

Article



Population Characteristics of the Limpet Patella caerulea (Linnaeus, 1758) in Eastern Mediterranean (Central Greece)

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Abstract: Limpets are pivotal for structuring and regulating the ecological balance of littoral communities and are widely collected for human consumption and as fishing bait. Limpets of the species *Patella caerulea* were collected between April 2016 and April 2017 from two sites, and two samplings per each site with varying degree of exposure to wave action and anthropogenic pressure, in Eastern Mediterranean (Pagasitikos Gulf, Central Greece). This study addresses a knowledge gap on population characteristics of *P. caerulea* populations in Eastern Mediterranean, assesses population structure, allometric relationships, and reproductive status. Morphometric characteristics exhibited spatio-temporal variation. Population density was significantly higher at the exposed site. Spatial relationship between members of the population exhibited clumped pattern of dispersion during spring. Broadcast spawning of the population occurred during summer. Seven dominant age groups were identified, with the dominant cohort in the third-year class. Significant negative allometric relationships were exhibited between morphometric characteristics. Differences in growth patterns among populations were indicated.

Keywords: *Patella caerulea;* Eastern Mediterranean; population structure; spawning season; age groups; allometric relationships

1. Introduction

Limpets of the genus *Patella* are grazing gastropods, common inhabitants of the hard substrate communities in the midlittoral and upper infralittoral zones of the East Atlantic and Mediterranean coasts in temperate latitudes [1,2]. They play an important role in controlling algal coverage and consequently, the ecological succession and biological communities established in coastal zones [3–7]. They are considered the "keystone" species of the midlittoral zone [8–12] and are widely collected for human consumption and as fishing bait. Limpets are pivotal for structuring and regulating the ecological balance of intertidal communities, directly through the key process of grazing that determines macroalgal abundance, and indirectly by enhancing or inhibiting the establishment of other organisms [3,6,12,13].

In the Mediterranean Sea the genus *Patella* is represented by four species: *P. caerulea*, *P. ulyssiponensis*, *P. rustica*, and *P. ferruginea* [14]. The native Mediterranean limpet *P. caerulea* (Linnaeus, 1758), the common or rayed Mediterranean limpet, is among the most common of rocky shores in the whole infralittoral and midlittoral Mediterranean basin [15], also present in a few places in the eastern Atlantic (Bay of Biscay, Canary Islands, Moroccan coast) [16–18] and considered endemic to the Mediterranean Sea [19,20].

Abiotic factors, mainly environmental, have been suggested to effect morphological changes on the shell shape in several species of Atlantic and Mediterranean limpets [21–23]. Limpet distribution and density can be affected by both abiotic and biotic factors. Abiotic factors include wave exposure, substratum morphology, and inclination [18,24–26] whereas biotic factors include intra and interspecific competition [27–29].

Although a number of studies have been carried out on the biology, distribution, and ecology of *Patella* species in the Mediterranean Sea [7,14,15,25,30–36], little is known on the occurrence and population characteristics of *P. caerulea* in eastern Mediterranean, apart from fragmented information (morphometry, distribution, ecology, reproduction) occasionally collected in the framework of several ecological studies [26,37–41].

Our aim is to address a knowledge gap on population characteristics of *P. caerulea* populations in Eastern Mediterranean with an extensive assessment of *P. caerulea* population structure and characteristics, allometric relationships and reproductive status on the upper infralittoral zone in eastern Mediterranean. The present work can be used as a baseline in an ongoing study on the effects of climate change to this very sensitive part of the coastal zone, especially in climate sensitive Eastern Mediterranean.

2. Materials and Methods

2.1. Study Area

Pagasitikos, a semi-enclosed landlocked gulf, is located in the north western part of the Aegean Sea (Figure 1). The mean depth is 69 m, with its deepest area (108 m) located at the eastern part where larger depth gradients are observed. Total gulf area is 520 km² and total volume 36 km³ [42], connected with the Aegean Sea and north Evoikos through the narrow (5.5 km) and relatively deep (80 m) Trikeri channel [43]. Pagasitikos is a rather sensitive ecosystem due to its semi-enclosed nature and shallow depths. The predominant weak winds of the area result in small to moderate water currents while renewal occurs mainly through the deep-water layer of the Trikeri channel [44]. In contrast with other enclosed gulfs in Greece, Pagasitikos is considerably less eutrophic with a unique and stable circulation pattern which includes a cyclone in the central-west and an anticyclone in the eastern part [45]. Water renewal of the gulf takes approximately 105 days according to Petihakis et al. [46]. The only major city is Volos located at the north part of the gulf, with a population of 120,000 inhabitants and a well-developed industrial sector.

2.2. Field Sampling

Four study stations were selected (Figure 1) based on the degree of exposure and anthropogenic pressure. Two stations were selected at each site in order to obtain disparate samples. The first two stations were located at the first study site (Site 1 Agios Stefanos, Latitude: 39.298531 and Longitude: 22.941732) characterized by low wave exposure (approximately 7 degree slope) and low anthropogenic pressure only in the summer months whereas the third and fourth stations were located at the second study site (Site 2 Plakes, Latitude: 39.348283 and Longitude: 22.969542) characterized by mid to high wave exposure (approximately 10 degree slope) and high anthropogenic pressure (trampling by swimmers) year round. Both study sites experience similar wave-wash because of maritime traffic.

Monthly samples of *P. caerulea* were recorded and collected at each sampling station (Figure 1) from April 2016 to April 2017. Population density and distribution patterns were estimated using randomly placed quadrant plots (20×20 cm metal frame). The frame was placed randomly ten times on the substrate covering a sampling area of 0.04 m² recording *P. caerulea* numbers at each quadrant for every placement [47]. From each sampling station and period, 20 *P. caerulea* individuals, randomly chosen from the quadrat counts were transferred to the laboratory. Four biometric characteristics were determined for each individual (shell length—greatest distance between the anterior and posterior, shell width—greatest distance perpendicular to the anterior posterior axis, shell height—greatest vertical distance from the apex to the shell base, posterior shell length—distance between apex and posterior shell base) were recorded using a digital Vernier caliper to the nearest 0.01 mm (Figure 2). Limpet shells were individually weighed (Wt) on a digital balance to the nearest 0.01 g. Soft tissues were carefully separated from the shells and washed in distilled water to remove dirt. Soft entire bodies were dried at 80 °C for 48 h and then weighted to determine dry tissue mass (Wf). The main abiotic factors, i.e., temperature, salinity, and dissolved oxygen were measured on the water surface with the portable instrument HACK HQ 40d multi (HACK, Colorado, CO, USA) pH was measured with the portable instrument WTW PH 340i/SET (WTW, Weilheim, Germany). Based on sea temperature, monthly means of these data were processed through seasons.



Figure 1. Pagasitikos Gulf depth profile and sample locations, Site 1 (sheltered), Site 2 (exposed).

2.3. Data Analysis

The null hypothesis of no significant spatial and temporal differences in the abundance and the mean values of the biometric characters of the limpet were tested with one way ANOVA [48] and hierarchical structure using Nested ANOVA. Normal distribution was assessed using the Anderson-Darling normality test. Bartlett's and Levene's tests were used to assess homogeneity of variance. Statistical analyses were performed using Minitab 19 software (Minitab, Pennsylvania, USA) with significance level at p < 0.05. The spatial distribution of *P. caerulea* was estimated calculating Morisita index of aggregation (I\delta) [49,50].



Figure 2. Annotated shell dimensions: shell length (L), shell width (W), and shell height (H), posterior shell length (PL).

To test the null hypothesis of randomness (significance of departure from random distribution), $(I\delta = 1)$ the chi-square test was used (d.f. = n - 1) [50–52]. Spatial and temporal abundance variation was assessed using one-way ANOVA, Tukey's pairwise comparisons were used to identify possible differences between sample means. Condition index (the general physiological condition of the mollusk) was calculated for each individual according to Nakhlé et al. [53] as the ratio: (dry mass of soft tissues/shell weight) × 100.

The non-parametric Kruskal–Wallis test was used to investigate the possible temporal differences. The equation describing the best fit (highest correlation coefficient) was identified with the use of Curve Expert 1.4 software (Hyams Development, Alabama, USA). All identified relationships were curvilinear power regression equations ($Y = aX^b$). Allometric relationships were assessed for each population and were compared using the standard student t-test. Regression equations for each population were compared between sampling sites, using the two-sample t-test. Length frequency distribution calculated per 1 cm size classes, were divided into age groups using Bhattacharya's method [54] in order to obtain initial guesses, using the software FiSAT II (FAO, Rome, Italy) (version 1.2.2.) [55]. The results were refined using the maximum likelihood concept (NORMSEP) [56] separating normally distributed components of size-frequency samples (modal progression analysis).

3. Results

3.1. Physio-Chemical Measurements

The physical parameters measured in the water surface showed similar spatio-temporal values. Temperature ranged seasonally from 13.17 °C to 27.12 °C. Minimum surface sea water temperature was recorded in February and maximum in July. Salinity ranged seasonally from 36.12 psu to 38.46 psu. Minimum salinity was recorded in August and maximum in March. Monthly surface temperature and salinity exhibited minor variations between sites, indicating homogeneity (Table 1).

Table 1. Spatial variation of the physical (T, temperature; S, salinity) and chemical (pH; O₂, dissolved oxygen) parameters recorded in Pagasitikos gulf surface layer.

Comulius Davis d		Sit	e 1			Sit	te 2	
Sampring Period	T (°C)	S (psu)	pН	O ₂ (mg/L)	T (°C)	S (psu)	pН	O ₂ (mg/L)
April	16.06	38.54	8.32	6.79	16.95	38.16	8.32	6.86
May	21.21	37.54	8.29	5.88	19.92	37.54	8.26	2.48
June	25.04	37.47	8.26	6.61	26.45	36.64	8.24	5.71
July	27.08	36.46	8.26	5.44	27.12	36.18	8.23	2.45
August	26.67	36.12	8.26	2.06	26.78	36.76	8.31	5.02
September	24.28	36.84	8.29	4.92	25.03	36.49	8.29	5.92
Öctober	21.79	36.42	8.31	5.22	22.04	36.84	8.35	5.54
November	18.31	36.71	8.34	2.48	17.95	36.99	8.39	3.67
December	16.01	36.87	8.31	2.99	15.64	36.21	8.24	4.97
January	13.96	36.99	8.27	5.21	13.17	38.21	8.33	4.01
February	13.28	37.67	8.28	3.04	13.46	38.03	8.27	5.11
March	13.31	37.78	8.23	4.76	13.53	38.46	8.29	6.49
April	14.62	38.12	8.24	6.45	14.93	37.78	8.24	6.12

3.2. Biometric Relationships

Total number of *P. caerulea* specimens collected was 1040. Shell length ranged from 9.3 to 45.1 mm, shell width from 5.7 to 40.9 mm, shell height from 2.8 to 12.8 mm, posterior shell length from 0.8 to 21.9 mm, total weight from 0.2 to 8.4 gr, and foot weight from 0.04 to 2.4 gr. Temporal variation of biometric characters was exhibited, with highest values in spring and lowest values in autumn. No spatial differences were exhibited in the shell length and shell width between sites. However spatial differences were exhibited, with significantly higher shell height, posterior shell length, total weight, and foot weight at the sheltered site (Site 1). The full set of biometric measurements at each sampling site are presented in Table 2. Limpet shell length, shell width, shell height, and total weight frequency distributions (Figures 3–6) indicated greater variability of the morphometric characteristics of *P. caerulea* population at the sheltered site (Site 1).

3.3. Population Density

Population density at the sheltered site (Site 1) was higher in winter (126.7 ind/m² ± 55.4) followed by summer (120.0 ind/m² ± 52.7), autumn (115.8 ind/m² ± 37.4), and spring (107.5 ind/m² ± 35.0). Analysis of variance did not indicate significant differences in temporal population density at the sheltered site. Population density at the exposed site (Site 2) was higher in spring (195.0 ind/m² ± 34.4) followed by summer (165.83 ind/m² ± 13.77), winter (128.3 ind/m² ± 29.3), and autumn (125.8 ind/m² ± 20.1). Overall *P. caerulea* population density was 135.63 ind/m² ± 41.95. Population density at Site 1 (sheltered) was 117.6 ind/m² ± 39.9 and at Site 2 (exposed) 153.75 ind/m² ± 37.0. Highest temporal abundance of the total population was recorded in spring (151.3 ind/m² ± 23.3) followed by summer (142.9 ind/m² ± 17.4), winter (127.5 ind/m² ± 16.2), and autumn (120.8 ind/m² ± 11.2). Results of Nested ANOVA did not indicate temporal differences in the density of the total population. Spatial differences in the population density between sampling sites were indicated with higher abundance observed at the exposed site (Site 2), however not statistically significant (Table 3).

Sampling Period	No. of Individuals	$L \pm SE$	$W \pm SE$	$H\pm SE$	PL ± SE	Wt ± SE	$Wf \pm SE$
Site	(n)						
Site 1	520	23.47 ± 0.23	19.09 ± 0.21	6.22 ± 0.07	11.21 ± 0.13	1.43 ± 0.05	0.51 ± 0.06
Site 2	520	23.24 ± 0.15	18.83 ± 0.13	5.97 ± 0.05	10.89 ± 0.09	1.24 ± 0.02	0.37 ± 0.01
		F = 0.66,	F = 1.13,	F = 8.51,	F = 4.12,	F = 12.23,	F = 20.58,
		p = 0.42	p = 0.29	p < 0.05	p < 0.05	p < 0.001	p < 0.001
Season	(n)						
Winter	242	22.780 ± 0.27	18.716 ± 0.23	5.973 ± 0.08	10.576 ± 0.14	1.150 ± 0.04	0.320 ± 0.01
Spring	318	25.140 ± 0.25	20.462 ± 0.24	6.568 ± 0.08	12.506 ± 0.15	1.663 ± 0.06	0.526 ± 0.02
Summer	240	23.601 ± 0.28	19.136 ± 0.25	6.398 ± 0.09	10.912 ± 0.16	1.484 ± 0.06	0.467 ± 0.02
Autumn	240	21.322 ± 0.25	17.044 ± 0.23	5.288 ± 0.07	9.733 ± 0.13	0.943 ± 0.03	0.274 ± 0.01
		F = 39.02,	F = 37.07,	F = 50.82,	F = 68.59,	F = 39.80,	F = 51.18,
		p < 0.001	p < 0.001	p < 0.001	p < 0.001	p < 0.001	p < 0.001
Total	1040	23.36 ± 0.14	18.96 ± 0.12	6.09 ± 0.04	11.05 ± 0.08	1.34 ± 0.03	0.41 ± 0.01

Table 2. Spatial and temporal variation of the biometric characters, mean value + standard error (SE) (L shell length, W shell width, H shell height, PL posterior shell length, Wt total weight, Wf foot weight) measured of the *Patella caerulea* population in Pagasitikos Gulf and one way ANOVA results (F, *p*).



Figure 3. Shell length-frequency distribution of *Patella caerulea* population with overlaid fitted normal distribution at both sites.



Figure 4. Shell width-frequency distribution of *Patella caerulea* population with overlaid fitted normal distribution at both sites.



Figure 5. Total shell height-frequency distribution of *Patella caerulea* population with overlaid fitted normal distribution at both sites.



Figure 6. Total weight-frequency distribution of *Patella caerulea* population with overlaid fitted lognormal distribution at both sites.

Table 3. Nested ANOVA results of spatial and temporal effects on the surveyed *Patella caerulea* population abundance.

Source of Variation	DF	SS	MS	F	р
Site	1	7884.38	7884.38	4.45	0.077
Season	6	10,397.92	1732.99	1.25	0.334
Error	16	22,195.83	1387.24		
Total	23	40,478.13			

No spatiotemporal differences were recorded among sampling stations within each sampling site. Spatial abundance is shown in Figure 7. Comparative densities and morphometric characteristics of *P. caerulea* from various Mediterranean areas are displayed in Table 4.



Figure 7. Abundance of *Patella caerulea* at each sampling site. Values are means (dots), medians (lines), standard deviation (interquartile range box), and minimal and maximal value (whiskers).

Table 4. Densities and morphometric characteristics of *Patella caerulea* reported from various Mediterranean areas.

Area	Density (ind/m²)	Shell Length (mm)	Shell Width (mm)	Shell Height (mm)	Total Weight (gr)	References
Strait of Gibraltar	125					[37]
Strait of Gibraltar	100	28.87 ± 3.66			2.87 ± 1.09	[39]
French Mediterranean coast	16.5 ± 9.9					[38]
Northern Adriatic	3–38	13.5-56.1	19.91-25.52	3.5-17.5		[25]
Tunisia		21.03-35.57	17.93-30.15	4.99-9.4		[40]
Turkey (Izmir Bay)		24.36-30.75	10.5-46.9	6.26-8.9	2.59-4.21	[41]
Pagasitikos Gulf (Central Greece)	135.63 ± 41.95	23.36 ± 4.46	18.96 ± 4.01	6.09 ± 1.38	1.34 ± 0.89	Present study

3.4. Distribution Pattern

Spatial point pattern analysis used to examine the spatial distribution of *P. caerulea*, exhibited significant clustered spatial dispersion pattern in spring at the sheltered site (Site 1), and in winter and spring at the exposed site (Site 2) (Table 5).

3.5. Condition Index (C.I.)

Analysis of variance indicated temporal differences in the C.I. (Table 6). Tukey pairwise comparisons between sample means revealed significant temporal differences in the C.I. of the total population between spring (31.36 ± 5.04) and summer (31.45 ± 4.39), in comparison with winter (28.03 ± 4.65) and autumn (28.90 ± 4.78).

Maximal C.I. occurred in April 2017 (32.762 ± 7.38) followed by August (32.143 ± 4.78) and September (32.043 ± 4.54), whereas minimal C.I. occurred in February (26.58 ± 4.47) followed by November (27.425 ± 4.75). Spawning season of *P. caerulea* occurs at the end of summer (Figure 8), indicated by an increase of the C.I. from winter to summer (February to July) and a sudden decrease at the end of summer (September).

Sampling Period	Sites	Population Density (ind/m ² ± SD)	Iδ	X ²	Dispersion Pattern	Significance Level	DF
April	Site 1	55 ± 30.73	1.29	6.18	clustered	ns	9
-	Site 2	177.5 ± 2.56	1.13	8.29	random	ns	9
May	Site 1	122.5 ± 91.6	1.51	24.74	clustered	< 0.05	9
-	Site 2	225 ± 55.3	1.05	4.89	random	ns	9
June	Site 1	132.5 ± 85.8	1.38	19.98	clustered	< 0.05	9
	Site 2	202.5 ± 113.3	1.29	22.8	clustered	< 0.05	9
July	Site 1	115 ± 69.9	1.34	15.31	clustered	ns	9
-	Site 2	152.5 ± 27.5	1.03	1.79	random	ns	9
August	Site 1	175 ± 76.3	1.11	7.71	random	ns	9
Ū	Site 2	165 ± 71.9	1.17	11.27	random	ns	9
September	Site 1	70 ± 30.7	1.18	4.86	random	ns	9
-	Site 2	180 ± 85.6	1.21	14.71	random	ns	9
October	Site 1	105 ± 28.4	1.07	2.76	random	ns	9
	Site 2	105 ± 61.0	1.31	12.76	clustered	ns	9
November	Site 1	85 ± 44.4	1.25	8.35	clustered	ns	9
	Site 2	145 ± 35.0	1.05	3.03	random	ns	9
December	Site 1	157.5 ± 80.0	1.24	14.63	clustered	ns	9
	Site 2	127.5 ± 71.2	1.29	14.59	clustered	ns	9
January	Site 1	102.5 ± 60.6	1.32	12.89	clustered	ns	9
	Site 2	150 ± 60.1	1.15	8.67	random	ns	9
February	Site 1	190 ± 62.6	1.1	7.42	random	ns	9
-	Site 2	95 ± 38.7	1.15	5.68	random	ns	9
March	Site 1	87.5 ± 51.7	1.32	10.99	clustered	ns	9
	Site 2	140 ± 96.9	1.44	23.95	clustered	< 0.05	9
April	Site 1	77.5 ± 36.2	1.20	6.09	random	ns	9
-	Site 2	137.5 ± 71.9	1.25	13.54	random	ns	9

Table 5. Population density (ind/m²) and dispersion pattern of *Patella caerulea* per sampling site and period (SD standard deviation, I δ Morisita index of aggregation, DF degrees of freedom, X² chi-square values corresponding to the statistic obtained with indication of their significance at 95% confidence level).



Figure 8. Temporal variability (95% confidence interval for the mean of each group) in the condition index of *Patella caerulea*.

Source of Variation	DF	MS	F	p
Abundance	3	773.98	34.35	< 0.001
Error	1036	22.53		
Total	1039			

Table 6. ANOVA results of reproductive status of the surveyed *Patella caerulea* population.

3.6. Age Composition

Seven dominant age groups were identified (Figure 9, Table 7). The dominant cohort was the third-year class, with 42% of the total population.



Figure 9. Patella caerulea cohorts identified with modal progression analysis.

Table 7. Population characteristics of the age groups identified for the entire population (mean length, standard deviation, population size, separation index, and population percentage at each age class.

Age Group	Mean Length (mm)	Standard Deviation	Population Size	Separation Index (SI)	Population %
1	11.83	2.220	8	3.370	0.82
2	18.78	1.900	228	2.620	23.41
3	23.13	1.420	408	2.400	41.89
4	26.17	1.110	213	3.930	21.87
5	30.96	1.330	78	3.010	8.01
6	34.62	1.100	28	3.890	2.87
7	40.53	1.940	11	3.370	1.13

3.7. Allometric Relationships

Equations describing the best fit (highest correlation coefficient) between different morphometric characteristics of *P. caerulea* populations throughout the sampling period and their allometric relationships are displayed in Table 8. Comparison of regression lines (Table 8) indicated no significant difference in regression lines of shell length vs. shell width among sampling sites. Significant differences among sampling sites were observed in the slopes of the regression lines of total weight vs. shell length and total weight vs. shell width. Highly significant differences among sampling sites were observed in the slopes of shell weight vs. shell height, shell length vs. shell height, and shell width vs. shell height. Significant differences exhibited in the regression lines are indicative of differences in the growth patterns among studied populations.

Table 8. Allometric equations between shell length (L), shell width (W), shell height (H), and total weight (Wt) of *Patella caerulea* for sampling sites, Site 1 (sheltered) and Site 2 (exposed), during the study. N: number of individuals, R²: coefficient of determination, t-test: statistical significance of the allometric relationship, allometry: allometric relationship between the two variables, slopes (b): statistical comparison between the slopes of the equations, intercepts (a): statistical comparison between the intercepts of the equations, significance level (ns: non-significant, *: p < 0.05, **: p < 0.001).

	Morphometric Relationships						
Sampling Site	Equation	Ν	R ²	t-test	Allometry	Slopes	Intercepts
Site 1	Wt = $0.000083234 \times L^{3.03929}$	520	96.2	ns	Isometry	*	ns
Site 2	$Wt = 0.000133015 \times L^{2.88733}$	520	90.8	ns	Isometry		
Site 1	$Wt = 0.000496301 \times W^{2.65566}$	520	94.6	**	-ve Allometry	*	ns
Site 2	$Wt = 0.000750993 \times W^{2.50773}$	520	89.8	**	-ve Allometry		
Site 1	$Wt = 0.0135219 \times H^{2.48436}$	520	91.5	**	-ve Allometry	**	**
Site 2	$Wt = 0.0291897 \times H^{2.07913}$	520	82.7	**	-ve Allometry	**	
Site 1	$L = 5.72765 \times H^{0.774654}$	520	88.4	**	-ve Allometry	**	**
Site 2	$L = 8.04943 \times H^{0.595556}$	520	76.2	**	-ve Allometry		
Site 1	$L = 1.88689 \times W^{0.855741}$	520	93.2	**	-ve Allometry	na	ns
Site 2	$L = 2.14392 \times W^{0.812553}$	520	90.3	**	-ve Allometry	115	
Site 1	$W = 4.12051 \times H^{0.841331}$	520	87.4	**	-ve Allometry	**	**
Site 2	$W = 6.32293 \times H^{0.612731}$	520	70.6	**	-ve Allometry	-1-1	

4. Discussion

Several studies of rocky coastal communities at temperate latitudes have identified limpets as "keystone" grazers [57] and important structuring agents [58] with numerous functions, including roles as herbivores, as prey for higher trophic-level consumers, and as space occupiers that limit the recruitment of other invertebrates [8,10,59]. Limpets are highly vulnerable because of their restricted habitat and easy access to humans [60], threatened by a number of stressors [61] including habitat degradation [62], overfishing [63], pollution and sedimentation [64,65], eutrophication [66], invasive species [67], and climate change [68], among others. These stressors often act simultaneously [61,69].

4.1. Biometric Relationships

Significant differences were also exhibited on a temporal scale, with smallest values occurring during autumn and largest during spring, possibly attributed to the reproductive cycle of *P. caerulea* in the study area with spawning occurring at the end of summer. In Turkey (Izmir Bay) [41] minimum shell length was reported in autumn ($25.13 \pm 0.77 \text{ mm}$) and maximum in summer ($29.88 \pm 0.87 \text{ mm}$), maximum total weight in summer ($3.92 \pm 0.29 \text{ mm}$) and minimum in fall ($2.85 \pm 0.26 \text{ mm}$). Long-term studies on rocky shores have shown that communities are continually changing, with both rapid inter-annual fluctuations and longer-term trends [70].

P. caerulea biometric relationships exhibited significant differences on a spatial scale, with significantly higher shell height, posterior shell length, total weight and foot weight at the sheltered site, possibly attributed to the variable degree of wave exposure and anthropogenic pressure among sites and density differences.

Several studies support that greater growth in sheltered areas is due to lower densities per unit of grazeable area, meaning higher food availability [71–73]. Shell alterations in gastropods can be induced by environmental and biological factors, such as wave action, salinity, and predatory pressures [74]. Limpets from very exposed sites often appear to be different from specimens living in more sheltered situations [75]. Limpets tend to vary greatly in size, shape, sculpture, and color pattern, because of ecological factors (particularly the relative exposure to wave stress, and the nature of the substratum) [76]. Limpet growth rate and biomass are highly dependent on rates of algal production [77] and the microalgal film coating the rocky shore, consisting predominantly of organic material, diatoms, and cyanobacteria that provide a food supply for microphagous grazers [71].

4.2. Population Density

Population density (135.63 ind/m² ± 41.95) displayed seasonal variation, with highest numbers observed in spring (151.3 ind/m² \pm 23.3) followed by summer (142.9 ind/m² \pm 17.4), winter (127.5 ind/m² \pm 16.2), and autumn (120.8 ind/m² \pm 11.2). Higher abundance was exhibited at the exposed site (Site 2) (153.75 ind/m² \pm 37.0) compared to the sheltered (Site 1) (117.6 ind/m² \pm 39.9), however, it was not statistically significant. In agreement with [71], who concluded that limpet density declines with increasing shelter and [78] who suggested that the overall density of *P. vulgata* declines as shelter increases, a possible direct result of predatory activity, since heavy wave action can limit the activity of predators and grazers at exposed sites [79,80]. Patellid limpets are consumed by a wide variety of predators including fish [81], octopi [82], crabs [83], other gastropods [84], starfish [85], birds [86], and humans [87]. It has been suggested [88] that predation is an important factor controlling limpet abundance on the lower shore. Taking into consideration that limpets have annual recruitment, yearly effects of predation could be quite substantial. Predators have been shown to regulate the abundance of juvenile mussels on rocky shores in New Zealand [28] and predation by crabs in the U.K. can influence the diversity of intertidal prey assemblages [29]. Predators can be significantly more abundant on sheltered than on exposed shores [89] resulting in greater direct and indirect effects of predation on sheltered shores.

Several studies reported higher densities of *Patella* sp. in exposed areas, inversely related to body size and reproductive investment [71,78,90]. It has been suggested [90] that the density of *Patella* populations is determined by the balance between recruitment and survival. According to the intraspecific variability among populations of *P. vulgata*, abundance differences might be related to the aggregation of specimens in relation to trophic resources or use of habitat, being indifferent whether they are on rocky shores or artificial seawalls [91].

Variations in the density of *Patella* spp. have been observed in areas with different degrees of wave exposure [71,90]. According to Casal et al. [2] the estimated average densities of *P. vulgata* and *P. depressa* were lower in sheltered than in exposed areas. In contrast no differences were observed in the density of limpets between sheltered and exposed sites in Scotland [92].

4.3. Distribution Pattern

Clustered spatial distribution pattern was indicated for *P. caerulea* in spring at the sheltered site and in winter and spring at the exposed site, possibly a consequence of recruitment. Recruitment of *Patella* is lower in sheltered areas [72,73], which is attributed to lower connectivity or poorer conditions for settlement [93]. Habitat physical characteristics may have a great influence in processes such as recruitment, competition, and predation, which, in turn, affect the structure of populations [94,95]. Changes in the spatial distribution of organisms can have implications for all parts of an ecosystem, biotic and abiotic. Clustering, dispersion, or spatially random patterns of individuals may be evidence of either an endogenous biological or ecological process or a response to environmental variation or environmental change [96]. The importance of several abiotic factors affecting the settlement and recruitment of benthic organisms (orientation of the substratum, texture, current regime, sediment load, light attenuation/depth, and water quality and nutrient level) has been pointed out [97]. Differences in substratum preferences in *P. caerulea* and *P. ulyssiponensis*, such that larvae of both species settled preferably on sedimentary rocks rather than on igneous ones have been identified [98].

4.4. Condition Index

Spawning of *P. caerulea* occurs during the end of summer, which is indicated by an increase of the C.I. from winter to summer (February to July) and a sudden decrease at the end of summer (September). The highest C.I. can signify the period before spawning in gastropods, water temperature can also affect both the index and reproduction of *Patella* species [99]. *P. caerulea* is a hermaphrodite protandric species and along the southwestern coast of Italy spawning occurs from autumn to spring [100].

In Turkey (Izmir) maximum C.I. of *P. caerulea* occurs during winter (41.20 ± 1.18) and minimum in fall (30.46 ± 1.54) [41]. Significant temporal differences of the condition index were exhibited, with summer displaying the largest difference. In Tunisia maturation began in August/September in both sexes for *P. caerulea*. Male, spawning took place between March and August 2006 and between April and June. Female spawning took place between April and July. A secondary spawning was observed in January for both sexes [101]. It has been reported [102] that limpets spawn in winter (November, January, February, March) in south eastern Australia, whereas in Adriatic Sea the reproductive cycle of *P. rustica* is between November and December [36].

4.5. Age Composition

Seven cohorts were identified with the dominant cohort in the third-year class, with roughly 42% of the total population. Growth and longevity of *P. vulgata* are directly related to habitat with limpets under the shelter of fucoids growing rapidly but may live only 2–3 years, whereas those on bare rock grow slowly but live up to 15–17 years [78,90,99]. Such differences in life history pattern due to local environmental conditions may drive spatial variability in the duration of such cycles.

4.6. Allometric Relationships

Significant negative allometric relationships exhibited in the morphometric characteristics of the populations, indicated differences in growth patterns, with the tendency of *P. caerulea* to grow in weight, faster than in width and height and in length and width, faster than in height. Significant differences in growth patterns among the studied populations were indicated possibly because of variable degree of exposure of the sampling sites. *Patella* species show substantial morphological variability possibly attributed to environmental variation [16,18,22,103].

A curvilinear function of shell length vs. shell height was reported by [75] for *Patella* sp. In Portugal, by [16] for *P. ulyssiponensis* and *P. vulgata* in the UK, and by [104] for *P. ulyssiponensis* and *P. caerulea* in southern Spain. Power regression equations (curvilinear) in three sites in Tunisia with significant negative allometric relationships for *P. caerulea* describing the relationships of shell length vs. shell height, shell length vs. shell width, and shell width vs. shell height were reported [40]. In western Algeria [105] *P. rustica* exhibited similar curvilinear negative allometric regression equations, describing the relationships between shell length, shell height, and total weight.

Rocky intertidal communities are sensitive to the effects of anthropogenic disturbance. Common forms of disturbance range from indirect (often chronic) agents, such as sewage and industrial effluent [106], to more direct agents, such as harvesting and development [107–110]. These impacts have led to decreased biomass, decreased species richness, and shifts in community composition worldwide [106,107,111,112]. Identification of the simultaneous effects of multiple human-induced threats is one of the major challenges in modern ecology [69,113] directly affecting biodiversity. All stressors have the potential to cause important changes in population and/or assemblage dynamics and their effects need to be reduced [114,115].

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References

- Niu, C.; Nakao, S.; Goshima, S. Growth, population age structure and mortality of the limpet *Collisella heroldi* (DUNKER, 1861) (gastropoda: acmaeidae) in an intertidal rocky shore, in Southern Hokkaido. *Bull. Jpn. Soc. Sci. Fish.* 1992, *58*, 1405–1410. [CrossRef]
- 2. Casal, G.; Aceña-Matarranz, S.; Fernández-Márquez, D.; Fernández, N. Distribution and abundance patterns of three coexisting species of *Patella* (Mollusca Gastropoda) in the intertidal areas of the NW Iberian Peninsula: Implications for management. *Fish. Res.* **2018**, *198*, 86–98. [CrossRef]
- Jenkins, S.R.; Coleman, R.A.; Della Santina, P.; Hawkins, S.J.; Burrows, M.T.; Hartnoll, R.G. Regional scale differences in the determinism of grazing effects in the rocky intertidal. *Mar. Ecol. Prog. Ser.* 2005, 287, 77–86. [CrossRef]
- 4. Coleman, R.; Hawkins, S.; Wood, H. Testing the reproductive benefits of aggregation: The limpet *Patella vulgata* shows no evidence of synchrony in gonad development. *Mar. Ecol. Prog. Ser.* **2006**, 306, 201–207. [CrossRef]
- Coleman, R.A.; Underwood, A.J.; Benedetti-Cecchi, L.; Aberg, P.; Arenas, F.; Arrontes, J.; Castro, J.; Hartnoll, R.G.; Jenkins, S.R.; Paula, J.; et al. A continental scale evaluation of the role of limpet grazing on rocky shores. *Oecologia* 2006, 147, 556–564. [CrossRef] [PubMed]
- 6. Moore, P.; Thompson, R.C.; Hawkins, S.J. Effects of grazer identity on the probability of escapes by a canopy-forming macroalga. *J. Exp. Mar. Biol. Ecol.* **2007**, 344, 170–180. [CrossRef]
- Prusina, I.; Peharda, M.; Ezgeta-Balić, D.; Puljas, S.; Glamuzina, B.; Golubić, S. Life-history trait of the Mediterranean keystone species *Patella rustica*: Growth and microbial bioerosion. *Mediterr. Mar. Sci.* 2015, 16, 393–401. [CrossRef]
- 8. Branch, G.M. The biology of limpets: Physical factors, energy flow, and ecological interactions. *Oceanogr. Mar. Biol. Annu. Rev.* **1981**, *19*, 235–380.
- 9. Branch, G.M. Limpets: Their role in littoral and sublittoral community dynamics. In *The Ecology of Rocky Coast*; Moore, P.G., Seed, R., Eds.; Columbia University Press: New York, NY, USA, 1985; pp. 97–116.
- Hawkins, S.; Hartnoll, R. Grazing of intertidal algae by marine invertebrates. *Oceanogr. Mar. Biol. Annu. Rev.* 1983, 21, 195–282.
- 11. Menge, B.A.; Berlow, E.L.; Blanchette, C.A.; Na-varrete, S.A.; Yamada, S.B. The keystone species concept: Variation in interaction strength in a rocky intertidal habitat. *Ecol. Monogr.* **1994**, *64*, 249–286. [CrossRef]
- 12. Menge, B.A. Top-down and bottom-up community regulation in marine rocky intertidal habitats. *J. Exp. Mar. Biol. Ecol.* **2000**, 250, 257–289. [CrossRef]
- Arrontes, J.; Arenas, F.; Fernández, C.; Rico, J.M.; Oliveros, J.; Martínez, M.; Viejo, R.M.; Alvarez, D. Effect of grazing by limpets on mid-shore species assemblages in northern Spain. *Mar. Ecol. Prog. Ser.* 2004, 277, 117–133. [CrossRef]
- 14. Bouzaza, Z.; Mezali, K. Discriminant-based study of the shell morphometric relationships of *Patella caerulea* (Gastropoda: Prosobranchia) of the western Mediterranean Sea. *Turk. J. Zool.* **2018**, *42*, 513–522. [CrossRef]
- 15. Bannister, J.V. Shell parameters in relation to zonation in Mediterranean limpets. *Mar. Biol.* **1975**, *31*, 63–67. [CrossRef]
- 16. Davies, P.S. Effect of environment on metabolic activity and morphology of Mediterranean and British species of *Patella*. *Pubbl. Stn. Zool. Napoli* **1969**, *37*, 641–656.
- 17. Šimunović, A. Ecological study of Prosobranchiata (Gastropoda) in the eastern part of the Adriatic Sea and their relationship to benthic biocenosis. *Acta Adriat*. **1995**, *36*, 3–162.
- 18. Mauro, A.; Arculeo, M.; Parrinello, N. Morphological and molecular tools in identifying the Mediterranean limpets *Patella caerulea*, *Patella aspera* and *Patella rustica*. J. Exp. Mar. Biol. Ecol. **2003**, 295, 131–143. [CrossRef]
- 19. Christiaens, J. Révision du genre Patella (Mollusca, Gastropoda). *Bull. Mus. Hist. Nat.* **1973**, *182*, 1305–1392. (In French)
- 20. Frenkiel, L. Contribution à l'étude des cycles de reproduction des Patellidae en Algérie. *Pubbl. Staz. Zool. Napoli* **1975**, *39*, 153–189.
- 21. Beaumont, A.R.; Wei, J.H.C. Morphological and genetic variation in the antartic limpet *Nacella concinna* (Strebel, 1908). *J. Molluscan Stud.* **1991**, *57*, 443–450. [CrossRef]
- 22. Nolan, C.P. Size, shape, and shell morphology in the Antarctic limpet *Nacella concinna* at Signy Island, South Orkney Islands. *J. Molluscan Stud.* **1991**, *57*, 225–238. [CrossRef]

- 23. Corte-Real, H.B.S.M.; Hawkins, S.J.; Thorpe, J.P. Population differentiation and taxonomic status of the exploited limpet *Patella candei* in the Macaronesian islands (Azores, Madeira, Canaries). *Mar. Biol.* **1996**, 125, 141–152. [CrossRef]
- 24. Christofoletti, R.A.; Takahashi, C.K.; Oliveira, D.N.; Flores, A.A.V. Abundance of sedentary consumers and sessile organisms along the wave exposure gradient of subtropical rocky shores of the south-west Atlantic. *J. Mar. Biol. Assoc. UK* **2011**, *91*, 961–967. [CrossRef]
- 25. Prusina, I.; Sarà, G.; De Pirro, M.; Dong, J.W.; Han, G.D.; Glamuzina, B.; Williams, G.A. Variations in physiological responses to thermal stress in congeneric limpets in the Mediterranean Sea. *J. Exp. Mar. Biol. Ecol.* **2014**, 456, 34–40. [CrossRef]
- 26. Battelli, C. Morphometric characteristics, vertical distribution and density of the limpet Patella caerulea L. in relation to different substrata of the bay of Koper (Gulf of Trieste, northern Adriatic). *Ann. Ser. Hist. Nat. Koper* **2016**, *26*, 145–156.
- 27. Coleman, R.A. Limpet aggregation does not alter desiccation in the limpet *Cellana tramoserica*. J. Exp. Mar. Biol. Ecol. **2010**, 386, 113–118. [CrossRef]
- 28. Rilov, G.; Schiel, D.R. Trophic linkages across seascapes: Subtidal predators limit effective mussel recruitment in rocky intertidal communities. *Mar. Ecol. Prog. Ser.* **2006**, 327, 83–93. [CrossRef]
- 29. Griffin, J.N.; De la Haye, K.L.; Hawkins, S.J.; Thompson, R.C.; Jenkins, S.R. Predator diversity and ecosystem functioning: Density modifies the effect of resource partitioning. *Ecology* **2008**, *89*, 298–305. [CrossRef] [PubMed]
- 30. Bacci, G.; Sella, G. Correlations between characters and environmental conditions in *Patella* of the *caerulea* group. *Pubbl. Staz. Zool. Napoli* **1970**, *38*, 1–24.
- 31. Guerra, M.T.; Gaudencio, M.J. Aspects of the ecology of *Patella* spp. on the Portuguese coast. *Hidrobiología* **1986**, 142, 57–69. [CrossRef]
- 32. Della Santina, P.; Sonni, C.; Sartoni, G.; Chelazzi, G. Food availability and diet composition of three coexisting Mediterranean limpets (*Patella* spp.). *Mar. Biol.* **1993**, *116*, 87–95. [CrossRef]
- 33. Navarro, P.G.; Ramirez, R.; Tuya, F.; Fernandez-Gil, C.; Sanchez-Jerez, P.; Haroun, R.J. Hierarchical analysis of spatial distribution patterns of patellid limpets in the Canary Islands. *J. Molluscan Stud.* **2005**, *71*, 67–73. [CrossRef]
- 34. Espinosa, F.; Guerra-García, J.M.; Fa, D.; García-Gómez, J.C. Effects of competition on an endangered limpet *Patella ferruginea* (Gastropoda: Patellidae): Implications for conservation. *J. Exp. Mar. Biol. Ecol.* **2006**, 330, 482–492. [CrossRef]
- 35. Cabral, J. Shape and growth in European Atlantic *Patella* limpets (Gastropoda, Mollusca). Ecological implications for survival. *Web Ecol.* **2007**, *7*, 11–21. [CrossRef]
- 36. Prusina, I.; Ezgeta-Balić, D.; Ljubimir, S.; Dobroslavić, T.; Glamuzina, B. On the reproduction of the Mediterranean keystone limpet *Patella rustica*: Histological overview. *JMBA* **2014**, *94*, 1651–1660. [CrossRef]
- 37. Ocana, T.M.J. An Investigation into the Ecology and Life History Dynamics of the Pulmonate Limpet *Siphonaria pectinata* (L.) at Gibraltar. Unpublished Ph.D. Thesis, King's College, London, UK, 1997.
- 38. Ruitton, S.; Francour, P.; Boudouresque, C.F. Relationships between algae, benthic herbivorous invertebrates and fishes in rocky sublittoral communities of a temperate sea (Mediterranean). *Estuar. Coast. Shelf Sci.* **2000**, *50*, 217–230. [CrossRef]
- Espinosa, F.; Guerra-García, J.M.; Fa, D.; García-Gómez, J.C. Aspects of reproduction and their implications for the conservation of the endangered limpet, *Patella ferruginea*. *Invertebr. Reprod. Dev.* 2006, 49, 85–92. [CrossRef]
- 40. Belkhodja, H.; Romdhane, M.S. Etude morphométrique du mollusque gastéropode "Patella caerulea Linnaeus", 1758 des côtes nord de la Tunisie. Bulletin de l'Institut National des Sciences et Technologies de la Mer 2012, 39, 15–23.
- 41. Küçükdermenci, A.; Aynur, L.Ö.K.; Kirtik, A.; Kurtay, E. The meat yield variations of *Patella caerulea* (Linnaeus, 1758) in Urla, Izmir Bay. *Acta Biol. Turc.* **2017**, *30*, 174–177.
- 42. Triantafyllou, G.; Petihakis, G.; Dounas, C.; Theodorou, A. Assessing marine ecosystem response to nutrient inputs. *Mar. Pollut. Bull.* **2001**, *43*, 175–186.
- 43. Friligos, N. Eutrophication assessment in Greek coastal waters. *Toxicol. Environ. Chem.* **1987**, *15*, 185–196. [CrossRef]

- Korres, G.; Triantafyllou, G.; Petihakis, G.; Raitsos, D.E.; Hoteit, I.; Pollani, A.; Tsiaras, K. A data assimilation tool for the Pagasitikos Gulf ecosystem dynamics: Methods and benefits. *J. Mar. Syst.* 2012, 94, 102–117. [CrossRef]
- 45. Petihakis, G. Triantafyllou, G.; Pollani, A.; Koliou, A.; Theodorou, A. Field data analysis and application of a complex water column biogeochemical model in different areas of a semi enclosed basin: Towards the development of an ecosystem management tool. *Mar. Environ. Res.* **2005**, *59*, 493–518. [CrossRef]
- 46. Petihakis, G.; Triantafyllou, G.; Korres, G.; Pollani, A.; Theodorou, A. Ecosystem modeling: Towards the development of a management tool for a marine coastal system: Part I: General circulation, hydrological and dynamical structure. *J. Mar. Syst.* **2012**, *94*, 34–48. [CrossRef]
- 47. Bakus, G.J. Quantitative Ecology and Marine Biology; Balkema: Rotterdam, The Netherlands, 1990; 157p.
- 48. Underwood, A.J. *Experiments in Ecology. Their Logical Design and Interpretation Using Analysis of Variance;* Cambridge University Press: Cambridge, UK, 1997.
- 49. Morisita, M. Measuring of the Dispersion of individuals and analysis of the distributional patterns. *Mem. Fac. Sci. Kyushu Univ. Ser.* **1959**, *3*, 65–80.
- 50. Elliott, J.M. *Some Methods for the Statistical Analysis of Samples of Benthic Invertebrates*, 2nd ed.; Freshwater Biological Association: Toulouse, France, 1977; 156p.
- 51. Morisita, M. Iδ-Index, a measure of dispersion of individuals. Res. Popul. Ecol. 1962, 4, 1–7. [CrossRef]
- 52. Dale, M.R.T.; Dixon, P.; Fortin, M.J.; Legendre, P.; Myers, D.E.; Rosenberg, M.S. Conceptual and mathematical relationships among methods for spatial analysis. *Ecography* **2002**, *25*, 558–577. [CrossRef]
- 53. Nakhlé, K.F.; Cossa, D.; Khalaf, G.; Beliaeff, B. *Brachidontes variabilis* and *Patella* sp. as quantitative biological indicators for cadmium, lead and mercury in the Lebanese coastal waters. *Environ. Pollut.* 2006, 142, 73–82.
- 54. Bhattacharya, C.G. A simple method of resolution of a distribution into Gaussian components. *Biometrics* **1967**, 23, 115–134. [CrossRef]
- 55. Gayanilo, F.; Sparre, P.; Pauly, D. *The FiSAT User's Guide, FAO Computerized Information Series Fisheries, 99;* ICLARM, DIFMAR: Rome, Italy, 1995.
- 56. Pauly, D.; Caddy, J.F. A Modification of Bhattacharya's Method for the Analysis of Mixtures of Normal Distributions. FAO Fisheries Circular; Food and Agricultural Organization of the United Nations: Rome, Italy, 1985; 16p.
- 57. Power, M.E.; Tilman, D.; Estes, J.A.; Menge, B.A.; Bond, W.J.; Mills, L.S.; Daily, G.; Castilla, J.C.; Lubchenco, J.; Paine, R.T. Challenges in the quest for keystones. *Bioscience* **1996**, *46*, 609–620. [CrossRef]
- Lindberg, D.R.; Estes, J.A.; Warheit, K.I. Human influences on trophic cascades along rocky shores. *Ecol. Appl.* 1998, *8*, 880–890. [CrossRef]
- 59. Underwood, A.J. The ecology of intertidal gastropods. Adv. Mar. Biol. 1979, 16, 111-210.
- 60. Nakin, M.D.V.; McQuaid, C.D. Marine reserve effects on population density and size structure of commonly and rarely exploited limpets in South Africa. *Afr. J. Mar. Sci.* **2014**, *3*, 1–9. [CrossRef]
- 61. Halpern, B.S.; Walbridge, S.; Selkoe, K.A.; Kappel, C.V.; Micheli, F.; D'Agrosa, C.; Bruno, J.F.; Casey, K.S.; Ebert, C.; Fox, H.E.; et al. A global map of human impact on marine ecosystems. *Science* **2008**, *319*, 948–952. [CrossRef] [PubMed]
- 62. Gray, J.S. Marine biodiversity: Patterns, threats and conservation needs. *Biodivers. Conserv.* **1997**, *6*, 153–175. [CrossRef]
- 63. Jackson, J.B.C.; Kirby, M.X.; Berger, W.H.; Bjorndal, K.A.; Botsford, L.W.; Bourque, B.J.; Bradbury, R.H.; Cooke, R.; Erlandson, J.; Estes, J.A.; et al. Historical overfishing and the recent collapse of coastal ecosystems. *Science* 2001, 293, 629–638. [CrossRef] [PubMed]
- 64. Thompson, R.C.; Crowe, T.P.; Hawkins, S.J. Rocky intertidal communities: Past environmental changes, present status and predictions for the next 25 years. *Environ. Conserv.* **2002**, *29*, 168–191. [CrossRef]
- Henriques, P.; Delgado, J.; Sousa, R. Patellid Limpets: An Overview of the Biology and Conservation of Keystone Species of the Rocky Shores; Ray, S., Ed.; Intech, Organismal and Molecular Malacology: Rijeka, Croatia, 2017; pp. 71–95.
- 66. Diaz, R.J.; Rosenberg, R. Spreading dead zones and consequences for marine ecosystems. *Science* 2008, 321, 926–929. [CrossRef] [PubMed]
- 67. Molnar, J.L.; Gamboa, R.L.; Revenga, C.; Spalding, M.D. Assessing the global threat of invasive species to marine biodiversity. *Front. Ecol. Environ.* **2008**, *6*, 485–492. [CrossRef]

- Poloczanska, E.S.; Babcock, R.C.; Butler, A.; Hobday, A.; Hoegh-Guldberg, O.; Kunz, T.J.; Matear, R.; Milton, D.A.; Okey, T.A.; Richardson, A.J. *Climate Change and Australian Marine Life, Oceanography and Marine Biology*; Crc Press-Taylor & Francis Group: Boca Raton, FL, USA, 2007; Volume 45, pp. 407–478.
- 69. Crain, C.M.; Kroeker, K.; Halpern, B.S. Interactive and cumulative effects of multiple human stressors in marine systems. *Ecol. Lett.* **2008**, *11*, 1304–1315. [CrossRef]
- Little, C.; Trowbridge, C.D.; Pilling, G.M.; Stirling, P.; Morritt, D.; Williams, G.A. Long-term fluctuations in intertidal communities in an Irish sea-lough: Limpet-fucoid cycles. *Estuar. Coast. Shelf Sci.* 2017, 196, 70–82. [CrossRef]
- 71. Jenkins, S.R.; Hartnoll, R.G. Food supply, grazing activity and growth rate in the limpet *Patella vulgata* L.: A comparison between exposed and sheltered shores. *J. Exp. Mar. Biol. Ecol.* **2001**, 258, 123–139. [CrossRef]
- 72. Fernández, N.; Alborés, I.; Aceña-Matarranz, S. Characterization of the reproductive cycle and physiological condition of *Patella vulgata* in the NW of the Iberian Peninsula: Relevant in-formation for a sustainable exploitation. *Fish. Res.* **2015**, *164*, 293–301. [CrossRef]
- 73. Fernández, N.; Alborés, I.; Aceña-Matarranz, S. Spatial variability of the reproductive cycle and physiological condition of *Patella* spp. (Mollusca Gastropoda) in the NW of the Iberian Peninsula: Implications for exploitation. *Fish. Res.* **2016**, *179*, 76–85. [CrossRef]
- 74. Crothers, J.H. Variation in dog-whelk shells in relation to wave action and crab predation. *Biol. J. Linn. Soc.* **1983**, *20*, 85–102. [CrossRef]
- 75. Cabral, J.P.; da Silva, A.C.F. Morphometric analysis of limpets from an Iron-Age shell midden found in northwest Portugal. *J. Archaeol. Sci.* 2003, *30*, 817–829. [CrossRef]
- 76. Powell, W.B. The Patellid limpets of the world (Patellidae). Indo Pac. Mollusca 1973, 3, 75–206.
- 77. Bosman, A.L.; Hockey, P.A.R. Life-history patterns of populations of the limpet *Patella granularis*: The dominant roles of food supply and mortality rate. *Oecologia* **1988**, *75*, 412–419. [CrossRef]
- Thompson, G.B. Distribution and population dynamics of the limpet *Patella vulgata* L in Bantry Bay. *J. Exp. Mar. Biol. Ecol.* **1980**, 45, 173–217. [CrossRef]
- 79. Menge, B.A. Predation intensity in a rocky intertidal community: Effect of an algal canopy, wave action and desiccation on predator feeding rates. *Oecologia* **1978**, *34*, 17–36. [CrossRef]
- 80. Menge, B.A. Predation intensity in a rocky intertidal community: Relationship between predator foraging activity and environmental harshness. *Oecologia* **1978**, *34*, 1–16. [CrossRef] [PubMed]
- 81. Milton, P. Biology of littoral blennid fishes on the coast of south-west England. *J. Mar. Biol. Assoc. UK* **1983**, 63, 223–237. [CrossRef]
- 82. Ambrose, R.F. Effects of octopus predation on motile invertebrates in a rocky subtidal community. *Mar. Ecol. Prog. Ser.* **1986**, *30*, 261–273. [CrossRef]
- 83. Silva, A.C.F.; Boaventura, D.M.; Flores, A.; Ré, P.; Hawkins, S.J. Rare predation by the intertidal crab *Pachygrapsus marmoratus* on the limpet *Patella depressa*. *J. Mar. Biol. Assoc. UK* **2004**, *84*, 367–370. [CrossRef]
- 84. Black, R. Tactics of whelks preying on limpets. Mar. Biol. 1978, 46, 157–162. [CrossRef]
- 85. Markowska, M.; Kidawa, A. Encounters between Antarctic limpets, *Nacella concinna*, and predatory sea stars, *Lysasterias* sp., in laboratory and field experiments. *Mar. Biol.* **2007**, *151*, 1959–1966. [CrossRef]
- 86. Bosman, A.; Hockey, P.A.R. Oystercatcher predation and limpet mortality: The importance of refuges in enhancing the reproductive output of prey populations. *Veliger* **1989**, *32*, 120–129.
- 87. Weber, L.; Hawkins, S. Evolution of the limpet *Patella candei d'Órbigny* (Mollusca, Patellidae) in Atlantic archipelagos: Human intervention and natural processes. *Biol. J. Linn. Soc.* **2002**, *77*, 341–353. [CrossRef]
- Silva, A.C.F.; Hawkins, S.J.; Boaventura, D.M.; Thompson, R.C. Predation by small mobile aquatic predators regulates populations of the intertidal limpet *Patella vulgata* (L.). *J. Exp. Mar. Biol. Ecol.* 2008, 367, 259–265. [CrossRef]
- 89. Silva, A.C.F. Predation by Crabs on Rocky Shores in North-East Atlantic. Biological Sciences. Ph.D. Thesis, University of Plymouth, Plymouth, UK, 2008; p. 220.
- 90. Lewis, J.R.; Bowman, R. Local habitat-induced variations in the population dynamics of *Patella vulgata* L. *J. Exp. Mar. Biol. Ecol.* **1975**, *17*, 165–203. [CrossRef]
- 91. Diaz-Agras, G.; Moreira, J.; Tato, R.; Garcia-Regueira, X.; Urgorri, V. Distribution and population structure of *Patella vulgata* Linnaeus, 1758 (Gastropoda: Patellidae) on intertidal seawalls and rocky shores in the Ria De Ferrol (Galicia, NW Iberian Peninsula). *Thalassas* **2010**, *26*, 79–91.

- 92. Holmes, S.P.; Walker, G.; Van der Meer, J. Barnacles, limpets and periwinkles: The effects of direct and indirect interactions on cyprid settlement and success. *J. Sea Res.* **2005**, *53*, 181–204. [CrossRef]
- 93. Bowman, R.S.; Lewis, J.R. Geographical variation in the breeding cycles and recruitment of *Patella* spp. *Hydrobiologia* **1986**, *142*, 41–56. [CrossRef]
- 94. McGuinness, K.A. Effects of some natural and artificial substrata on sessile marine organisms at Galeta Reef, Panama. *Mar. Ecol. Prog. Ser.* **1989**, *52*, 21–28. [CrossRef]
- Underwood, A.J.; Chapman, M.G. Experiments on Topographic Influences on Density and Dispersion of Littorina unifasciata in New South Wales. In Proceedings of the Third International Symposium on Littorinid Biology, The Malacological Society of London, London, UK, 30 August–5 September 1992; pp. 181–195.
- 96. Hayes, J.J.; Castillo, O. A new approach for interpreting the Morisita index of aggregation through quadrat size. *ISPRS Int. J. Geo Inf.* **2017**, *6*, 296. [CrossRef]
- 97. Perkol-Finkel, S.; Benayahu, Y. Differential recruitment of benthic communities on neighboring artificial and natural reefs. *J. Exp. Mar. Biol. Ecol.* **2007**, 340, 25–39. [CrossRef]
- 98. Coll, R.C.; Ortuño, P.M.; Aldeguer, M.D.P.; Berenguer, M.L.P.; Carratalá, E.S.; Sánchez-Jerez, P. Aportación al conocimiento de las poblaciones de *Patella caerulea* y *P. aspera* en la reserva marina de Tabarca (Alicante): Densidad poblacional y frecuencia de tallas según el tipo de sustrato y grado de presión antrópica. In *Trabajos de Campo en la Reserva Marina de Tabarca (Alicante)*; Universitat d' Alacant/Universidad de Alicante, Secretariado de Publicaciones de la Universidad de Alicante: Murcia, Spain, 1994; pp. 45–52.
- 99. Fretter, V.; Graham, A. The prosobranch molluscs of Britain and Denmark Part I—Pleurotomariacea, Fissurellacea and Patellacea. *J. Molluscan Stud. Suppl.* **1976**, *1*, 1–37.
- Bacci, G. L'inversione del sesso ed il ciclo stagionale della gonade in *Patella caerulea* L. *Pubbl. Staz. Zool. Napoli* 1947, 21, 183–217. (In Italian)
- 101. Belkhodja, H.; Jaafoura, M.H.; Missaoui, H.; Romdhane, M.S. Histological investigation of the reproductive cycle of the limpet *Patella caerulea* Linnaeus, 1758. *Cah. Biol. Mar.* **2011**, *52*, 279–290.
- 102. Parry, G.D. Reproductive effort in four species in intertidal limpets. Mar. Biol. 1982, 67, 267–282. [CrossRef]
- 103. Sella, G. Biometrical relationships between mesolitoral and infralitoral *Patella* population in the Mediterranean. *Pubbl. Staz. Zool. Napoli.* **1976**, *40*, 123–132.
- 104. Munoz, M.A.; Acuna, J.D. On the taxonomic discrimination between *P. aspera* Roding and *P. caerulea* Linnaeus (Gasteropoda: Patellidae) using conchological traits. *J. Conchol.* **1994**, *35*, 37–43.
- 105. Amer, L.A.M.; Benali, I.; Dermeche, S.; Bouderbala, M. Seasonal variations of the biometric indices of *Patella rustica* Linnaeus, 1758 (Gastropoda Patellidae) from contrasted sites of the western Algerian coast. *Biodivers. J.* 2018, *9*, 205–212. [CrossRef]
- 106. Littler, M.M.; Murray, S.N. Impact of sewage on the distribution, abundance and community structure of rocky intertidal macro-organisms. *Mar. Biol.* **1975**, *30*, 277–291. [CrossRef]
- 107. Duran, L.R.; Castilla, J.C. Variation and persistence of the middle rocky intertidal community of central Chile, with and without human harvesting. *Mar. Biol.* **1989**, *103*, 555–562. [CrossRef]
- 108. Underwood, A.J.; Kennelly, S.J. Pilot studies for designs of surveys of human disturbance of intertidal habitats in New South Wales. *Aust. J. Mar. Freshw. Res.* **1990**, *41*, 165–173. [CrossRef]
- 109. Povey, A.; Keough, M.J. Effects of trampling on plant and animal populations on rocky shores. *Oikos* **1991**, *61*, 355–368. [CrossRef]
- 110. Kingsford, M.J.; Underwood, A.J.; Kennelly, S.J. Humans as predators on rocky reefs in New South Wales, Australia. *Mar. Ecol. Prog. Ser.* **1991**, 72, 1–14. [CrossRef]
- 111. Keough, M.J.; Quinn, G.P.; King, A. Correlations between human collecting and intertidal mollusc populations on rocky shores. *Conserv. Biol.* **1993**, *7*, 378–391. [CrossRef]
- Lasiak, T. Multivariate comparisons of rocky infratidal macrofauna assemblages from replicate exploited and non-exploited localities on the Transkei coast of South Africa. *Mar. Ecol. Prog. Ser.* 1998, 167, 15–23. [CrossRef]
- 113. Sala, O.E.; Chapin, F.S.; Armesto, J.J.; Berlow, E.; Bloomfield, J.; Dirzo, R.; Huber-Sanwald, E.; Huenneke, L.F.; Jackson, R.B.; Kinzig, A.; et al. Biodiversity—Global biodiversity scenarios for the year 2100. *Science* 2000, 287, 1770–1774. [CrossRef] [PubMed]

- 114. Paine, R.T. Ecological determinism in the competition for space: The Robert H. MacArthur Award Lecture. *Ecology* **1984**, *65*, 1339–1357. [CrossRef]
- 115. Atalah, J.; Crowe, T.P. Combined effects of nutrient enrichment, sedimentation and grazer loss on rock pool assemblages. *J. Exp. Mar. Biol. Ecol.* **2010**, *388*, 51–57. [CrossRef]



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