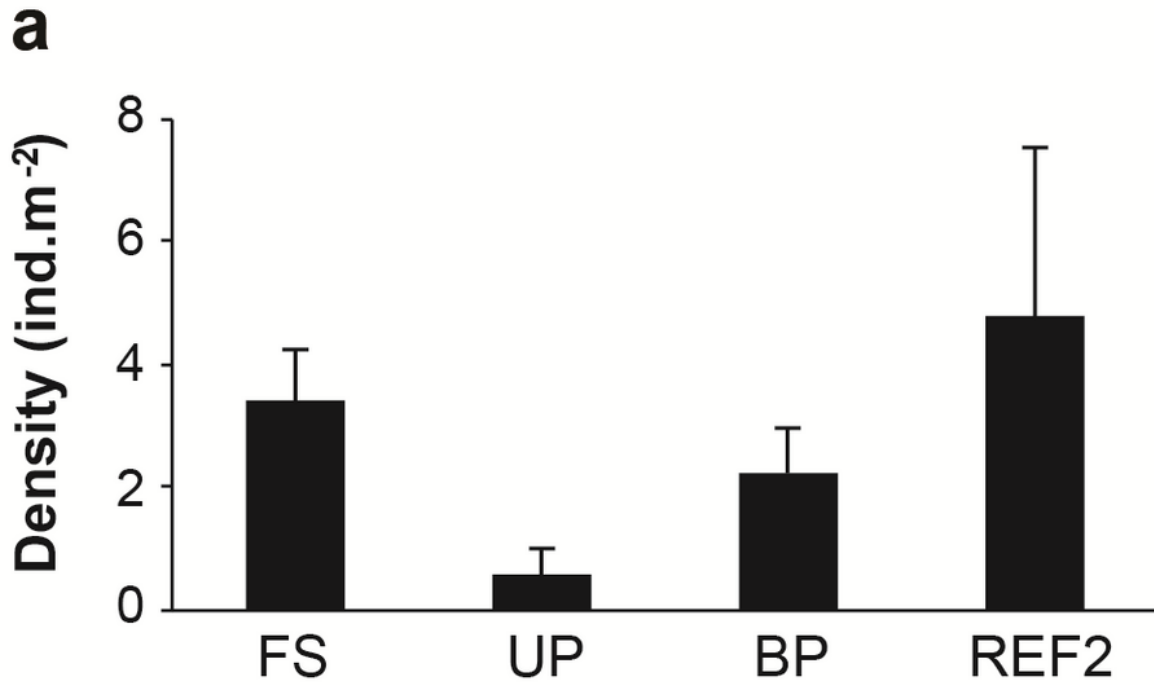
Figure 2

a Density (ind.m^{-2}) and **b** biomass (WWg.m^{-2}) of *Aequiyoldia eightsii* at four sampling stations in Admiralty Bay. Ferraz Station (FS), Ullmann Point (UP), Botany Point (BP) and Refuge 2 (REF2). Mean ± SE (N = 3)
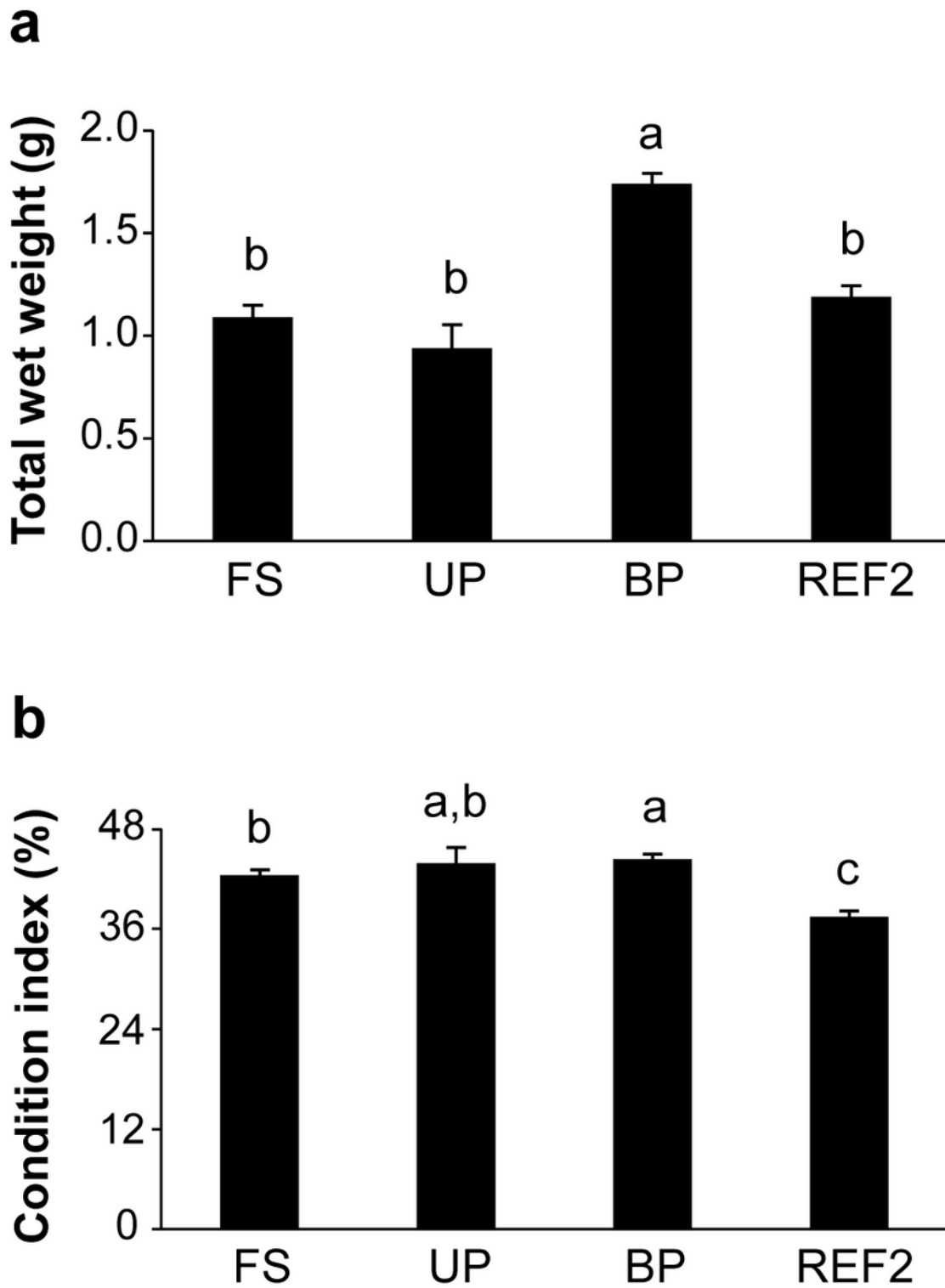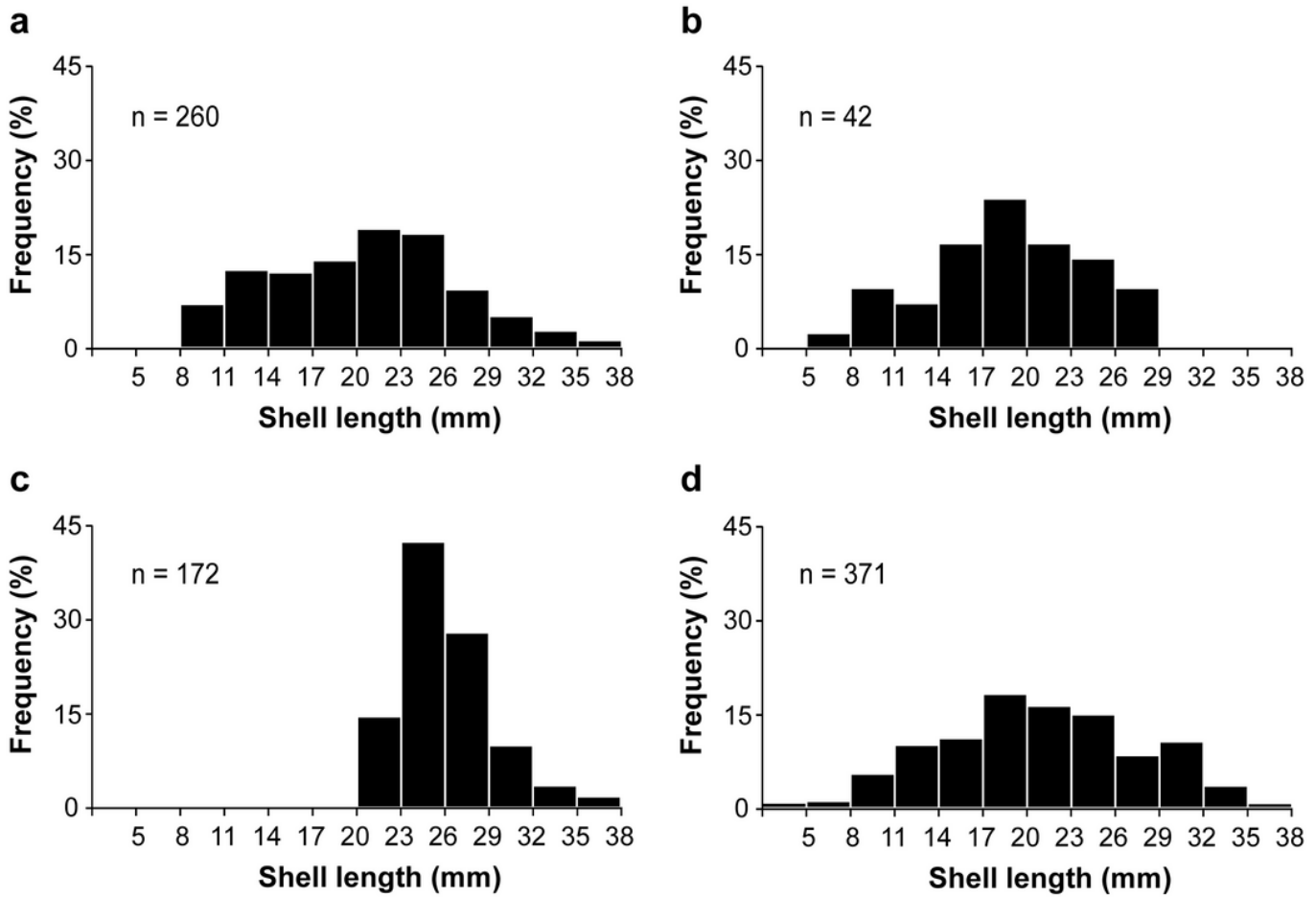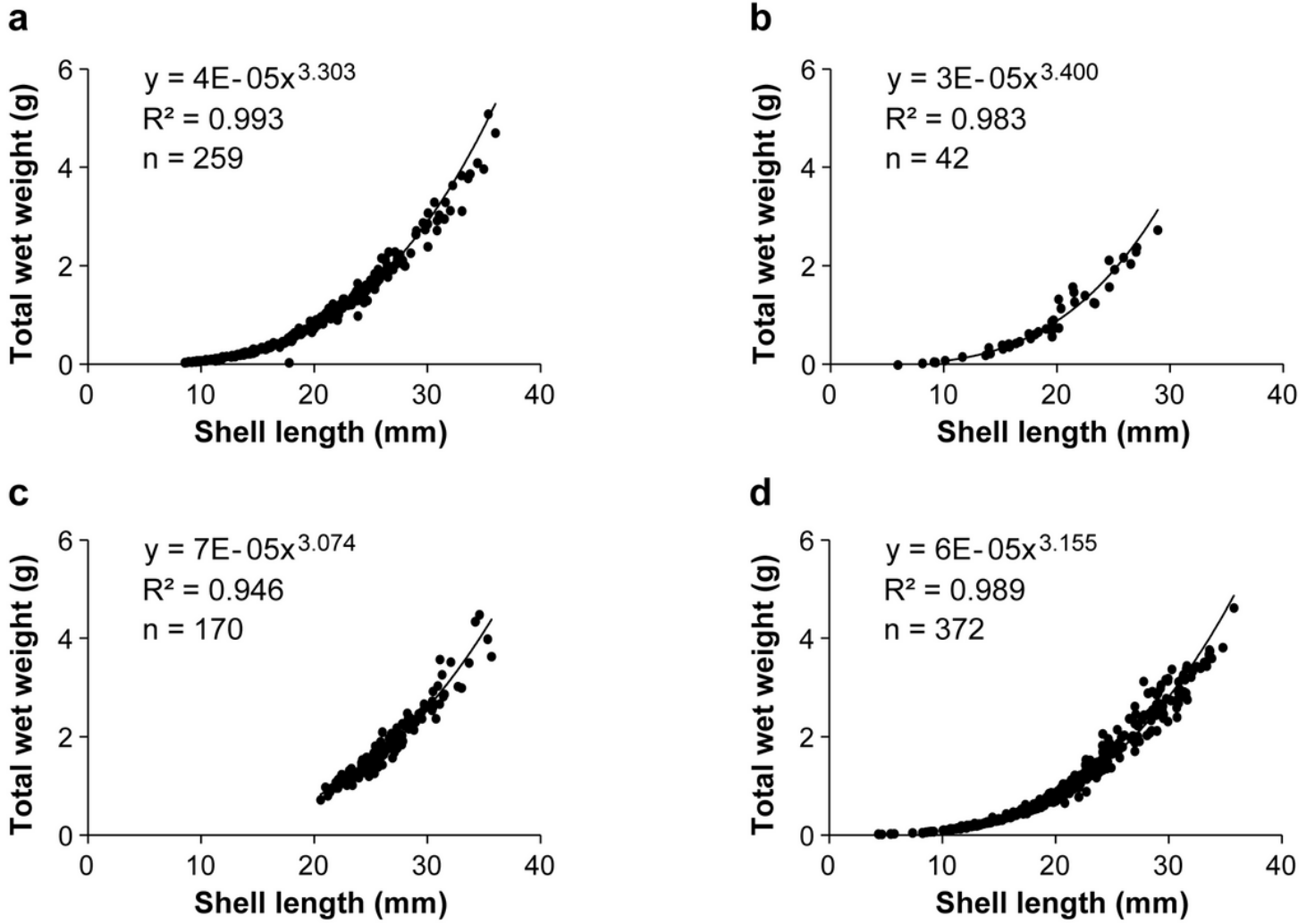
a

b

Figure 3

a Total individual wet weight (g) and **b** condition index (%) of *Aequiyoldia eightsii* at four sampling stations in Admiralty Bay. Ferraz Station (FS), Ullmann Point (UP), Botany Point (BP) and Refuge 2 (REF2). Mean ± SE. Different letters above bars indicate significant differences ($p < 0.05$)
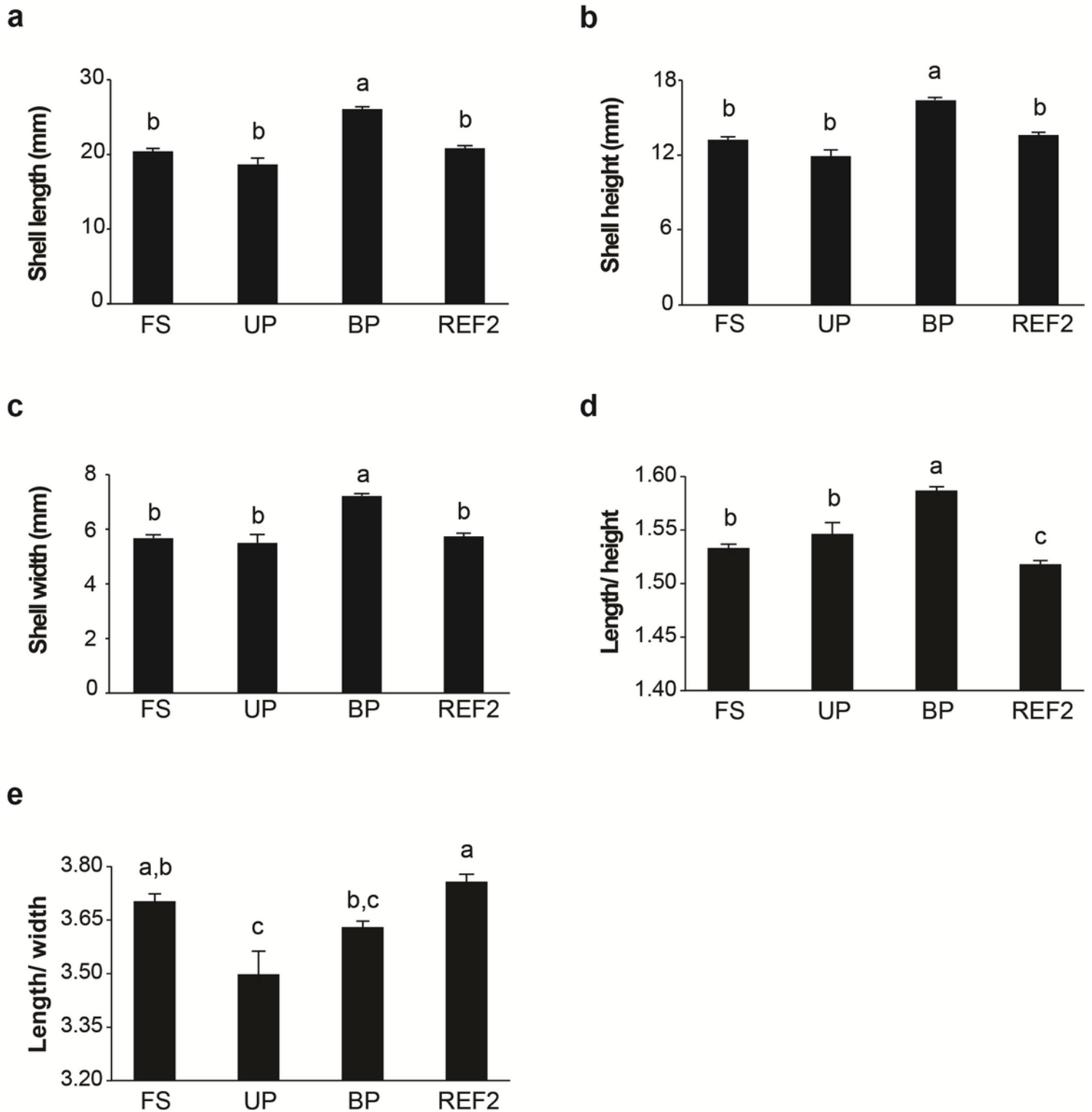
Figure 4

Size (shell length) frequency distribution of *Aequiyoldia eightsii* at four sampling stations in Admiralty Bay. a Ferraz Station, b Ullmann Point, c Botany Point and d Refuge 2

Figure 5

Total wet weight (g) versus shell length (mm) of *Aequiyoldia eightsii* at four sampling stations in Admiralty Bay. a Ferraz Station, b Ullmann Point, c Botany Point and d Refuge 2

a

b

c

d

e

Figure 6

Size parameters of *Aequiyoldia eightsii* at four sampling stations in Admiralty Bay. **a** Shell length (mm), **b** shell height (mm), **c** shell width (mm), **d** shell length/height ratio and **e** shell length/width ratio. Ferraz Station (FS), Ullmann Point (UP), Botany Point (BP) and Refuge 2 (REF2). Mean ± SE. Different letters above bars indicate significant differences ($p < 0.05$)