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EFFECT OF TIDAL HEIGHT ON GROWTH OF MUSSELS

Sohail Barkati and Yasmeen Choudhry

Institute of Marine Sciences, University of Karachi, Karachi-32

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Growth characteristics of three populations of the green mussels, *Perna viridis*, were studied. Analysis of covariance indicated that mussels occurring at low tidal height or remaining submerged for a long period under water, possessed shells of low weights. Shell length increased faster than height in all populations, but shell width increased faster than length in Buoys mussels reflecting that it is probably the space on the natural beds hindering the growth in shell width of mussels. Relative growth decreased with increasing shell length in all populations.

Key words: Tidal height, Growth, Population.

INTRODUCTION

Growth rate of mussels with reference to their submersion time in sea water is a subject about of which controversial opinions have been expressed in the literature. The effect of tidal height on various growth parameters have been attempted by a number of workers [1-6]. Recently Wallace [7] and Barkati [8] compared the growth rate of various populations of mussels from Norway.

Considering the importance of this aspect of mussel biology for aquaculturists and as a subject of academic interest, an attempt is being made in the present investigation to examine the growth characteristics of the edible green mussel, *Perna viridis*, occurring at different tidal heights.

MATERIAL AND METHODS

Mussels were sampled from three localities of the Karachi coast, namely, Manora rocky shore, Native Jetty bridge, and from the floating Buoys in the Manora Channel. Mussel populations at these localities experience altogether different tidal exposure periods.

Mussels at Manora rocky shore occur at about 0.5 ft. tidal height, facing direct surf action. The mussels are exposed to air for short periods time, 2 hours at the maximum. Native Jetty mussels remain submerged in water much of the time, getting uncovered only at very low tides, the mussel bed lies at about 0.2 ft. tidal level. Mussels on buoys in Manora channel are least affected with changes in tidal level as the buoys move up and down with the tides; the mussels, therefore remain submerged all the time. From 97 to 113 mussels from each site were used, ranging in shell length from 0.8 to 11.35 cm.

The following dimensions of the mussel shells were measured after removing the encrusted organisms: length (antero posterior axis), height (dorso ventral axis), width (lateral axis). All measurements were made using dial caliper with 0.05 mm precision. Mussels were dissected open to obtain wet tissue weight. Tissues and empty shells were dried to a constant weight at 70^{o} and the weight recorded to the nearest 0.01 gram.

Relationships between various growth parameters were studied by testing each pair of variables y and x for their fit to the allometric equation $Y = a\ x^{b}$, where a and b are constants. These contants were estimated by least squares regression. In order to compare the variability of different parameters between mussel populations of three sites, coefficients of variation were calculated. The coefficient of variation is defined as the standard deviation expressed as percentages of the means. The condition index of mussels is defined, in the present study, as the proportion of dry tissue weight to total weight (dry shell + dry tissue).

The data was transferred on to a floppy disk using TSP statistical package. All computations regarding analysis of regression parameters such as constants (a,b), correlation coefficients, 95 percent confidence interval, ratios between various shell and tissue dimensions, were carried out on an IBM compatible computer (Mitac-MPC 160S).

EXPERIMENTS

The mussel *Perna viridis* occurs at several locations on the coast of Sind and Baluchistan. Barkati and Ahmed [9] studied the seasonal changes in gonadal development of *P. viridis* and provided information regarding spawning periodicity of species. The mussel is dioecious; it seems to spawn during the September-October period with the likelihood that individual specimens might be spawning any time during the year.

Regression parameters describing various shell and tissue relationships are given in Tables 1–3. Results of allometric studies for various growth parameters are mentioned below.

Shell height. A negative allometric relationship was found between shell length and height in the three mussel populations studied. At-test for the coefficient of allometry (slope) showed that the two variables are not related isometrically which means that shell length grows faster than height.

Changes in ratios of shell length to height are shown in Fig. 1. The ratios increased as the length of the mussels increased, indicating a greater rate of growth in length compared to height.

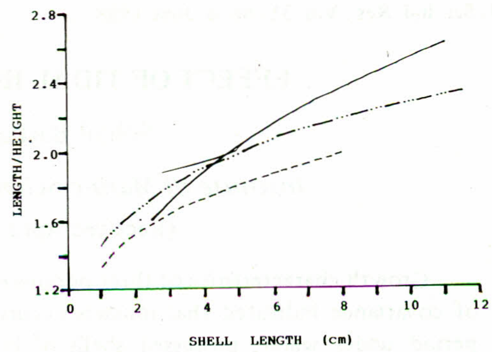

Fig. 1. Relationship between shell length and ratio of length to height in three populations of muussels.
— Manora shore, — Native Jetty, – Buoys.

Table 1. Regression coefficients for various parameters in Buoys mussels,

Dependent variable	Independent variable	Sample size	log a	95% C.I of log a	b	95% C.I of b	r^2
Height	Length	113	–0.178	0.08	0.672	0.04	0.91
Width	Length	113	–0.929	0.10	0.920	0.05	0.91
Width	Height	113	–0.578	0.10	1.277	0.09	0.87
Shell weight	Length	113	–2.601	0.17	2.559	0.08	0.97
Dry tissue weight	Length	78	–4.026	0.44	2.106	0.22	0.82
Wet tissue weight	Length	78	–3.507	0.52	2.570	0.27	0.82
Water weight	Length	78	–4.368	0.81	2.85	0.41	0.70
Height/length	Length	113	–0.178	0.08	–0.327	0.04	0.70
Width/length	Length	113	–0.929	0.10	–0.079	0.05	0.07
Width/height	Length	113	–0.750	0.11	0.248	0.05	0.39
Condition index index	Length	78	–1.615	0.42	–0.410	0.21	0.15

Table 2. Regression coefficients for various parameters in Manora shore mussels,

Dependent variable	Independent variable	Sample size	log a	95% C.I of log a	b	95% C.I. of b	r^2
Height	Length	108	–0.284	0.069	0.805	0.044	0.927
Width	Lenght	108	–0.822	0.075	0.897	0.048	0.929
Width	Height	108	–0.449	0.068	1.054	0.068	0.899
Dry tissue weight	Length	108	–4.069	0.252	2.615	0.160	0.909
Wet tissue weight	Length	108	–3.371	0.204	3.001	0.129	0.953
Water	Length	108	–4.220	0.250	3.324	0.158	0.943
Height/length	Length	108	–0.284	0.069	–0.194	0.044	0.424
Width/length	Length	108	–0.822	0.076	–0.102	0.048	0.146
Width/height	Length	108	–0.538	0.087	0.092	0.055	0.094
Shell weight	Length	108	–2.133	0.264	2.460	0.167	0.89
Condition index	Length	108	–2.054	0.251	0.119	0.159	0.021
Ash weight	Length	108	–2.228	0.714	0.743	0.436	0.112

Table 3. Regression coefficients for various parameters in Native Jetty mussels.

Dependent variable	Independent variable	Sample size	log a	95% C.I. of log a	b	95% C.I. of b	r^2
Height	Length	97	–0.376	0.071	0.803	0.035	0.955
Width	Length	97	–0.750	0.010	0.902	0.053	0.924
Width	Height	97	–0.276	0.094	1.080	0.076	0.895
Shell weight	Length	90	–2.469	0.419	2.582	0.206	0.877
Height/length	Length	97	–0.376	0.071	–0.196	0.035	0.561
Width/length	Length	97	–0.750	0.106	–0.097	0.053	0.124
Width/height	Length	97	–0.373	0.121	0.099	0.061	0.101
Condition index	Length	89	–1.209	0.613	–0.577	0.301	0.145
Dry tissue wet	Length	95	–5.887	0.443	3.13	0.222	0.895
Water weight	Length	90	–4.469	0.418	3.068	0.21	0.906
Wet tissue weight	Lenght	90	–4.221	0.388	3.071	0.195	0.918
Ash weight	Length	93	–2.172	0.748	0.727	0.372	0.143

Shell width. A negative allometry was displayed between shell length and its width in two populations of mussels i.e. Manora shore and Native Jetty, whereas Buoys mussels showed isometric relationship. The coefficient of allometry in this population is not significantly different from the theoritical slope of 1.0 at $P < 0.001$. Shell width and length increased at almost similiar rate.

Figure 2 shows that ratios of shell length to width increased as the shell length increased indicating that length increased faster than width in all populations. However, in mussels from Buoys, rate of increase in shell width is much less compared to other populations.

The results of shell height to shell width relationship are indicative of a positive allometry. The rate of growth in shell width is faster in Buoys mussels whereas in mussels of Native Jetty and Manora shore, growth rate of shell height and width is indentical ($P < 0.001$).

Shell height to width ratios decreased with increasing length of mussels. (Fig. 3). Decrease in ratio is obviously much pronounced in Buoys population. Mussels from Native Jetty have the lowest height/width values for corresponding shell lengths, which means that mussels from Native Jetty possessed relatively greater width. Manora shore mussels have smaller width and those from Buoys showed considerable change with increase in shell length.

The value of unity for the height/width ratio was not observed in any mussel population studied, which means that shell height and width never attained equality in these mussels.

Shell weight. A characteristic exponential relationship exists between the shell length and shell weight of mussels (Fig. 4). Regression analyses indicated that shell length increased faster than shell weight in all populations; values of slopes are significantly less than the isometric value of 3.

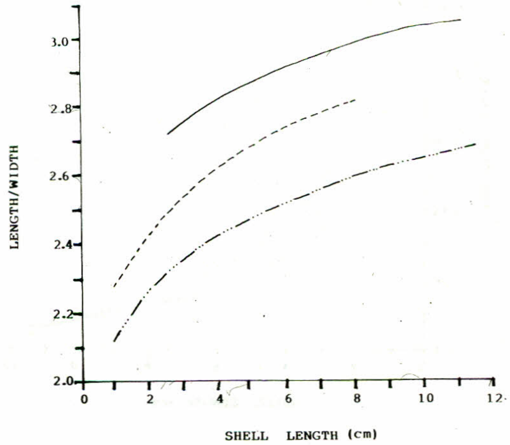

Fig. 2. Relationship between shell length and ratio of length to width in three populations of mussels.
— Manora shore, — Native Jetty, – Buoys.

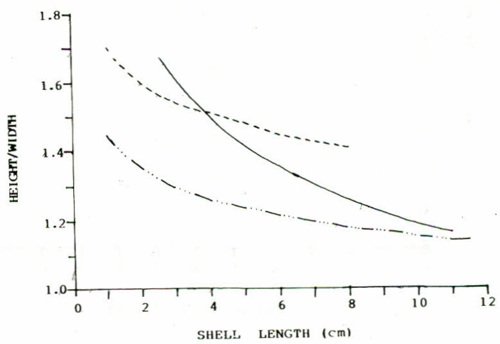

Fig. 3. Relationship between shell length and ratio of height to width in three populations of mussels.
— Manora shore, — Native Jetty, – Buoys.

As expected, relatively faster increase in shell weight was observed in Manora shore mussels. The shells of Buoys mussels were the lightest and those from Native Jetty were in between the two i.e. heavier than Buoys and lighter than Manora shore mussels.

Tissue weight. There exists two trends in the length to dry tissue weight relationship. Shell length increased faster than tissue weight in mussels from Buoys and Manora shore, whereas an isometric relationship occurred in Native Jetty mussles i.e. shell length and tissue weight increased at equal rate (Fig. 5). A comparison of tissue content of similar sized mussels from three localities showed that mussels from Manora possessed the highest tissue weight and the lowest tissue weight was found in Buoys mussels.

Water content. Mussels sampled from Manora shore possesed highest amount of water in tissues (Fig. 6) Mussels of this population showed positive allometry for shell length to tissue water content relationship, indicating faster increase in tissue water content than in shell length. Mussels of Native Jetty and Buoys showed relatively less amount of water and are also isometric in length to water relationship.

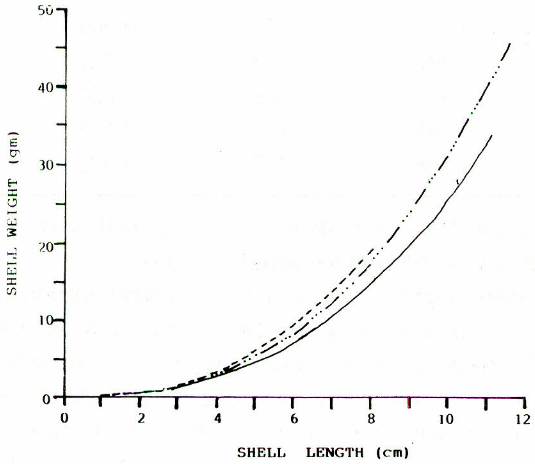

Fig. 4. Relationship between shell length and shell weight in three populations of mussels.
— Manora shore, — Native Jetty, – Buoys.

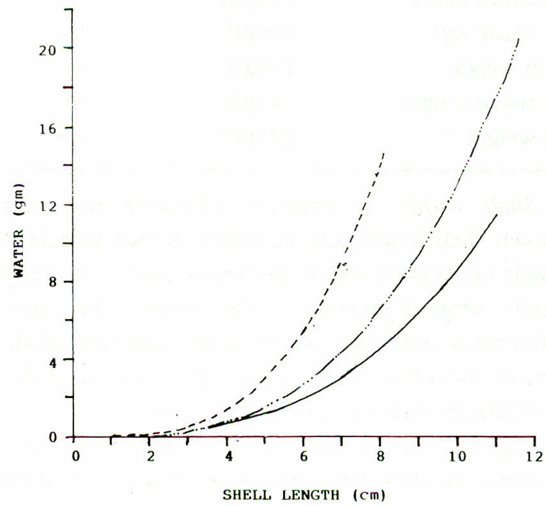

Fig. 6. Relationship between shell length and water content in three populations of mussels.
— Manora shore, — Native Jetty, – Buoys.

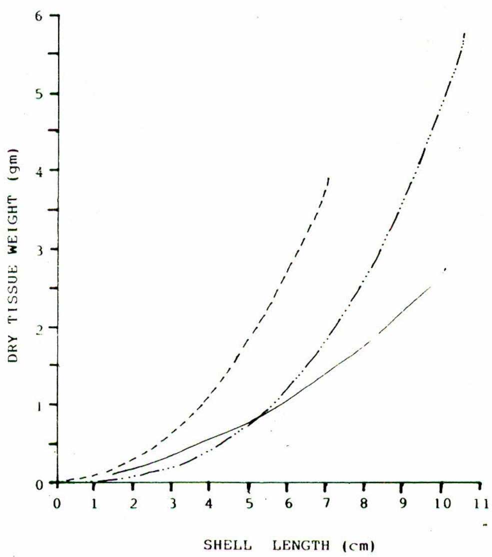

Fig. 5. Relationship between shell length and dry tissue weight in three populations of mussels.
— Manora shore, — Native Jetty, – Buoys.

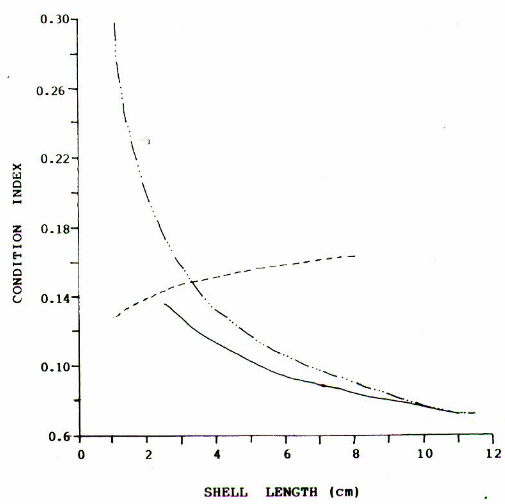

Fig. 7. Relationship between shell length and condition index in three populations of mussels.
— Manora shore, — Native Jetty, – Buoys.

Ash. Ash content of mussels was studied for two populations, Manora shore and Native Jetty. In both cases shell length increased faster than ash weight (negative allometry). No significant difference was found in the rate of increase of ash weight.

Actual and relative increment. Mussels of the three sites were grouped in 5 cm classes. Tables 4–6 shows the actual and percent (relative) increase in various growth parameters (linear and weight) with increasing shell length. A decrease in growth of height was observed in mussels of all populations, and the relative growth in height was also decreased as the length of the mussel increased. Actual growth in shell width remained almost constant in mussels of Buoys, whereas a decrease in growth of width

Table 4. Actual and relative growth in shell and tissue parameters of Buoys mussels.

Size class (cm)	Height		Width		Shell weight		Dry Tissue Weight	
	cm	%	cm	%	gm	%	gm	%
2.5 – 3.0	0.20	12.9	0.166	18.04	0.46	59.70	0.057	46.34
3.0 – 3.5	0.19	10.86	0.164	15.10	0.60	48.78	0.069	38.33
3.5 – 4.0	0.18	9.28	0.165	13.2	0.74	40.44	0.081	32.53
4.0 – 4.5	0.179	8.44	0.165	11.66	0.91	35.41	0.093	28.18
4.5 – 5.0	0.171	7.44	0.16	10.13	1.07	30.75	0.105	24.82
5.0 – 5.5	0.16	6.48	0.157	9.02	1.26	27.69	0.118	22.35
5.5 – 6.0	0.16	6.08	0.159	8.38	1.45	24.96	0.129	19.97
6.0 – 6.5	0.15	5.38	0.154	7.49	1.65	22.73	0.143	18.45
6.5 – 7.0	0.15	5.10	0.16	7.24	1.87	20.99	0.155	16.88
7.0 – 7.5	0.15	4.85	0.156	6.59	2.08	19.29	0.167	15.56
7.5 – 8.0	0.145	4.48	0.154	6.09	2.3	17.88	0.18	14.52
8.0 – 8.5	0.141	4.16	0.151	5.63	2.55	16.82	0.195	13.73
8.5 – 9.0	0.138	3.91	0.153	5.4	2.79	15.75	0.205	12.69
9.0 – 9.5	0.14	3.82	0.154	5.16	3.04	14.83	0.22	12.09
9.5 – 10.0	0.13	3.42	0.15	4.78	3.30	14.02	0.23	11.27
10.0 – 10.5	0.13	3.30	0.15	4.56	3.57	13.30	0.25	11.01
10.5 – 11.0	0.13	3.20	0.15	4.36	3.85	12.66	0.26	10.32

Table 5. Actual and relative growth in shell and tissue parameters in Manora shore mussels.

Size class (cm)	Height		Width		Shell		Dry Tissue	
	cm	%	cm	%	gm	%	gm	%
1.0 – 1.5	.29	38.67	.193	43.96	.203	172.03	0.0319	186.55
1.5 – 2.0	.27	25.96	.186	29.43	.33	102.8	0.056	114.28
2.0 – 2.5	.26	19.85	.181	22.13	.477	73.27	0.083	79.05
2.5 – 3.0	.25	15.92	.181	18.12	.638	56.56	0.114	60.64
3.0 – 3.5	.24	13.18	.17	14.41	.814	46.09	.15	49.67
3.5 – 4.0	.24	11.65	.17	12.59	1.0	38.76	.188	41.59
4.0 – 4.5	.23	10.00	.17	11.18	1.21	33.80	.232	36.26
4.5 – 5.0	.22	8.69	.17	10.06	1.416	29.56	.277	31.77
5.0 – 5.5	.22	8.00	.166	8.95	1.64	26.43	.326	28.37
5.5 – 6.0	.21	7.07	.161	7.93	1.87	23.87	.375	25.42
6.0 – 6.5	.22	6.91	.165	7.53	2.11	21.76	.43	23.24
6.5 – 7.0	.21	6.17	.165	7.01	2.366	19.99	.49	21.49
7.0 – 7.5	.20	5.54	.16	6.35	2.627	18.50	.549	19.82
7.5 – 8.0	.20	5.249	.16	5.97	2.893	17.19	.611	18.41

Table 6. Actual and relative growth in shell and tissue parameters of Native Jetty mussels.

Size class (cm)	Height		Width		Shell cut		Dry tissue	
	cm	%	cm	%	gm	%	gm	%
1.0 – 1.5	.264	38.48	.209	44.28	.155	182.35	0.0071	257.4
1.5 – 2.0	.247	26.00	.201	29.52	.267	111.25	0.014	142.42
2.0 – 2.5	.233	19.47	.197	22.34	.393	77.51	0.025	104.17
2.5 – 3.0	.227	15.87	.193	17.89	.540	60.0	0.037	75.51
3.0 – 3.5	.219	13.22	.19	14.94	.709	49.24	0.054	62.79
3.5 – 4.0	.212	11.30	.187	12.79	.881	40.99	0.073	51.79
4.0 – 4.5	.207	9.91	.185	11.22	1.081	35.58	0.094	44.47
4.5 – 5.0	.203	8.84	.183	9.98	1.285	31.26	0.12	39.09
5.0 – 5.5	.199	7.966	.187	8.97	1.506	27.91	0.149	34.89
5.5 – 6.0	.195	7.23	.180	8.19	1.739	25.196	0.18	31.25
6.0 – 6.5	.188	6.50	.178	7.49	1.984	22.96	0.216	28.57
6.5 – 7.0	.190	6.17	.176	6.89	2.24	21.08	0.253	26.03
7.0 – 7.5	.189	5.78	.176	6.44	2.505	19.47	0.296	24.16
7.5 – 8.0	.187	5.23	.174	5.98	2.79	18.15	0.34	22.35
8.0 – 8.5	.181	4.98	.174	5.65	3.079	16.95	0.389	20.9
8.5 – 9.0	.179	4.69	.172	5.28	3.377	15.90	0.441	19.6
9.0 – 9.5	.176	4.39	.171	4.99	3.688	14.98	0.496	18.43
9.5 – 10.0	.175	4.20	.171	4.75	4.008	14.16	0.555	17.41
10.0 – 10.5	.174	3.99	.170	4.51	4.338	13.43	0.617	16.49
10.5 – 11.0	.172	3.80	.169	4.29	4.678	12.76	0.684	15.69
11.0 – 11.5	.172	3.66	.168	4.09	5.022	12.15	0.752	14.91

Table 7. Coefficients of variation in various growth variables from three localities.

Variables	Native Jetty	Buoys	Manora shore
Shell length	27.64	21.41	28.36
Shell height	23.59	15.58	25.72
Shell width	28.99	21.66	26.77
Dry tissue	51.14	55.66	51.99
Shell weight	53.49	55.55	51.98
Wet tissue	49.05	62.13	55.16
Ash	75.56	–	44.69
Condition index	33.54	24.08	33.04
Water	50.42	64.85	57.27

occurred in mussels of Manora shore and Native Jetty. Relative growth, however, decreased with increase in shell length in all populations.

Actual growth in weights (shell, tissue) increased with increase in shell length. Percentage growth in weights decreased with increase in length of the mussel. For each size class, rates of linear increase were lower compared to shell and tissue weights.

Condition index. Two trends were observed in condition index studies. The condition index decreased as the mussel length increased in mussels of Native Jetty and Buoys, whereas it increased slightly with mussel length in Manora shore mussels (Fig. 7). The condition index values in mussels of smaller length of the three sites are almost the same. Individuals of larger length from Manora shore showed much higher values than the other populations. All three populations showed very low r^2 values for shell length to condition index relationship, indicating a very weak relationship between the two variables.

Coefficient of variation. Variability of various growth parameters in mussels of the three sites are presented in Table 7. Coefficients of variation were calculated for shell length, width, height, weight, tissue weight, ash weight, water weight and condition index. It is evident from the Table that variability displayed by buoys mussels is altogether different from those of Native Jetty and Manora shore mussels. Linear variables (length, width, height) of buoys population are much less variable than those of other two populations, whereas the reverse is true for weight variables (shell, dry tissue, wet tissue, water, ash) which are highly variable in Buoys mussels.

Shell height is found to be the least variable and water content the most variable parameter. It is notable that relative variability for most parameters in mussels from Native Jetty and Manora shore was the same.

DISCUSSION

The present study was initiated under the premise that tidal level could be affecting the growth pattern of mussels facing varying tidal exposures. In the present investigation mussels growing on buoys in the Manora channel remain submerged permanently whereas mussels at Native Jetty are exposed to air only at very low tides and those at Manora rocky shore often get exposed.

Mussels for cultivation are mostly grown off bottom employing floating structures in the sea. These mussels have been found to grow fast and to possess clean and sharp edged shells. Studies on these aspects of growth in Mussels are mostly related to the blue mussel, *Mytilus edulis* [10-16]. Growth of mussels was also shown to vary considerably with the time of submergence [1,4,17,18]. According to Coulthard [2] exposure to air inhibits the growth rate through curtailment of food and oxygen supply in combination with a rise in temperature. Studies on shell shape variation with reference to tidal exposure were carried out by Seed [5] and Barkati [8].

Results of the present investigation are indicative of faster increase in shell length than height in all three populations. Rate of increase in shell width is slower than length in mussels of Manora and Native Jetty, but width increased faster than length in Buoys mussels. Mussels growing on Buoys are thus wider in shape than mussels of Native Jetty and Manora shore.

The mussels at Manora rocky shore live in crevices in a limited area of rocky bottom exposed to ocean surf. The substratum there is pretty hard where mussels usually grow with their anterior end (umbo) downwards. The mussels, therefore finds relatively less space to increase in shell width compared to shell length. The same is true for Native Jetty mussels. On the contrary, mussels living on the buoys are more crowded but did not face the space problem. Seed [5,6] reported faster increase in width relative to height to an extent that in some cases shell width exceed the height. In the present study shell width grows faster than height but never exceeded the height in any population.

Mussels growing on buoys possessed lighter shells, those from Native Jetty are slightly heavier than buoys mussels but shells of Manora shore are the heaviest. The present study supports the findings of Baird and Drinnan [4]. Coe and Fox [19]. Fox and Coe [18] and Seed [6]. who demonstrated that as the time of exposure increased the shell weight also increased. Barkati [8] drew the same conclusion working on several populations of *M. edulis in* Norwegian waters.

Recently Barkati and Khan [20] demonstrated that species of oysters occurring higher in the intertidal area possessed heavier shells when compared with those living low in the tidal zone or those which were uncovered for short periods.

However, views contrary to that mentioned above also exists. Rao [21] found heavier shells in sublittoral mussels (*Mytilus edulis* and *M. californianus*) compared to intertidal ones. Similar conclusions were drawn for oysters by Dame [22] and Wilbur and Jordey [23]. They found that shell weight decreased as the intertidal exposure of mussels increased.

Condition index is generally considered a seasonal phenomenon which is mainly dependent on the spawning season and the nutritive conditions in the environment. The high condition index values of Manora shore mussels during the present study are evidently due to the relatively faster growth of tissue. Although mussels of Native Jetty and Buoys possess light shells, condition index in these mussels decreased with increasing size due to low growth in dry tissue. The results suggest that seasonal observations are required to determine the seasonal changes in condition index.

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