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MORPHOLOGY OF *PHORCUS TURBINATUS* (GASTROPODA) IN THE EASTERN LIBYAN MEDITERRANEAN SEA

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ABSTRACT: *Three hundred and five Phorcus turbinatus collected from the rocky shores of Al-Haneah and Susah, eastern Libya's Mediterranean Sea, were used to establish 15 measured shell-parameters and 18 calculated shell-shape indicators, which were then compared between sites, and related to shell height (HBA) and length of shell base (LB) by regression equations to find out how they vary as the animal grows. Al-Haneah P. turbinatus was larger than Susah's (HBA = 13.729 and 12.818mm consecutively, corresponding to total weights (TW) of 3.766 and 3.179gm). As a result, the majority of Al-Haneah's P. turbinatus measured parameters were of greater magnitude. The exponents "b" of the TW-HBA power regressions indicated negative allometric growth, while that of TW-LB indicated positive allometry. The values of the shell shape indicators of P. turbinatus in both sites were close, the shell apex was tilted to the front and to the left, the shell base was almost circular, the opening was slightly oval, and the operculum was circular. All the measured parameters, and most of the shell-shape indicators, increased with growth.*

KEYWORDS: Phorcus turbinatus, Monodonta turbinata, morphometry, shell shape, Mediterranean Sea

INTRODUCTION

Morphological traits are the morphogenic (descriptive), morphometric, and meristic bodily characteristics of a living organism (Mohammed, 2018). Descriptive traits are the immeasurable and uncountable features such as body shape, orientation, and color; morphometric traits are the measurable parameters such as total weight and body length; meristic traits are countable parameters such as the number of whorls and dentition of a gastropod shell. Morphometry is very useful in distinguishing taxa and establishing phylogenic relationships. It is the genetic expression of the cumulative adaptations of a living organism to its changing environment in the long run. Morphological traits, taking into account the role of anatomical, physiological, and behavioral adaptations, can often be explained on the basis of environmental traits of the habitat.

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In Libya's southern Mediterranean Sea coast, the trochid *P. turbinatus* and members of the genus Patella, dominate the lower rocky littoral (Hamad, 2019; Faidallah *et al*., 2021), where they actively shape the community by grazing encrusting microalgae, the main primary producer in the zone. The littoral zone is an exceptionally harsh transitional environment due to extreme variations in magnitudes of prevailing parameters induced by repeated inundation and exposure following tides. The littoral community is repeatedly subjected to "access/no access" to food, overheating/overcooling, extreme salinities, desiccation, etc.; however, inhabitants of the zone, including *P. turbinatus*, are morphologically, anatomically, physiologically, and behaviorally well adapted to their habitat.

The aim of the present study was to establish morphological traits of *P. turbinatus* inhabiting Al-Haneah and Susah shores, typical of eastern Libya's rocky littoral, and, when possible, show how they adapt the snail to its habitat.

MATERIALS AND METHODS

The study sites

a- Al-Haneah

Al-Haneah, Fig. 1a, is a typical artisanal fishing landing site and resort on the eastern coast of Libya (Eisay, 2020). Its littoral shore is mostly rocky, alternating with sandy tongues.

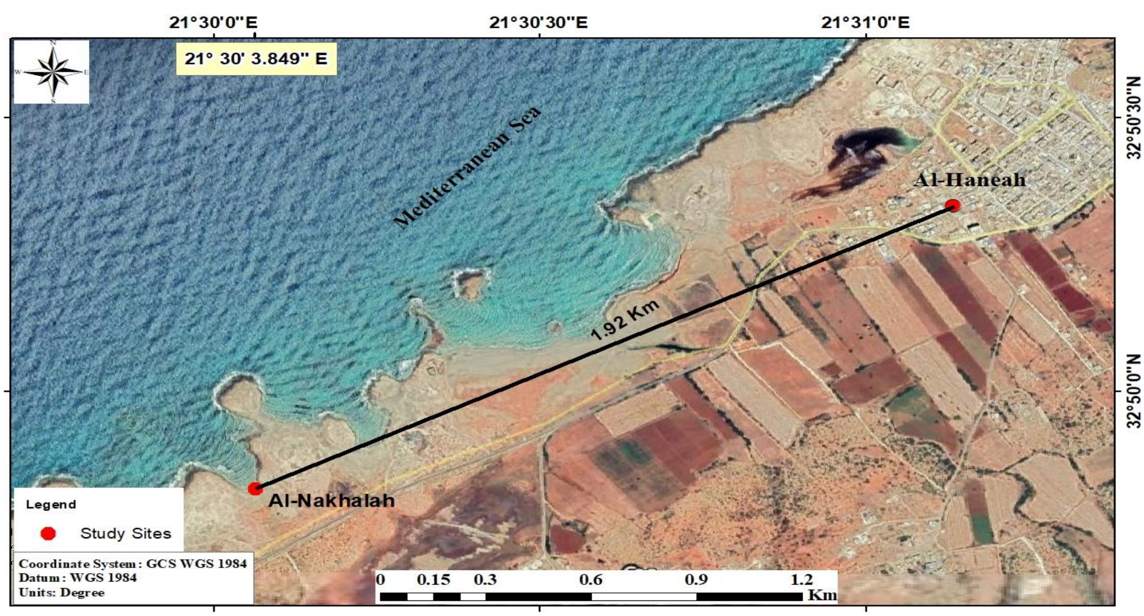

Fig. 1a. Al-Haneah site.

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The rocky shore terrain is very rough with rocks of variable sizes, crevices, cracks, and an abundance of tidal pools. The biota is richest in the lower littoral and decreases upwards. Encrusting algae dominate the flora, while trochid gastropods and tube worms dominate the fauna.

b- Susah

Susah is a small commercial and fishery port located in northeast Libya, Fig. 1b, (Eisay, 2020). It is characterized by beautiful beaches, natural sceneries, and well-preserved ancient and historic Greek and Romanian remains (Faidallah *et al*., 2021). Its littoral zone is similar to that of Al-Haneah but it is more populated.

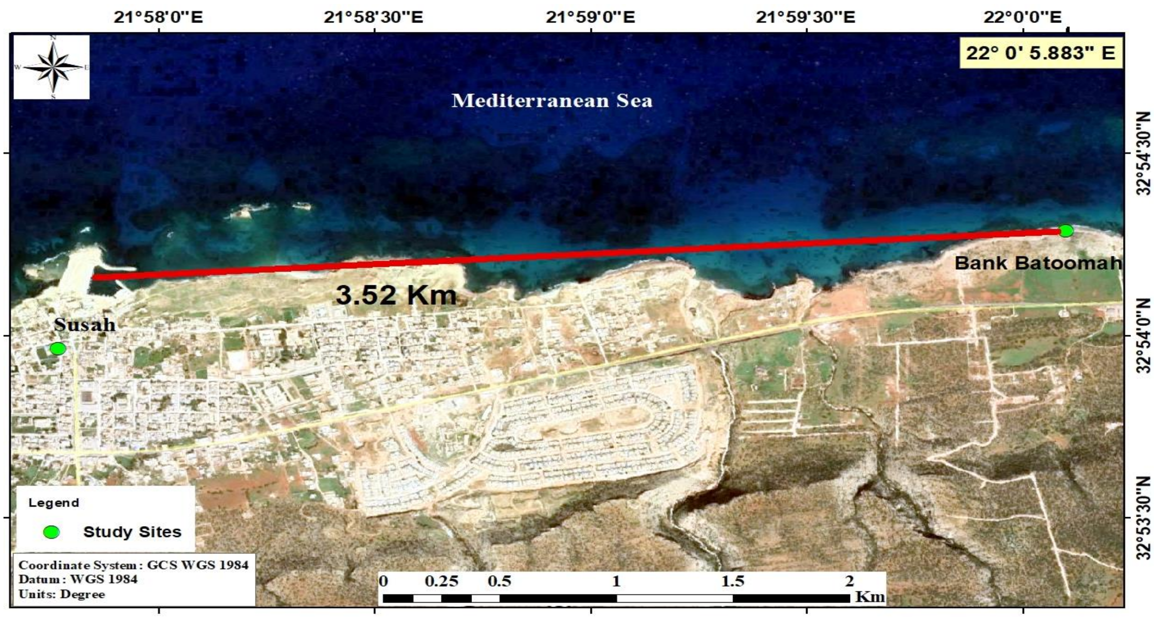

Fig. 1b. Susah site.

Characterizing the littoral zones and collecting *Phorcus turbinatus* samples

Several visits were made to the rocky littoral zones of Al-Haneah and Susah, Eastern Libyan Mediterranean Sea, during December 2020, where:

- Characteristics of the rocky littoral were recorded (*P. turbinatus* was absent in the sandy littoral, Faidallah *et al*., 2021).
- 157 and 148 *P turbinatus* collected from the rocky littorals of Al-Haneah and Susah consecutively were used for measuring the shell parameters shown in Figs. 2a and b. In addition, total weight (TW), empty weight (EW), soft tissue weight (STW), and thickness of operculum (TOp), were established.

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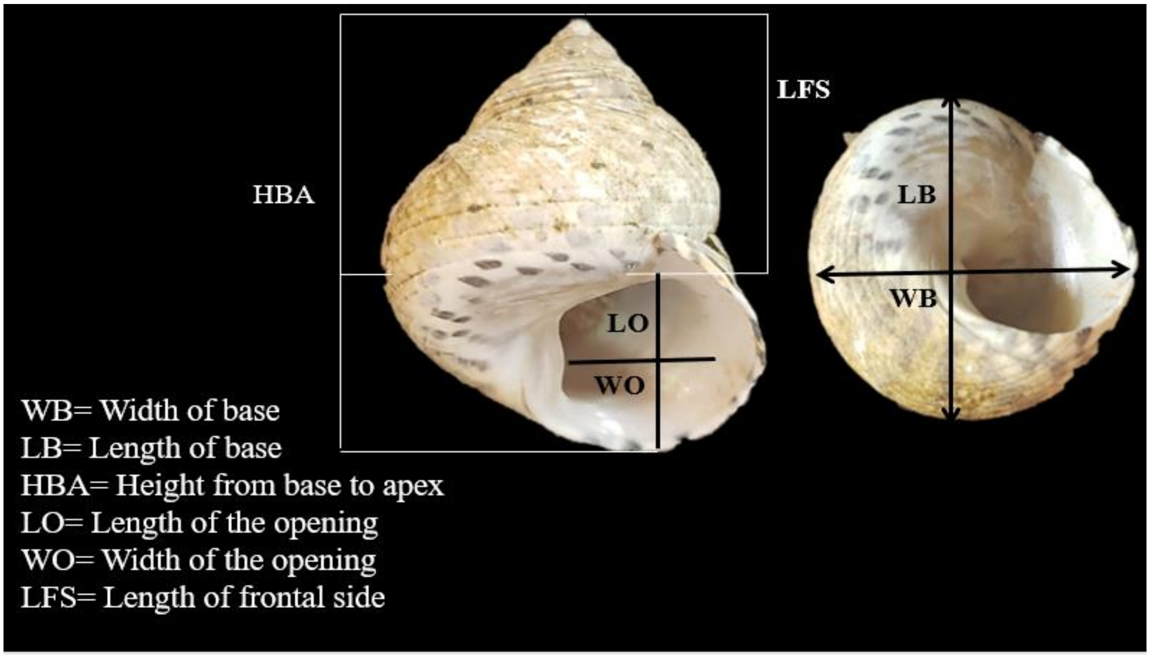

Fig. 2a. The shell parameters measured in *Phorcus turbinatus* obtained from Al-Haneah and Susah.

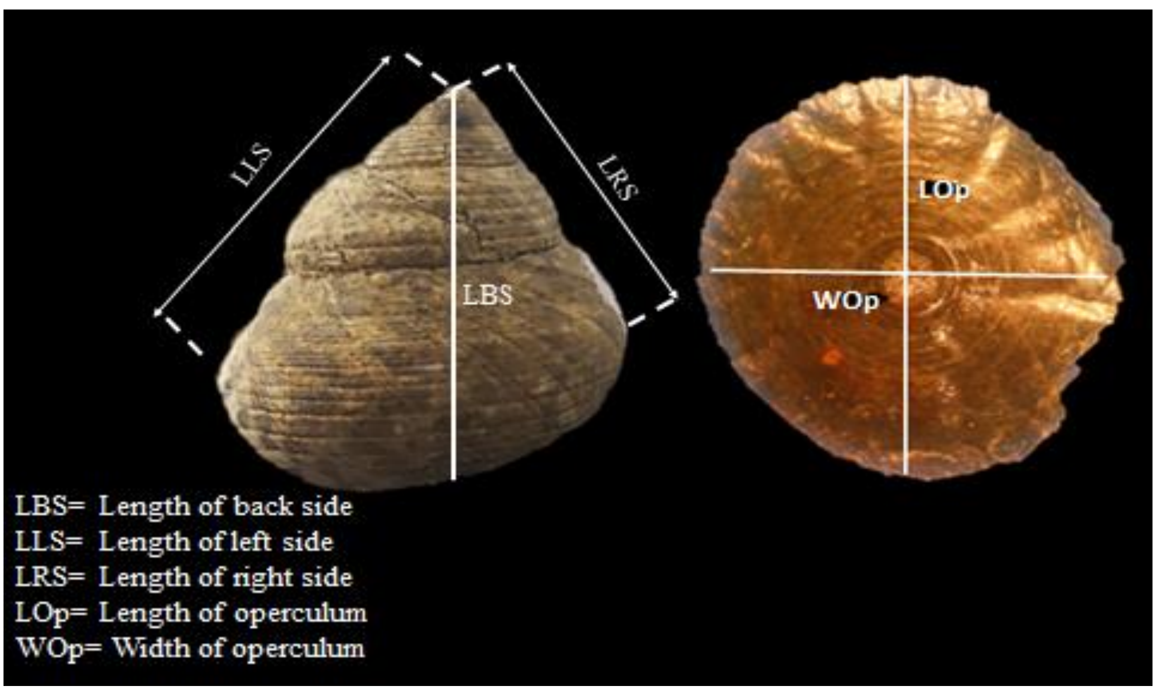

Fig. 2b. Measured parameters established for *Phorcus turbinatus* shell (on left), and operculum (on right).

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Calculating the shell-shape indicators of *Phorcus turbinatus*

The shell shape indicators calculated from the measured shell morphometric parameters are shown in Table 1**.**

Table 1. Acronyms and formulae of shell shape indicators calculated from the measured *Phorcus turbinatus* morphometric parameters.

shell-shape indicator	Meaning	Formula and explanation
TFB	Back-Front tilt of apex.	LBS/LFS; TFB=1: no tilt TFB>1: tilt to front TFB<1: tilt to back
TRL	Right-Left tilt of apex.	LRS/LLS: same as for TFB
RB	Roundness of Base	LB/WB; RB=1: base circular RB>1 or <1: base oval
L	Length of slant side.	$\sqrt{}(h^2+r^2)$.
SC	Curved surface area of cone.	$\pi r(L+r)$
SB	Surface area of base.	(πrB^2)
TS	Total surface area of cone.	SC+SB
VC	Volume of cone.	$(1/3)\pi rB^2hBA$
RO	Roundness of opening.	WO/LO; RO=1: opening circular RO>1 or <1: opening oval
SO	Surface area of opening.	$rO^2\pi$
RP	Roundness of operculum.	Wop/Lop; RP=1: operculum circular RP>1 or <1: operculum oval
SP	Surface area of operculum.	πrP^2
rB	Radius of base.	((LB+WB)/2)/rB
rO	Radius of opening.	(WO+LO)/2
rP	Radius of operculum.	(Wop+Lop)/2
BP	Base perimeter.	$2rB\pi$
OP	Opening perimeter.	$2rO\pi$
PP	Operculum perimeter.	$2rP\pi$

RESULTS

Phorcus turbinatus of Al-Haneah and Susah was a small trochid with a hard shell of 3 to 6 whorls. The shell, originally white, maybe secondarily colored gray-green by algae, was decorated with black rectangular tints that are spirally arranged. Al-Haneah *P. turbinatus* was larger in size than that of Susah. Its minimum, maximum, and mean weights (TW) were 0.470, 10.740, and 3.766gm in Al-Haneah, and 0.570, 8.530, and 3.179gm in Susah; the minimum, maximum, and mean height from base to apex (HBA) were 6.430, 22.710,

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and 13.729mm in Al-Haneah, and 6.740, 20.820, and 12.818mm in Susah. Consequently, all measured shell-parameters of Al-Haneah *P. turbinatus* (except LO and WO) were larger in magnitude than those of Susah *P. turbinatus* (Table 2); most differences were significant, insignificant differences are highlighted red in the table.

Table 2. Means of Al-Haneah and Susah *Phorcus turbinatus* measured shell parameters (n = 157, and 148 in both sites, in order).

Parameter	Site	Mean	St D.	St E	P
TW	**Al-Haneah**	3.77	2.31	0.185	0.008
	Susah	3.18	1.35	0.111	
EW	**Al-Haneah**	3.03	1.84	0.147	0.002
	Susah	2.47	1.09	0.09	
STW	**Al-Haneah**	0.734	0.506	0.040	0.541
	Susah	0.705	0.307	0.025	
LBS	**Al-Haneah**	16.52	4.08	0.325	0.011
	Susah	15.52	2.53	0.208	
LFS	**Al-Haneah**	12.71	3.49	0.279	0.003
	Susah	11.70	2.11	0.173	
LRS	**Al-Haneah**	19.71	4.83	0.386	0.014
	Susah	18.58	2.84	0.234	
LLS	**Al-Haneah**	13.79	3.66	0.292	0.006
	Susah	12.83	2.11	0.174	
HBA	**Al-Haneah**	13.73	3.60	0.288	0.008
	Susah	12.82	2.13	0.175	
LB	**Al-Haneah**	18.65	3.91	0.312	0.391
	Susah	18.33	2.25	0.185	
WB	**Al-Haneah**	16.8	3.55	0.284	0.203
	Susah	16.37	2.14	0.176	
LO	**Al-Haneah**	7.27	1.45	0.115	0.064
	Susah	7.53	.882	0.073	
WO	**Al-Haneah**	9.33	1.71	0.137	0.016
	Susah	9.73	1.08	0.089	
LOp	**Al-Haneah**	6.52	1.19	0.095	0.031
	Susah	6.28	0.735	0.060	
WOp	**Al-Haneah**	6.52	1.19	0.095	0.017
	Susah	6.23	0.883	0.073	
TOp	**Al-Haneah**	0.143	0.055	0.004	0.089
	Susah	0.134	0.036	0.003	

All the binary correlations of Al-Haneah and Susah *Phorcus turbinatus* measured shell parameters were very strong (they had high correlation coefficients) and highly significant (Tables 3 and 4).

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Table 3. Pearson's correlations of measured shell parameters of Al-Haneah *Phorcus turbinatus*.

Parameter	TW	EW	STW	LFS	LRS	LBS	LLS	HBA	LB	WB	LO	WO	LOp	WOp
EW	.996**													
STW	.948**	.917**												
LFS	.963**	.965**	.895**											
LRS	.965**	.967**	.897**	.985**										
LBS	.955**	.958**	.881**	.977**	.988**									
LLS	.963**	.968**	.882**	.982**	.992**	.988**								
HBA	.969**	.972**	.895**	.988**	.995**	.985**	.993**							
LB	.942**	.945**	.872**	.967**	.988**	.980**	.979**	.980**						
WB	.951**	.955**	.877**	.974**	.990**	.981**	.982**	.985**	.995**					
LO	.912**	.914**	.843**	.940**	.961**	.957**	.951**	.953**	.972**	.970**				
WO	.919**	.916**	.869**	.940**	.959**	.951**	.945**	.946**	.964**	.960**	.955**			
LOp	.908**	.910**	.840**	.941**	.965**	.963**	.956**	.959**	.975**	.971**	.959**	.954**		
WOp	.908**	.910**	.840**	.941**	.965**	.963**	.956**	.959**	.975**	.971**	.959**	.954**	.990**	
TOp	.910**	.914**	.839**	.898**	.911**	.892**	.912**	.918**	.891**	.897**	.852**	.835**	.864**	.864**

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Table 4. Pearson's correlations of measured-shell parameters of Susah *Phorcus turbinatus*.

Parametr	TW	EW	STW	LFS	LRS	LBS	LLS	HBA	LB	WB	LO	WO	LOp	WOp
EW	.991**													
STW	.877**	.804**												
LFS	.962**	.951**	.851**											
LRS	.973**	.960**	.869**	.991**										
LBS	.959**	.949**	.845**	.979**	.985**									
LLS	.956**	.945**	.847**	.986**	.984**	.977**								
HBA	.968**	.956**	.862**	.996**	.993**	.978**	.986**							
LB	.964**	.950**	.861**	.938**	.963**	.948**	.941**	.950**						
WB	.960**	.946**	.860**	.943**	.960**	.945**	.938**	.953**	.987**					
LO	.945**	.922**	.881**	.932**	.954**	.934**	.929**	.939**	.973**	.970**				
WO	.886**	.866**	.821**	.869**	.899**	.888**	.875**	.876**	.930**	.933**	.937**			
LOp	.867**	.851**	.791**	.835**	.870**	.852**	.830**	.851**	.903**	.901**	.884**	.856**		
WOp	.712**	.697**	.656**	.695**	.722**	.693**	.684**	.713**	.730**	.726**	.714**	.675**	.830**	
TOp	.763**	.760**	.653**	.779**	.786**	.768**	.770**	.784**	.756**	.751**	.766**	.703**	.680**	.571**

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The length-weight relationship

This relationship was represented by HBA or LB vs TW power regression:

TW= 0.003 * HBA$^{**2.640}$, R^2 = 0.987 for Al-Haneah (Fig. 3a),
TW= 0.006 * HBA$^{**2.443}$, R^2 = 0.958 for Susah (Fig. 3b).

TW= 0.001 * LB$^{**3.278}$, R^2 = 0.988 for Al-Haneah (Fig.3a),
TW= 0.001 *LB$^{**3.306}$, R^2 = 0.966 for Susah (Fig. 3b)

The exponent 'b' of the HBA-TW relationship (2.640 and 2.443) indicated negative allometric growth for Al-Haneah and Susah in order, that based on LB-TW indicted positive allometry (b = 3.278 and 3.306).

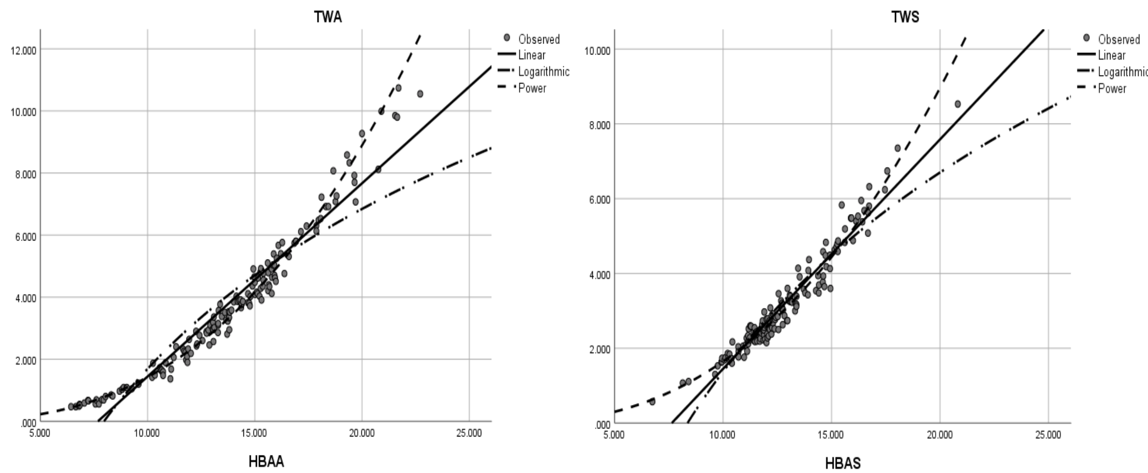

Fig. 3a. Power, Linear, and logarithmic regressions of HBA (on the x-axis)-TW (on the y-axis) relationship of Al-Haneah (left) and Susah (right) *Phorcus turbinatus.*

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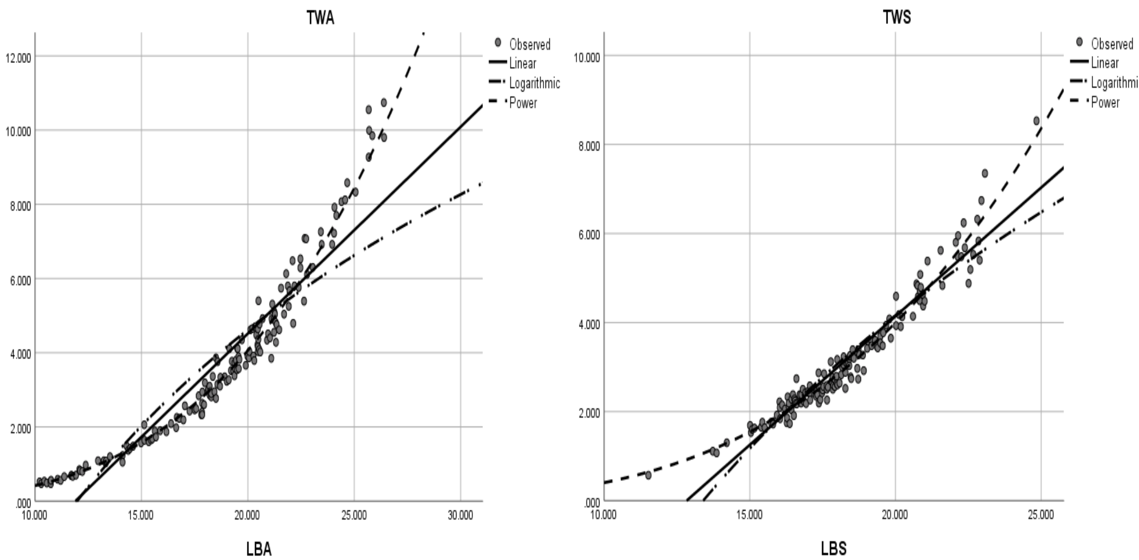

Fig. 3b. Power, Linear, and logarithmic regressions of LB (x-axis)-TW (y-axis) relationship of Al-Haneah (left) and Susah (right) *Phorcus turbinatus.*

The other measured shell-parameters are:

All regressions of the measured shell-parameters of Al-Haneah and Susah *P. turbinatus* vs, HBA (Table 5) and LB (Table 6) were positive, strong (having high and comparable R^2), and highly significant. Positive regressions mean that the measured parameter increased with the increase of HBA or LB. The used power, linear, and logarithm regressions represented the relationships very well, with a slight preference for the power regression which had a slightly higher R^2 than the other two regressions. It can be advised that in future studies concerning morphometric relationships of *Phorcus turbinatus*, measured parameters can be related to either HBA or LB, preferably with power regressions, though linear and logarithmic regressions can also be used.

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Table 5. Power (P.), Linear (L.), and logarithmic (Log.) regressions of measured shell parameters (on the y-axis) of Al-Haneah and Susah *Phorcus turbinatus* vs, HBA (on the x-axis).

Parameter	Reg.	Al-Haneah	Susah
TW/HBA	**P.**	Y= 0.003 * x**2.640, R^2 = 0.987	Y= 0.006 * x**2.443, R^2 = 0.958
	Li.	Y= 0.623 * x + -4.782, R^2 = 0.939	Y= 0.613 * x + -4.683, R^2 = 0.937
	Log.	Y= -15.423 + 7.433 * log(x), R^2 = 0.843	Y= -16.308 + 7.680 * log(x), R^2 = 0.884
EW/HBA	**P.**	Y= 0.002 * x**2.672, R^2 = 0.984	Y= 0.004 * x**2.473, R^2 = 0.940
	Li.	Y= 0.497 * x + -3.791, R^2 = 0.945	Y= 0.489 * x + -3.798, R^2 = 0.913
	Log.	Y= 12.333 + 5.951 * log(x), R^2 = 0.854	Y= -13.040 + 6.114 * log(x), R^2 = 0.858
STW/HBA	**P.**	Y= 0.001 * x**2.538, R^2 = 0.886	Y= 0.002 * x**2.310, R^2 = 0.761
	Li.	Y= 0.126 * x + -0.991, R^2 = 0.800	Y= 0.124 * x + -0.885, R^2 = 0.743
	Log.	Y= -3.089 + 1.481 * log(x), R^2 = 0.700	Y= -3.267 + 1.566 * log(x), R^2 = 0.713
LBS/HBA	**P.**	Y= 1.411 * x**0.940, R^2 = 0.974	Y= 1.336 * x**0.962, R^2 = 0.955
	Li.	Y= 1.115 * x + 1.207, R^2 = 0.970	Y= 1.161 * x + 0.637, R^2 = 0.957
	Log.	Y= -19.479 + 13.945 * log(x), R^2 = 0.955	Y= -22.105 + 14.829 * log(x), R^2 = 0.940
LFS/HBA	**P.**	Y= 0.835 * x**1.039, R^2 = 0.976	Y= 0.735 * x**1.085, R^2 = 0.990
	Li.	Y= 0.958 x + -0.442, R^2 = 0.975	Y= 0.986 * x + -0.934, R^2 = 0.991
	Log.	Y= -17.912 + 11.860 * log(x), R^2 = 0.942	Y= -20.248 + 12.593 * log(x), R^2 = 0.974
LRS/HBA	**P.**	Y= 1.715 * x**0.933, R^2 = 0.992	Y= 1.816 * x**0.912, R^2 = 0.985
	Li.	Y= 1.336 * x + 1.370, R^2 = 0.990	Y= 1.324 * x + 1.610, R^2 = 0.985
	Log.	Y= -23.283 + 16.654 * log(x), R^2 = 0.969	Y= -24.337 + 16.916 * log(x), R^2 = 0.968
LLS/HBA	**P.**	Y= 0.965 * x**1.015, R^2 = 0.987	Y= 1.057 * x**0.979, R^2 = 0.973
	Li.	Y= 1.009 x + -0.058, R^2 = 0.986	Y= 0.979 * x + 0.285, R^2 = 0.973
	Log.	Y= -18.606 + 12.549 * log(x), R^2 = 0.962	Y= -18.868 + 12.492 * log(x), R^2 = 0.955
LB/HBA	**P.**	Y= 2.335* x**0.795, R^2 = 0.973	Y= 3.037 * x**0.706, R^2 = 0.905
	Li.	Y= 1.065 * x + 4.026, R^2 = 0.961	Y= 1.004 * x + 5.471, R^2 = 0.902

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	Log.	Y= -16.110 + 13.464 * log(x), R^2 = 0.967	Y= -14.378 + 12.892 * log(x), R^2 = 0.896
WB/HBA	**P.**	Y= 2.102 * x**0.796, R^2 = 0.976	Y= 2.376 * x**0.757, R^2 = 0.913
	Li.	Y= 0.972 * x + 3.453, R^2 = 0.970	Y= 0.955 * x + 4.121, R^2 = 0.907
	Log.	Y= -14.742 + 12.217 * log(x), R^2 = 0.965	Y= -14.845 + 12.301 * log(x), R^2 = 0.906
LO/HBA	**P.**	Y= 1.087 * x**0.728, R^2 = 0.927	Y= 1.419 * x**0.655, R^2 = 0.878
	Li.	Y= 0.383 * x + 2.019, R^2 = 0.908	Y= 0.389 * x + 2.547, R^2 = 0.881
	Log.	Y= -5.230 + 4.843 * log(x), R^2 = 0.916	Y= -5.065 + 4.964 * log(x), R^2 = 0.865
WO/HBA	**P.**	Y= 1.727 * x**0.647, R^2 = 0.905	Y= 2.176 * x**0.588, R^2 = 0.770
	Li.	Y= 0.450 * x + 3.159, R^2 = 0.895	Y= 0.444 * x + 4.048, R^2 = 0.767
	Log.	Y= -5.239 + 5.645 * log(x), R^2 = 0.888	Y= -4.753 + 5.709 * log(x), R^2 = 0.765
LOp/HBA	**P.**	Y= 1.119 * x**0.676, R^2 = 0.943	Y= 1.339 * x**0.606, R^2 = 0.721
	Li.	Y= 0.317 * x + 2.169, R^2 = 0.919	Y= 0.294 * x + 2.513, R^2 = 0.724
	Log.	Y= -3.894 + 4.035 * log(x), R^2 = 0.937	Y= -3.332 + 3.786 * log(x), R^2 = 0.725
WOp/HBA	**P.**	Y= 1.119 * x**0.676, R^2 = 0.943	Y= 1.295 * x**0.611, R^2 = 0.138
	Li.	Y= 0.317 * x + 2.169, R^2 = 0.919	Y= 0.296 * x + 2.442, R^2 = 0.509
	Log.	Y= -3.894 + 4.035 * log(x), R^2 = 0.937	Y= -3.398 + 3.797 * log(x), R^2 = 0.505
TOp/HBA	**P.**	Y= 0.004 * x**1.371, R^2 = 0.882	Y= 0.006 * x**1.229, R^2 = 0.634
	Li.	Y= 0.014 * x + -0.051, R^2 = 0.842	Y= 0.013 * x + -0.036, R^2 = 0.615
	Log.	Y= -0.302 + 0.172 * log(x), R^2 = 0.788	Y= -0.292 + 0.168 * log(x), R^2 = 0.594

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Table 6. Regressions of measured shell parameters of Al-Haneah and Susah *Phorcus turbinatus* vs LB (measured parameter on the y-axis; LB on the x-axis).

Parameter	Reg.	Al-Haneah	Susah
TW/LB	P.	Y= 0.001 * x**3.278, R^2 = 0.988	Y= 0.001 * x**3.306, R^2 = 0.966
	Li.	Y= 0.557 * x + -6.624, R^2 = 0.888	Y= 0.578 * x + -7.413, R^2 = 0.929
	Log.	Y= -22.342 + 8.999 * log(x), R^2 = 0.803	Y= -26.953 + 10.386 * log(x), R^2 = 0.890
EW/LB	P.	Y= 0.001 * x**3.313, R^2 = 0.983	Y= 0.001 * x**3.351, R^2 = 0.951
	Li.	Y= 0.444 * x + -5.256, R^2 = 0.893	Y= 0.460 * x + -5.968, R^2 = 0.903
	Log.	Y= -17.847 + 7.196 * log(x), R^2 = 0.812	Y= -21.512 + 8.267 * log(x), R^2 = 0.864
STW/LB	P.	Y= 5.757 * x**3.170, R^2 = 0.899	Y= 7.597 * x**3.118, R^2 = 0.763
	Li.	Y= 0.113 * x + -1.368, R^2 = 0.761	Y= 0.117 * x + -1.445, R^2 = 0.742
	Log.	Y= -4.494 + 1.802 * log(x), R^2 = 0.674	Y= -5.442 + 2.119 * log(x), R^2 = 0.718
LBS/LB	P.	Y= 0.550 * x**1.161, R^2 = 0.966	Y= 0.398 * x**1.258, R^2 = 0.901
	Li.	Y= 1.022 * x + -2.532, R^2 = 0.961	Y= 1.065 * x + -4.005, R^2 = 0.899
	Log.	Y= -33.048 + 17.085 * log(x), R^2 = 0.932	Y= -40.795 + 19.411 * log(x), R^2 = 0.886
LFS/LB	P.	Y= 0.305 * x**1.271, R^2 = 0.950	Y= 0.210 * x**1.380, R^2 = 0.882
	Li.	Y= 0.863 * x + -3.392, R^2 = 0.936	Y= 0.879 * x + -4.418, R^2 = 0.881
	Log.	Y= -28.942 + 14.356 * log(x), R^2 = 0.897	Y= -34.792 + 16.026 * log(x), R^2 = 0.868
LRS/LB	P.	Y= 0.675 * x**1.152, R^2 = 0.983	Y= 0.573 * x**1.195, R^2 = 0.931
	Li.	Y= 1.221 * x + -3.059, R^2 = 0.976	Y= 1.216 * x + -3.715, R^2 = 0.928
	Log.	Y= -39.431 + 20.385 * log(x), R^2 = 0.944	Y= -45.729 + 22.167 * log(x), R^2 = 0.915
LLS/LB	P.	Y= 0.355 * x**1.248, R^2 = 0.970	Y= 0.325 * x**1.262, R^2 = 0.891
	Li.	Y= 0.915 * x + -3.277, R^2 = 0.959	Y= 0.884 * x + -3.373, R^2 = 0.886
	Log.	Y= -30.508 + 15.269 * log(x), R^2 = 0.925	Y= -33.900 + 16.106 * log(x), R^2 = 0.873
HBA/LB	P.	Y= 0.380 * x**1.224, R^2 = 0.973	Y= 0.307 * x**1.282, R^2 = 0.905
	Li.	Y= 0.902 * x + -3.092, R^2 = 0.961	Y= 0.898 * x + -3.653, R^2 = 0.902

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	Log.	Y= -29.853 + 15.022 * log(x), R^2 = 0.924	Y= -34.686 + 16.374 * log(x), R^2 = 0.888
WB/LB	**P.**	Y= 0.916 * x**0.994, R^2 = 0.991	Y= 0.761 * x**1.055, R^2 = 0.975
	Li.	Y= 0.904 * x + -0.063, R^2 = 0.991	Y= 0.937 * x + -0.810, R^2 = 0.975
	Log.	Y= -27.213 + 15.170 * log(x), R^2 = 0.967	Y= -33.394 + 17.151 * log(x), R^2 = 0.969
LO/LB	**P.**	Y= 0.499 * x**0.916, R^2 = 0.954	Y= 0.524 * x**0.917, R^2 = 0.946
	Li.	Y= 0.359 * x + 0.572, R^2 = 0.945	Y= 0.381 * x + 0.537, R^2 = 0.947
	Log.	Y= -10.311 + 6.060 * log(x), R^2 = 0.932	Y= -12.620 + 6.945 * log(x), R^2 = 0.932
WO/LB	**P.**	Y= 0.867 * x**0.813, R^2 = 0.930	Y= 0.845 * x**0.840, R^2 = 0.865
	Li.	Y= 0.422 * x + 1.466, R^2 = 0.930	Y= 0.445 * x + 1.567, R^2 = 0.864
	Log.	Y= -11.161 + 7.065 * log(x), R^2 = 0.903	Y= -13.927 + 8.155 * log(x), R^2 = 0.860
LOp/LB	**P.**	Y= 0.553 * x**0.845, R^2 = 0.957	Y= 0.513 * x**0.861, R^2 = 0.801
	Li.	Y= 0.297 * x + 0.991, R^2 = 0.950	Y= 0.295 * x + 0.871, R^2 = 0.815
	Log.	Y= -8.043 + 5.021 * log(x), R^2 = 0.943	Y= -9.360 + 5.389 * log(x), R^2 = 0.808
WOp/LB	**P.**	Y= 0.553 * x**0.845, R^2 = 0.957	Y= 0.641 * x**0.777, R^2 = 0.123
	Li.	Y= 0.297 * x + 0.991, R^2 = 0.950	Y= 0.287 * x + 0.982, R^2 = 0.533
	Log.	Y= -8.043 + 5.021 * log(x), R^2 = 0.943	Y= -8.913 + 5.221 * log(x), R^2 = 0.525
TOp/LB	**P.**	Y= 0.001 * x**1.686, R^2 = 0.867	Y= 0.001 * x**1.614, R^2 = 0.601
	Li.	Y= 0.013 * x + -0.092, R^2 = 0.793	Y= 0.012 * x + -0.088, R^2 = 0.571
	Log.	Y= -0.460 + 0.208 * log(x), R^2 = 0.746	Y= -0.503 + 0.220 * log(x), R^2 = 0.558

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The calculated shell-shape indicators

The values of most calculated shell shape indicators of Al-Haneah and Susah *Phorcus turbinatus* were very close (Table 7). In both Al-Haneah and Susah, the shell apex was tilted to the front side and the left side (TFB and TRL > 1), the base was almost circular (RB close to 1), the shell opening was slightly oval (RO was slightly more than 1, = 1.291 and 1.295), and the operculum was circular (RP almost = 1).

Table 7. Means of calculated shell shape indicators of *Phorcus turbinatus* of Al-Haneah and Susah. P-values of insignificant differences are shown in red.

Indicator	Site	Mean	StD	StE	P
TFB	Al-Haneah	1.313 apex tilted to front side	.084	.007	0.026
	Susah	1.331 apex tilted to front side	.054	.004	
TRL	Al-Haneah	1.439 apex tilted to left side	.058	.005	0.029
	Susah	1.452 apex tilted to left side	.045	.004	
RB	Al-Haneah	1.111 almost circular	.024	.002	0.000
	Susah	1.122 almost circular	.025	.002	
L	Al-Haneah	22.431	5.133	.410	0.076
	Susah	21.580	2.994	.246	
SC	Al-Haneah	2339.8	939.3	74.963	0.040
	Susah	2158.0	563.5	46.318	
SB	Al-Haneah	1030.7	403.4	32.195	0.067
	Susah	961.0	244.1	20.069	
TS	Al-Haneah	3370.6	1342.6	107.1	0.047
	Susah	3119.0	807.5	66.376	
VC	Al-Haneah	5190.9	3155.8	251.9	0.002
	Susah	4270.4	1824.7	150.0	
RO	Al-Haneah	1.291 slightly oval	.080	.006	0.653
	Susah	1.295 slightly oval	.051	.004	
SO	Al-Haneah	224.3	79.770	6.366	0.102
	Susah	237.0	53.691	4.413	
RP	Al-Haniah	1.004 circular	.050	.004	0.098
	Susah	.992 circular	.078	.006	
SP	Al-Haneah	137.9	47.099	3.759	0.005
	Susah	125.1	30.500	2.507	
rB	Al-Haneah	17.724	3.729	.298	0.283
	Susah	17.350	2.187	.180	
rO	Al-Haneah	8.303	1.561	.125	0.028
	Susah	8.631	.965	.079	
rP	Al-Haneah	6.517	1.191	.095	0.027
	Susah	6.262	.778	.064	
BP	Al-Haneah	111.4	23.437	1.870	0.283
	Susah	109.059	13.746	1.130	
OP	Al-Haneah	52.194	9.815	.783	0.028
	Susah	54.252	6.066	.499	
PP	Al-Haneah	40.965	7.487	.598	0.027
	Susah	39.359	4.892	.402	

All binary correlations between Al-Haneah (Table 8) and Susah (Table 9) *P. turbinatus* shell-shape indicators had moderate to high correlation coefficients and were highly significant. Some of the correlations were negative. The R^2 of the regressions of these indicators with HBA, as an indicator of growth (Table 10), ranged from weak to very strong. The situation in Susah was similar (Table 10) except that here RB was negative.

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Table 8. Pearson's correlations of calculated shell shape indicators of Al-Haneah *Phorcus turbinatus*

Indicator	TFB	TRL	RB	L	SC	SB	TS	VC	RO	SO	RP	SP	rBA	rO	rP	BP	OP
TRL	.157*																
RB	.252**	-.019															
L	-.45**	-.56**	-.036														
SC	-.44**	-.53**	-.060	.993**													
SB	-.43**	-.53**	-.053	.993**	.986**												
TS	-.44**	-.53**	-.058	.993**	.976**	.990**											
VC	-.45**	-.51**	-.107	.964**	.986**	.982**	.984**										
RO	.080	.276**	-.041	-.36**	-.33**	-.33**	-.33**	-.28**									
SO	-.41**	-.5**	-.016	.969**	.976**	.977**	.976**	.957**	-.3**								
RP	.155	.070	-.013	-.057	-.064	-.059	-.063	-.088	-.028	-.057							
SP	-.37**	-.53**	-.016	.969**	.969**	.970**	.969**	.945**	-.32**	.963**	-.057						
rB	-.43**	-.55**	-.019	.997**	.989**	.991**	.990**	.951**	-.36**	.969**	-.045	.968**					
rO	-.41**	-.52**	.014	.974**	.968**	.971**	.969**	.932**	-.33**	.993**	-.043	.962**	.978**				
rP	-.37**	-.55**	.012	.971**	.958**	.960**	.959**	.917**	-.35**	.953**	-.043	.992**	.974**	.966**			
BP	-.43**	-.55**	-.019	.997**	.989**	.991**	.990**	.951**	-.36**	.969**	-.045	.968**	.980**	.978**	.974**		
OP	-.41**	-.52**	.014	.974**	.968**	.971**	.969**	.932**	-.33**	.993**	-.043	.962**	.978**	.988**	.966**	.978**	
PP	-.37**	-.55**	.012	.971**	.958**	.960**	.959**	.917**	-.35**	.953**	-.043	.992**	.974**	.966**	.988**	.974**	.966**

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Table 9. Pearson's correlations of calculated shell shape indicators of Susah *Phorcus turbinatus*

Indicator	TFB	TRL	RB	L	SC	SB	TS	VC	RO	SO	RP	SP	rB	rO	rP	BP	OP
TRL	.313**																
RB	.338**	.111															
L	-.44**	-.30**	-.38**														
SC	-.4**	-.27**	-.36**	.993**													
SB	-.38**	-.26**	-.36**	.990**	.999**												
TS	-.39**	-.26**	-.36**	.993**	.998**	.989**											
VC	-.41**	-.28**	-.34**	.984**	.990**	.985**	.989**										
RO	.297**	.049	-.024	-.26**	-.26**	-.25**	-.26**	-.28**									
SO	-.35**	-.23**	-.35**	.955**	.966**	.967**	.966**	.953**	-.119								
RP	-.090	.061	.063	-.039	-.046	-.053	-.048	-.025	-.069	-.068							
SP	-.32**	-.117	-.3**	.865**	.874**	.875**	.874**	.859**	-.210*	.848**	.228**						
rB	-.39**	-.26**	-.37**	.992**	.995**	.996**	.995**	.972**	-.24**	.963**	-.059	.872**					
rO	-.36**	-.24**	-.37**	.958**	.964**	.965**	.964**	.943**	-.109	.997**	-.073	.847**	.968**				
rP	-.32**	-.116	-.3**	.843**	.845**	.847**	.846**	.828**	-.207*	.818**	.295**	.995**	.848**	.822**			
BP	-.39**	-.26**	-.37**	.992**	.995**	.996**	.995**	.972**	-.24**	.963**	-.059	.872**	.988**	.968**	.848**		
OP	-.36**	-.24**	-.37**	.958**	.964**	.965**	.964**	.943**	-.109	.997**	-.073	.847**	.968**	.990**	.822**	.968**	
PP	-.32**	-.116	-.3**	.843**	.845**	.847**	.846**	.828**	-.207*	.818**	.295**	.995**	.848**	.822**	.988**	.848**	.822**

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Table 10. Regressions of calculated shell shape parameters of Al-Haneah and Susah *Phorcus turbinatus* vs HBA (calculated shell-shape indicators on the y-axis; HBA on the x-axis).

Indicator	Reg.	Al-Haneah	Susah
TFB/HBA	P.	Y= 1.691 * x**-0.099, R^2 = 0.194	Y= 1.819 * x**-0.123, R^2 = 0.256
	Li.	Y= -0.011 * x + 1.463, R^2 = 0.217	Y= -0.013 * x + 1.492, R^2 = 0.251
	Log.	Y= 1.653 + -0.132 * log(x), R^2 = 0.198	Y= 1.750 + -0.165 * log(x), R^2 =0.260
TRL/HBA	P.	Y= 1.779 * x**-0.082, R^2 = 0.349	Y= 1.717 * x**-0.066, R^2 = 0.126
	Li.	Y= -0.009 * x + 1.566, R^2 = 0.335	Y= -0.007 * x + 1.545, R^2 = 0.120
	Log.	Y= 1.749 + -0.120 * log(x), R^2 = 0.354	Y= 1.698 + -0.097 * log(x), R^2 = 0.129
RB/HBA	P.	Y= 1.111 * x**-0.001, R^2 = 0.000	Y= 1.278 * x**-0.052, R^2 =0.152
	Li.	Y= -0.0004 * x + 1.116, R^2 = 0.003	Y= -0.004 * x + 1.177, R^2 = 0.139
	Log.	Y= 1.112 + -0.0005 *log(x),R^2 = 0.000	Y= 1.269 + -0.058 * log(x), R^2 = 0.153
L/HBA	P.	Y= 2.306 * x**0.870, R^2 = 0.992	Y= 2.638 * x**0.825, R^2 = 0.970
	Li.	Y= 1.418 * x + 2.958, R^2 = 0.989	Y= 1.384 * x + 3.845, R^2 = 0.969
	Log.	Y= -23.391 + 17.749 * log(x), R^2 = 0.976	Y= -23.412 + 17.732 * log(x), R^2 = 0.958
SC/HBA	P.	Y= 15.477 * x**1.591, R^2 = 0.982	Y= 45.004 * x**1.512, R^2 = 0.934
	Li.	Y= 257.701 * x + -1198.268, R^2 = 0.976	Y= 255.195 * x + -1112.998, R^2 = 0.931
	Log.	Y= -5833.545 + 3165.989 * log(x), R^2 = 0.928	Y= -6063.400 + 3240.218 * log(x), R^2 = 0.903
SB/HBA	P.	Y= 15.477 * x**1.591, R^2 = 0.977	Y= 22.936 * x**1.460, R^2 = 0.914
	Li.	Y= 110.363 * x + -484.491, R^2 = 0.970	Y= 109.385 * x + -441.035, R^2 = 0.911
	Log.	Y= -2480.098 + 1359.933 * log(x), R^2 = 0.928	Y= -2568.497 + 1391.052 * log(x), R^2 =0.887
TS/HBA	P.	Y= 46.837 * x**1.620, R^2 = 0.981	Y= 67.808 * x**1.496, R^2 =0.928
	Li.	Y= 368.063 * x + -1682.759, R^2 = 0.974	Y= 364.580 * x + -1554.033, R^2 = 0.925
	Log.	Y= -8313.644 + 4525.923 * log(x), R^2 = 0.928	Y= -8631.897 + 4631.271 * log(x), R^2 =0.899
VC/HBA	P.	Y= 5.159 * x**2.591, R^2 = 0.991	Y= 7.645 * x**2.460, R^2 =0.968
	Li.	Y= 850.903 * x + -6491.579, R^2 = 0.942	Y= 833.854 * x + -6417.734, R^2 =0.948
	Log.	Y= -21013.178 + 10150.245 * log(x), R^2 = 0.845	Y= -22204.418 + 10434.222 * log(x), R^2 = 0.893
RO/HBA	P.	Y= 1.589 * x**-0.081, R^2 =0.140	Y= 1.534 * x**-0.067, R^2 = 0.079

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	Li.	Y= -0.008 * x + 1.396, R^2 = 0.119	Y= -0.007 * x + 1.384, R^2 = 0.084
	Log.	Y= 1.569 + -0.107 * log(x), R^2 = 0.148	Y= 1.510 + -0.085 * log(x), R^2 = 0.075
SO/HBA	**P.**	Y= 6.176 * x**1.363, R^2 =0.934	Y= 10.066 * x**1.235, R^2 =0.843
	Li.	Y= 21.249 * x + -67.426, R^2 =0.920	Y= 23.150 * x + -59.700, R^2 = 0.844
	Log.	Y= -452.872 + 262.308 * log(x), R^2 = 0.883	Y= -508.560 + 293.850 * log(x), R^2 = 0.818
RP/HBA	**P.**	Y= 1.027 * x**-0.009, R^2=0.003	Y= 0.992 * x**-0.006, R^2 = 0.000
	Li.	Y= -0.001 * x + 1.018, R^2 =0.005	Y= -0.0004 * x + 0.996, R^2 = 0.000
	Log.	Y= 1.026 + -0.009 * log(x), R^2 = 0.002	Y= 1.015 + -0.009 * log(x), R^2 = 0.000
SP/HBA	**P.**	Y= 3.908 * x**1.353, R^2 =0.943	Y= 5.415 * x**1.225, R^2 = 0.613
	Li.	Y= 12.577 * x + -34.760, R^2 =0.924	Y= 11.929 * x + -27.785, R^2 = 0.694
	Log.	Y= -266.644 + 156.707 * log(x), R^2 =0.904	Y= -261.336 + 152.308 * log(x), R^2 = 0.681
rB/HBA	**P.**	Y= 2.219 * x**0.795, R^2 = 0.977	Y= 2.701 * x**0.730, R^2 = 0.914
	Li.	Y= 1.019 * x + 3.740, R^2 =0.967	Y= 0.979 * x + 4.796, R^2 = 0.910
	Log.	Y= -15.426 + 12.841 * log(x), R^2 =0.968	Y= -14.612 + 12.597 * log(x), R^2 = 0.906
rO/HBA	**P.**	Y= 1.402 * x**0.682, R^2 =0.934	Y= 1.790 * x**0.618, R^2 = 0.843
	Li.	Y= 0.416 * x + 2.589, R^2 =0.921	Y= 0.416 * x + 3.297, R^2 =0.844
	Log.	Y= -5.235 + 5.244 * log(x), R^2 = 0.921	Y= -4.909 + 5.336 * log(x), R^2 = 0.835
rP/HBA	**P.**	Y= 1.115 * x**0.677, R^2 = 0.943	Y= 1.313 * x**0.613, R^2 = 0.613
	Li.	Y= 0.317 * x + 2.161, R^2 = 0.920	Y= 0.297 * x + 2.453, R^2 = 0.661
	Log.	Y= -3.904 + 4.037 * log(x), R^2 = 0.938	Y= -3.444 + 3.825 * log(x), R^2 = 0.660
BP/HBA	**P.**	Y= 13.949 * x**0.795, R^2 = 0.977	Y= 16.981 * x**0.730, R^2 =0.914
	Li.	Y= 6.403 * x + 23.507, R^2 =0.967	Y= 6.157 * x + 30.146, R^2 = 0.910
	Log.	Y= -96.964 + 80.714 * log(x), R^2 =0.968	Y= -91.846 + 79.181 * log(x), R^2 = 0.906
OP/HBA	**P.**	Y= 8.812 * x**0.682, R^2 = 0.934	Y= 11.249 * x**0.618, R^2 = 0.843
	Li.	Y= 2.616 * x + 16.273, R^2 = 0.921	Y= 2.616 * x + 20.725, R^2 =0.844
	Log.	Y= -32.904 + 32.963 * log(x), R^2 = 0.921	Y= -30.857 + 33.543 * log(x), R^2 = 0.835
PP/HBA	**P.**	Y= 7.009 * x**0.677, R^2 = 0.943	Y= 8.250 * x**0.613, R^2 = 0.613
	Li.	Y= 1.994 * x + 13.585, R^2 =0.920	Y= 1.868 * x + 15.419, R^2 = 0.661
	Log.	Y= -24.540 + 25.374 * log(x), R^2 = 0.938	Y= -21.649 + 24.045 * log(x), R^2 = 0.660

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DISCUSSION

Large individuals of *Phorcus turbinatus* are difficult to swallow by predatory littoral birds of the study sites, and even if that happened, the shell could not be digested or pass easily through the alimentary canal of the bird. Juveniles avoid predation behaviorally by hiding under crevices during the day. The outer color of the shell and the decoration are possibly related to thermal balance and camouflage. The shell-shape indicators established in the present study are certainly related to habitat specifications, but how? In addition to habitat traits, other factors related to the snail, such as its limited mobility, its inability to fix itself strongly to bottom rocks like the patella, its tendency to forage at night, and its anatomical and physiological composition, collectively play important roles in adapting the snail to its habitat. Al-Haneah *P. turbinatus* was larger in size than that of Susah, *P. turbinatus* mean height from base to apex was 13.729mm in Al-Haneah, and 12.818mm in Susah. Its mean weight was 3.766gm in Al-Haneah, and 3.179gm in Susah. It is possible that the coastal environment around Al-Haneah is healthier than Susah's. Al-Haneah is less populated than Susah, municipal waste of Susah is discharged directly into the sea. Eisay (2020), on a study on the morphometric traits of *Pachygrapsus marmoratus*, found that the crab attained a larger size in Al-Haneah than in Susah. This difference was attributed to differences in the healthiness of the coastal environments of the two sites. Boucetta (2017) in a study on the heavy metal content of *P. turbinatus* from the eastern coasts of Algeria reported that the height of this gastropod ranged from 24.14mm to 27.96mm according to the study site, while weights ranged from 6.34gm to 14.47gm. Tryon (1889) reported that the size of the *P. turbinatus* shell varies between 15 mm and 43 mm. Because Al-Haneah *P. turbinatus* was larger than that of Susah, almost all of its measured shell parameters were larger in magnitude.

Binary correlations of all measured parameters of Al-Haneah and Susah *P. turbinatus* were very strong. Regressions of the measured parameters vs. length from the base to apex or length of the base were significant and had high coefficients of determination. This is in agreement with Boucetta *et al*. (2008), who reported that *P. turbinatus* showed a highly significant correlation between the various measured parameters and the height of the shell.

In the present study, the power, linear, and logarithmic regressions represented the length-weight relationship very well since they scored high R^2. The length-weight relationship of Al-Haneah and Susah *P. turbinatus* based on total weight vs. height from the base to the apex reflected negative allometric growth (b = 2.640 and 2.443 consecutively); however, the relationship based on length of base reflected positive allometric growth (b = 3.278 and 3.306 consecutively). Boucetta *et al*. (2008) established that growth of *P. turbinatus* in the Algerian coast is generally isometric; the regression equations of the length-weight relationship are: $TW = 2.415 H_1 - 2.113$ (Chetaibi Bay) and $TW = 2.153 H_1 - 1.718$ (Annaba Bay).

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Menzies *et al*. (1992) and Boucetta (2017) mentioned that plasticity is a function of the environment. The littoral zone is a transition between the marine and the terrestrial environments; therefore, it is a harsh environment where exposure at low tide may subject littoral animals to desiccation, overheating/overcooling, and exposure to extreme salinities; submersion at high tides subjects these animals to wave and current actions. The interaction between the tidal regime and the feeding activity of snails is yet to be understood. The values of the calculated shell shape indicators of Al-Haneah and Susah *P. turbinatus* were close. Differences between Al-Haneah and Susah regressions of calculated shell shape indicators vs. shell height from base to the apex are believed to be adaptations to the habitat, modulated by ontogeny.

Implication to research and practice

This work calls attention to the difficulties encountered when relating morphological traits of littoral animals to habitat traits. As morphology is not the only expression of environmental traits, other factors, such as anatomical and physiological makeup and behavioral techniques, work collectively with morphology to shape the adaptations of individuals in the littoral community. However, as of today, it appears that there are no means for separating these ramifications.

CONCLUSIONS

The morphology of *P. turbinatus* in Al-Haneah and Susah was established on the bases of morphogenic features of the shell, and measured shell parameters, from which shell-shape indicators were calculated. The morphology was compared between the two study sites and related to growth. However, explaining how the obtained morphology helps the snail to adapt to its habitat turns out to be a difficult job.

Future research

It is recommended that future studies on morphology as an adaptation of littoral animals to their environment include the role of anatomical, physiological and behavioral traits of the organism under the study.

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