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Baseline monitoring gastropods in the intertidal zone of Qatar - target species and bioindicators for hyper-thermic and hyper-saline Conditions

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Abstract: *The Arabian Gulf is subjected to some of the most intense sea water temperatures and salinity levels in the world. In an attempt to understand the distribution and species composition of gastropod assemblages which live in these hyper-thermic and hyper-saline conditions a rapid assessment survey was undertaken along the intertidal zone of Qatar. The research revealed an obvious geographical temperature/salinity gradient between sites on the southeast and southwest coastlines. Water temperatures of 34°C and salinities ranging from 39.9 to 56.8ppt were recorded in-situ. There was detectable change in gastropod assemblage composition in accordance with this gradient. The abundance and diversity of live species decreased as temperature and salinity rose while high densities of dead species were recorded at sites where extremes of temperatures and salinities were documented. Ceritidiopsila conica was the dominant species at sites which experienced the most extreme conditions and has value as a recognized bio-indicator of high temperature/salinity environments within the region.*

Keywords: *Extreme salinity and temperature; Taphonomic; Monitoring; Bioindicator; Benthic ecology; Coastal zone.*

1. Introduction

The Arabian Gulf is one of the most environmentally restricted ecoregions in the world [1]. It experiences some of the highest temperature and salinity conditions found in shallow water marine coastal zones, especially the west coast where Qatar is located. Atmospheric and water temperatures reach biologically challenging levels for animals which inhabit this environmental niche. During the summer months it is not unusual for seawater temperatures to be as high as 37 oC (subtidal) and air temperatures to reach up to 55 oC. These temperature conditions in the shallow marine zones are conducive to a high level of evaporation and subsequently salinity measurements can be as high as 70ppt [1–6]. The coastal regions of the western Arabian Gulf experience harsh environmental conditions, especially within the intertidal zone were species are not only exposed to high temperature and salinity but are also subjected to intense sunlight incidence and desiccation levels.

The region has a geological history of extreme environmental conditions. Records dating as far back as the mid-Holocene have shown that the eco-region presented intense temperatures with hyper-saline lagoons within the intertidal zone creating abiotic factors which influenced evolutionary selective pressures. This helps to explain the high endemism of the region which accommodates euryhaline species adapted to live in these intense conditions [7–9].

The gastropods are one of the most diverse and taxonomically well-described groups of marine species within the Arabian Gulf [10,11]. Similar to other marine species the gastropods present a well-divided assemblage in coastal zones in accordance with associated abiotic conditions, with species restricted to supratidal, intertidal and subtidal zone; species restricted to a certain substrate and species limited by physiochemical parameters [12–17]. The use of the Rapid Assessment Survey (RAS) has been shown to be an excellent tool when assessing species composition in highly fluid environmental conditions like those of the intertidal zone. In fact Underwood (1979) [18] and Smith (2005) [19]described it as one of the best ways of comparing intertidal marine ecosystems when using target species.

In order to conduct the Rapid Assessment Survey (RAS) technique for monitoring the shorelines of Qatar: We aimed to identify and describe target bio-indicator species which could be used to understand the influence that extreme hyper-thermic and hyper-saline conditions could have over intertidal gastropod assemblages.

2. METHODS

2.1. Study Area

The study was carried out at two sites on the exposed eastern and two on the enclosed western coastlines of Qatar: (Al-Wakra), 25° 7' 53" N - 51° 37' 2" E Northeast Coast; (Al-Khor), 25° 37' 312" N - 51° 32' 717" E, East Coast; (Zekreet) 25° 29' 326" N - 50° 50' 171" E, Northwest Coast; (Umm-Bab) 24° 48' 810" N - 50° 51' 779" E, West Coast (Figure 1).

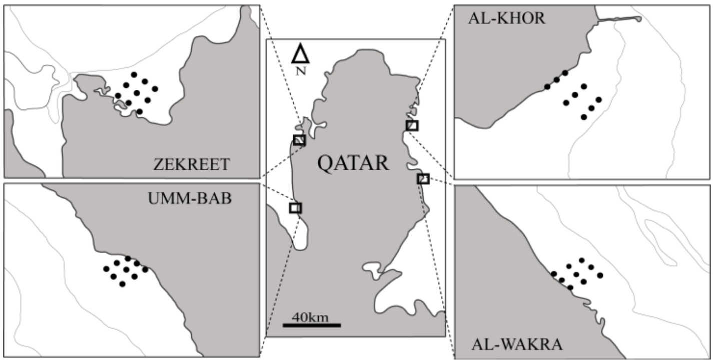

Figure1. *Map of Qatar in the Arabian Gulf, with the 4 sample sites and their position in the shoreline, being Al-Wakra, Al-Khor, Zekreet and Umm-Bab; highlighting the 9 intertidal sample areas in each sample site.*

At each sample site the intertidal zone was schematically divided into three levels. High Intertidal zone (HI), just below the visible supratidal line; Low Intertidal zone (LI) almost in contact with the water at low tide; and the third in the Middle intertidal zone (MI) in between and parallel to the HI and LI. These three zones were divided into 3 sample regions, fasted 20m each other. Totalling 9 sample areas at each site (Figure 1). Survey data was collected using the rapid assessment survey technique described by Smith, (2005) [19]. Three quadrats (0.5 m^2) were placed randomly at each survey location, sampling efforts comprised of 27 quadrats per site. Nine quadrats were taken at each designated intertidal level (9 at HI, 9 at MI and 9 at LI). This equated to a total of 108 quadrats for the whole study, 36 from each tidal level (36 from HI, 36 from MI and 36 from LI).

2.2. Methodology

Sampling took place in November 2014; at low tide; between 7:00 am and 1:00 pm. Gastropod species were collected manually within the quadrat area, transported to the laboratory and identified using the appropriate taxonomic references. Each specimen was visually inspected and probed with a dissection pin (trying to pin the operculum) to confirm if the shell was empty. To account for the aestivation of gastropod specimens further confirmation of shell occupancy was required by breaking the shell open (supposedly dead animal), as numerous gastropod species will retract deep inside the shell during harsh conditions. Aiming to classify the length of time the gastropod had been dead, each empty shells were classified (before broke) as: vibrantly coloured shell for recently dead gastropods; bleached and eroded shells for gastropod which had been dead a considerable length of time. Live specimens were conserved in 70% alcohol and deposited in the Marine Collection of Environmental Science Centre - ESCMC at Qatar University. Abiotic factors such as: salinity, temperature and conductivity of water were analysed using a TI – 4SI 6000 Series probe at each site. Each quadrat was photographed to qualify the percentage cover of rock and sand and percentage cover of tidal pools and dry substrate.

2.3. Data Analysis

To analyse the live species composition at each site and intertidal level the following ecological indices were used: Abundance (m^2); Frequency of occurrence (%) considered, Rare (Fa <10%), Occasional (10% ≤ Fa < 25%), Common (25% ≤ Fa < 50%), Very Common (50% ≤ Fa ≤ 75%) or Constant (75% ≤ Fa ≤ 100%); and Dominance (%) of species considered, Dominant (Da >10%), Representative (1% ≤ Da < 10%) and Inexpressive (Da <1%) [20].

To distinguish between the number of live species in aestivation and the dead species with coloured shell, bleached shell and eroded shell the total abundance of each categorised shell description was used in conjunction with species: Abundance (m^2) and Diversity Index (H') of Shannon-Wiener indices were used. The Student T test was used to verify the significance level of differences between the means of abundance and diversity ($p<0.05$). Diversity indices and statistical analysis were performed using the PAST© statistical software package.

Analysis of Similarities (ANOSIM) was compared the live species according to site and intertidal level; using a Bray-Curtis similarity matrix with transformed (log-1) and standardized data; R-values greater than 0.5 and a significance level less than 5% were considered statistically significant. To present the results a non-Metric Multidimensional Scaling plot (nMDS) and a principal component analysis plot (PCA) were used. SIMPER analysis was performed to identify the main components of the sites at the specific intertidal level. All multivariate ecological calculations were carried out using Primer® v6 software [21].

3. RESULTS

3.1. Abiotic Factors

At Al-Wakra (East) - 50% rock and 50% sand (Figure 2A); 30% of tidal pools and 70% of dry substrate (Figure 2B); water temperature of 34.8ºC, conductivity of 71.8 and salinity of 39.9 (Figure 2C). At Al-Khor (Northeast) - 26% rock and 74% sand (Figure 2A); 41% tidal pools and 59% dry substrate (Figure 2B); an in-situ water temperature of 35.9 ºC, conductivity of 80.5 and salinity of 44.8 (Figure 2C). At Zekreet (Northwest) - 30% rock and 70% sand (Figure 2A); 28% of tidal pools and 73% of dry substrate (Figure 2B); water temperature of 32.2 ºC, conductivity of 89.8 and salinity of 54.8 were recorded (Figure 2C). At Umm-Bab (West) 49% rock and 51% sand (Figure 2A); 35% tidal pools and 65% dry substrate (Figure 2B); water temperature of 33.9 ºC, conductivity of 95.7 and salinity of 56.8 (Figure 2C).

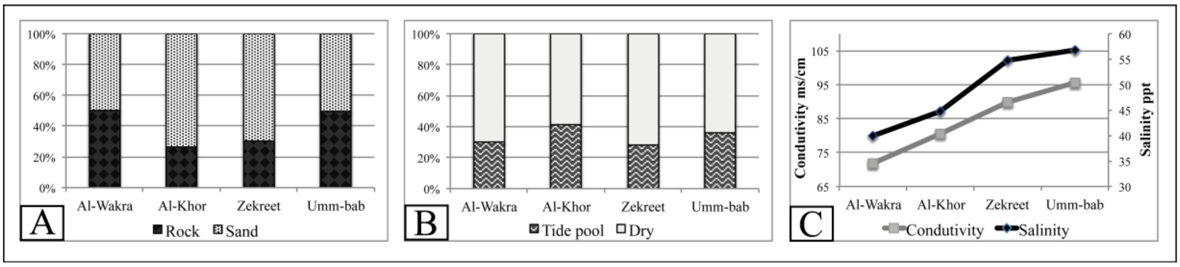

Figure2. *Abiotical samples in the sample sites in Qatar Al-Wakra, Al-Khor, Zekreet and Umm-Bab, being: [**A**] quadrat percentage average of rock and sand according with the sample sites; [**B**] quadrat percentage average of tide pools (wet area) and dry areas according with the sample sites; and [**C**] the conductivity (ms/cm) and salinity (ppt) collected in each sample sites.*

The Qatar shoreline presented two distinct salinity levels, with the west coast displaying a higher salinity than the east coast. A salinity gradient was clearly distinguishable between the southeast and southwest at Figure 2C.

3.2. Species composition – target species

A total of 11 live gastropod species were collected (Table 1) and considered as target species: belonging to the families Cerithiidae (2sp), Chilodontidae (1sp), Columbellidae (1sp), Littorinidae (1sp), Muricidae (1sp), Planaxidae (1sp), Potamididae (2sp), Trochidae (1sp), Turbinidae (1sp). Each target species is presented below in order of abundance and dominance:

Cerithideopsilla conica (Blainville, 1829) was the most dominant and abundant live species; followed by *Clypeomorus persica* Houbrick, 1985; *Echinolittorina arabica* (El Assal, 1990); *Planaxis sulcatus* (Born, 1778); *Cerithideopsilla cingulata* (Gmelin, 1791); *Priotrochus kotschyi* (Philippi, 1849); *Mitrella blanda* (Soverby, 1844); *Cerithium scabridum* (Philippi, 1848); *Thalessa savignyi* (Deshayes, 1844); *Lunella coronata* (Gmelin, 1791); and *Euchelus atratus* (Gmelin, 1791). Results at abundance, dominance and frequency are presented in Table 1; and SIMPER analysis was presented in Table 2.

Table1. *Presenting the [A] Abundance (specimen / m2), [F] Frequency (CT-Constant; VC-Very Common; Co-Common; Oc-Occasional; and Ra-Rare) and the dominance (dark grey cell is dominant; light grey cell is representative; and no colour cell is inexpressive) of the live gastropods collected in Qatar in each intertidal levels (high level, middle level and low level) of each sample sites (Al-Wakra, Al-Khor, Zekreet and Umm-Bab). * represent the intertidal species that were only captured in live conditions.*

	High Level								Middle Level								Low Level							
	Al-Wakra		Al-Khor		Zekreet		Umm-Bab		Al-Wakra		Al-Khor		Zekreet		Umm-Bab		Al-Wakra		Al-Khor		Zekreet		Umm-Bab	
Species	A	F	A	F	A	F	A	F	A	F	A	F	A	F	A	F	A	F	A	F	A	F	A	F
Clypeomorus persica	1.6	OC	-	-	-	-	-	-	57.1	CT	6.7	CT	-	-	-	-	22	CT	31.8	CT	-	-	-	-
Cerithium scabridum	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.2	Ra	2.7	VC	2.4	Co	-	-	-	-
Euchelus atratus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.4	Ra	-	-	-	-	-	-
Mitrella blanda	-	-	-	-	-	-	-	-	2.7	Co	0.2	Ra	-	-	-	-	1.1	Co	2.7	Co	1.8	VC	5.1	VC
Echinolittorina arabica	103.7	VC	50.4	VC	-	-	-	-	-	-	0.2	Ra	-	-	-	-	-	-	-	-	-	-	-	-
* *Thalessa savignyi*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.3	Co	0.2	Ra	-	-	-	-
Planaxis sulcatus	24.4	VC	-	-	-	-	-	-	22.9	CT	0.7	Co	-	-	-	-	0.4	Ra	-	-	17.8	Ra	-	-
Cerithideopsilla conica	7.6	Co	54.4	Co	-	-	14.7	VC	-	-	62.9	CT	138.2	CT	40.9	CT	-	-	1.6	Co	86	CT	24.4	CT
Cerithideopsilla cingulata	2	Oc	2	Co	-	-	-	-	21.6	CT	10.9	VC	-	-	-	-	-	-	0.2	Ra	-	-	-	-
Priotrochus kotschyi	0.2	Ra	-	-	-	-	-	-	0.9	Co	0.7	Co	-	-	-	-	24.2	CT	1.3	Co	4.2	Co	4.2	VC
Lunella coronata	0.2	Ra	-	-	-	-	-	-	0.4	Ra	-	-	-	-	-	-	2	Co	0.7	Oc	-	-	-	-

3.3. Aestivation, Mortality and Taphonomic relation

The number of retracted specimens in relation to sample site followed the salinity range (Figure 3A), with a higher number of specimens in aestivation on the west coast (Zekreet and Um-Bab) with the associated gastropod assemblage composed only of *Cerithideopsilla conica* and *Mitrella blanda* (Table 3). The sites with the lowest salinity level presented fewer specimens in aestivation (Figure 3A) and a large number of individual species when compared to sites on the west coast (Table 3). The number of specimens just dead (colour shells) also increases with salinity level (Figure 3A) with the main components at Table 3.

Table2. *SIMPER results presenting the most representative species according to sample sites (Al-Wakra, Al-Khor, Zekreet and Umm-Bab) and intertidal levels (high, middle and low level).*

Species	Sim/SD	Contribution %
Al-Wakra		
Clypeomorus persica	0.93	46.69
Planaxis sulcatus	0.52	19.16
Priotrochus kotschyi	0.4	15.66
Echinolittorina arabica	0.21	6.48
Cerithideopsilla cingulata	0.34	5.88
Al-Khor		
Cerithideopsilla conica	0.84	60.01
Clypeomorus persica	0.44	22.68
Cerithideopsilla cingulata	0.4	9.84
Zekreet		
Cerithideopsilla conica	1.5	96.4
Umm-Bab		
Cerithideopsilla conica	1.31	94.21
High Level		
Echinolittorina arabica	0.74	64.28
Cerithideopsilla conica	0.47	20.28
Planaxis sulcatus	0.38	10.98
Middle Level		
Cerithideopsilla conica	0.99	84.48
Clypeomorus persica	0.33	6.5
Low Level		
Priotrochus kotschyi	0.64	37.23
Cerithideopsilla conica	0.44	29.16
Clypeomorus persica	0.49	25.29

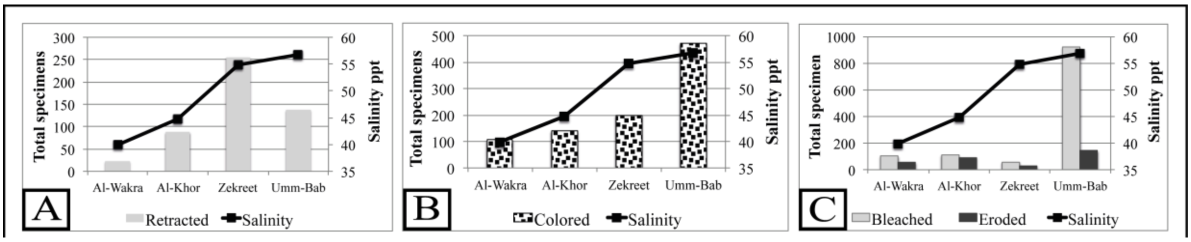

Figure3. *Comparison with the sample sites in Qatar (Al-Wakra, Al-Khor, Zekreet and Umm-Bab) with the number of specimens in each site that were found retracted (in aestivation) (**A**), just dead species with colour shell (**B**), and species that died a long time with shells blanched or eroded (**C**). All data correlated with the salinity level in each sample site.*

Table3. *Number of specimens visually considered dead in each sample sites (Al-Wakra, Al-Khor, Zekreet and Umm-Bab). Shells were classified as: live specimens but with animal retracted (Rt); dead specimen with colour shell (Co), bleached shell (Bl), and eroded shell (Er). * represent the intertidal species that were only captured dead shells; ** represent the subtidal species (dead shells) captured in the intertidal zone.*

	Al-Wakra				Al-Khor				Zekreet				Umm- Bab			
SPECIES	Rt	Co	Bl	Er	Rt	Co	Bl	Er	Rt	Co	Bl	Er	Rt	Co	Bl	Er
Clypeomorus persica	**10**	51	21	22	**41**	55	71	52	-	-	-	-	-	-	23	3
Cerithium scabridum	**11**	17	22	17	**4**	2	-	-	-	-	-	-	-	66	175	61
Euchelus atratus	-	1	-	-	-	-	-	-	-	1	-	-	-	9	11	7
Mitrella blanda	-	-	1	5	**2**	1	2	1	**3**	2	1	1	**9**	26	149	11
Echinolittorina arabica	-	-	12	-	**11**	4	-	-	-	1	-	-	-	-	-	-
Planaxis sulcatus	**2**	11	-	-	-	62	5	2	-	9	4	1	-	1	-	-
Cerithideopsilla conica	-	1	-	2	**29**	14	23	35	**252**	175	40	20	**129**	343	479	2
Cerithideopsilla cingulata	-	1	1	3	-	-	-	-	-	-	-	-	-	-	-	-
Priotrochus kotschyi	-	19	40	3	**1**	-	4	-	-	10	12	4	-	18	72	51
Lunella coronata	-	2	3	3	-	1	1	1	-	-	2	1	-	-	-	-
**Umbonium vestiarium*	-	1	2	1	-	-	3	1	-	-	-	-	-	-	-	-
**Bulla ampulla*	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
**Ancilla exigua*	-	-	1	-	-	-	1	-	-	-	-	-	-	6	1	3
**Semiricinula konkanensis*	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-
**Tricolia ios*	-	-	-	-	-	-	-	-	-	-	-	-	-	1	5	-
**Euchelus asper*	-	1	-	-	-	-	-	-	-	1	-	-	-	-	-	-
***Hexaplex rileyi*	-	-	-	-	-	-	-	-	-	-	-	1	-	-	4	6
***Pseudominolia nedyma*	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-

Among the 18 dead species (Table 3), 8 were found exclusively as dead shells (bleached and eroded) *Umbonium vestiarium* (Linnaeus, 1791), *Bulla ampulla* (Linnaeus, 1758), *Ancilla exigua* (G. B. Sowerby I, 1830), *Semiricinula konkanensis* (Melvill, 1893), *Tricolia ios* (Robertson, 1985), *Euchelus asper* (Gmelin, 1791), *Hexaplex rileyi* (D'Attilio and Myers, 1984) and *Pseudominolia nedyma* (Melvill, 1897). Dead specimens (coloured, bleached and eroded shells) were most abundant at Um-Bab (Figure 3C) with higher diversity suggesting that this shoreline may act as a deposit for dead shells probably a result of localised eddies generated by the hydrodynamic conditions experienced at the site.

3.4. Sites and Levels

A total of 3395 live gastropods were collected during the survey, with an average of 63 gastropods per m^2, being 1325 (98 / $1m^2$) at Al-Wakra; 947 (70 / $1m^2$) at Al-Khor; 857 (63 / $1m^2$) at Zekreet; and 266 (19 / $1m^2$) at Umm-Bab (Figure 4). The abundance of live species was higher at Al-Wakra when compared to Zekreet (p=0.034), and Umm-Bab (p=0.00041); and higher in Al-Khor when compared to Umm-Bab (p=0.0015). The dead specimens totalled 2946 with an average of 55 shells per m^2 composed of; 327 (24 / $1m^2$) at Al-Wakra, 496 (36 / $1m^2$) at Al-Khor, 433 (32 / $1m^2$) at Zekreet and 1690 (125 / $1m^2$) at Umm-Bab (Figure 4). The abundance of dead species was only significantly higher at Umm-Bab when compared to Al-Wakra (p=0.00013), Al-Khor (p=0.00081) and Zekreet (p=0.00076).

The diversity of live species was highest at Al-Wakra followed by Al-Khor, Umm-Bab and Zekreet (Figure 4); significantly higher at Al-Wakra compared to Al-Khor (p=0.038), Zekreet (p=0.00022) and Umm-Bab (p=0.00025); and highest at Al-Khor when compared to Zekreet (p=0.00036) and Umm-Bab (p=0.0003). The diversity of dead shell species was highest at Umm-Bab compared to Al-Wakra (p=0.00018), Al-Khor (p=0.0047) and Zekreet (p=0.000049).

Abundance and Diversity of live specimens (Figure 4) decrease according with the increase of salinity/conductivity (Figure 2C); while the Abundance and Diversity of dead specimens (Figure 4) increase according with the increase of salinity/conductivity (Figure 2C).

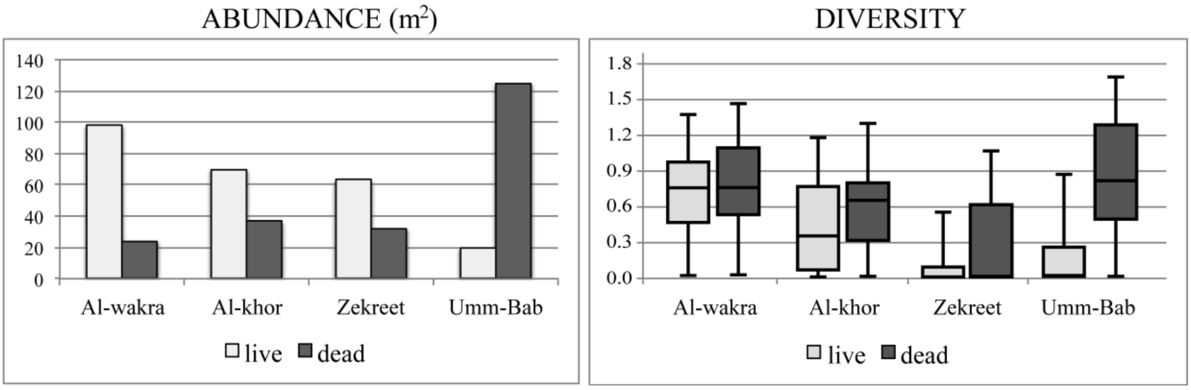

Figure4. *The abundance (m^2) and diversity (Shannon-Wiener) of live and dead gastropods according with the sample sites Al-Wakra, Al-Khor, Zekreet and Umm-Bab*

The cluster analysis comparing intertidal levels and sites in relation to live species (including retracted ones) are displayed in Figure 5 and Table 4. Al-Wakra present distinct population according with intertidal levels (high, middle and low); Al-Khor high and middle was the same population with a different population in the low levels; Zekreet and Umm-Bab were similar in all levels. Middle levels population were different between Al-Wakra and Al-Khor. At PCA in figure 5 it is possible to observe that almost all species are related to Al-Wakra and other sites only samples at their low intertidal levels are more related with the higher diversity; while Um-Bab, Zekreet and middle and high levels at Al-Khor was related only with *Cerithideopsilla conica.*

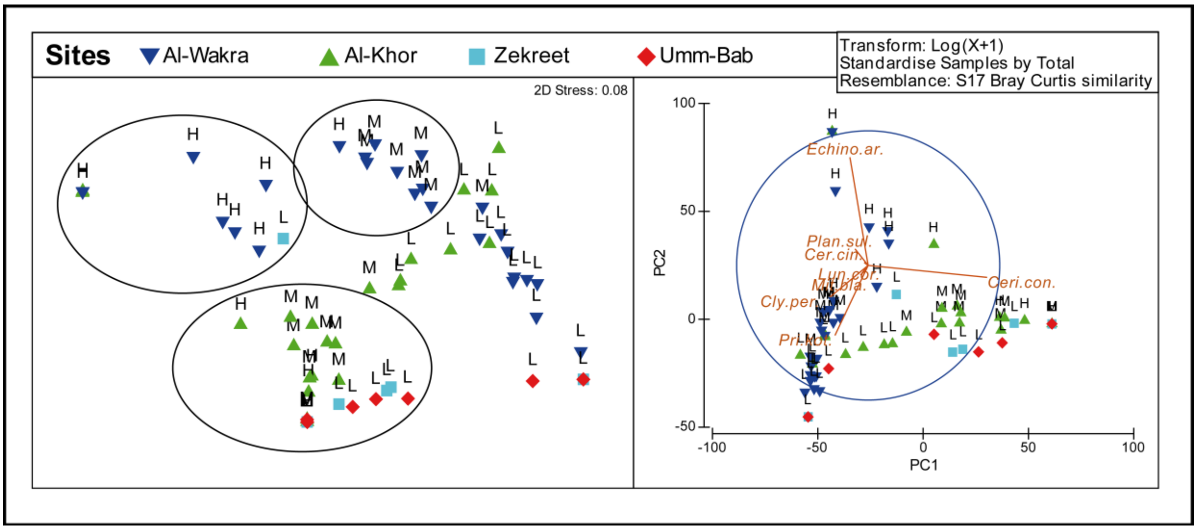

Figure5. *Multivariate analysis with nMDS (non-Metric Multidimensional Scaling) and PCA (Principal Component Analysis) comparing the sample sites Al-Wakra, Al-Khor, Zekreet and Umm-Bab according with the intertidal levels [**H**] high level, [**M**] middle level and [**L**] low level; using the main species Cerithideopsilla conica (Pot.con.), Cerithideopsilla cingulata (Cer.cin.), Echinolittorina arabica (Nod.sp), Planaxus sulcatus (Plan.sul.), Mitrella blanda (Mit.bla.), Lunella coronata (Lun.cor.), Clypeomorus persica (Cly.B.per.) and Priotrochus kotschyi (Osi.ko)*

4. Discussion

The research revealed some ecological patterns within gastropod assemblages in relation to environmental conditions in Qatar. The region presented a low diversity and high abundance of species in comparison to other studies carried out in the Arabian and Omani Gulfs [11,22–24]. The combination of high abundance and low diversity are characteristic of populations that live in extreme conditions such as cold temperatures [25] or anthropogenically impacted environments [26,27]. In addition the ecological pattern were a single species dominates an environment are typical of a historically well-established old ecosystem, corroborating with the historical harsh condition reported to Arabian Gulf since the mid-Holocene [7–9].

One of the most significant results of the research is the influence that physiochemical parameters have in driving species diversity and abundance. This influence is observed within this study when comparing the east and west coast of Qatar; but can also be observed when comparing the gastropod assemblage in this study performed in the west coast of Arabian Gulf with the gastropod assemblage in Iran in the East side of the Gulf [24]. Remembering that the marine area in Iran keep changing water masses between the Indian Ocean and the Gulf [5]. In Qatar on the western gulf, environmentally acceptable conditions for marine life were considered to start at 34.8oC sea temperature and salinity of 39.9ppt. In contrast on the eastern gulf in Iran a study investigating intertidal gastropod diversity considered a summer temperature of 33oC with a level of 39ppt as ecologically harsh [24]. In addition in this same study in iran [24] it was reported a significantly higher diversity of species with a low number of dominant species. Furthermore C. conica was un-significant in dominance in Iran, while here on the western coast of the Arabian Gulf it was the overwhelming dominant species in salinities > 45ppt. This study has shown that the salinity ranges are the main factor driving the abundance and diversity of species and it was obvious from the results as salinity increased species diversity and abundance decreased and single species dominance became prevalent. However although salinity is the governing factor it in turn is being driven by temperature and by the hydrodynamic regimen (depth and intensity of water curents) and this last one represents the great diference when comparing as the east and west coast of Qatar as the east and west coast of Arabian Gulf [5].

Another ecological patterns within gastropod assemblages reported here is the relation between abiotic factors with the aestivation and mortality of species. In this study the number of specimens in aestivation and the number of recently dead specimens (colour shells), increased according with the increase of salinity, suggesting that an intense mortality and aestivation is driven by an increase in salinity (see table 3 and figure 3). Remembering that this influence of salinity occurred with indigenous gastropod species in the western Arabian Gulf such as C.conica, C. persica, E. arabica, L. coronata, M. blanda, C. scabridum and P. kotschyi, some of which are endemic to the region and have fossil records that date back to the mid-Holocene when extreme saline lakes dominated the region [7,9,28,29]. Therefore these species have adapted over time to the intense salinities and temperatures subjected to the region.

Aestivation in gastropods is an adaptation when specimens are exposed to extremes conditions and they initiate an instantaneous suppression of metabolic rate and enter into short-term metabolic diapause reducing the loss of water [30]. Each species presents a differing level of tolerance to each abiotic factor and when the environmental tolerance level for the species is exceeded the coping mechanism of the gastropod ceases and the animal dies. [30]. It is possible to see in table 3 the influence of salinity levels in relation to the number of each species dead or in aestivation. A particular gradient of each species absence and mortality is visible with the increasing salinity levels. For example, even C. conica an euryhaline species [8] and the main bio-indicator of high salinity levels (proposed here) revealed increases in the number of individuals in aestivation at sites were salinity was >54 while also displaying low densities at high shore zones (long period in desiccation). Highlighting that beyond salinity the desiccation has a great influence in defining the presence or absence of gastropods (see each species per tide levels in table 1).

It was also evident that were species presented a high density of dead individuals was also the site were the species would be recorded alive in its highest densities. The exception however was Um-Bab which presented a disproportional number of dead bleached shells in comparison to those recorded as alive; it may be that the site acts as a depository for dead shells and the deposits of dead shell is influenced by the tidal characteristics and hydrodynamics of the area bringing shell material for surrounding areas.

The harsh environmental conditions during the summer [5] and the high mortalities recorded here in the summer along the intertidal suggest a cyclic mortality event takes place in Qatar in relation to temperature rises in combination with salinity and desiccation. Similar examples of cyclic mass mortalities have been described in other parts of the world with species that survive these events having population strategies or species specific adaptations to withstand these events [5,31].

Gastropod species have developed numerous adaptations to survive the challenging conditions and abiotic factors of the intertidal zone [32]. The suite of gastropod adaptations include thermos-regulation capabilities [33]; evaporative cooling systems, light shell colouration as a reflective strategy [34]; and the aestivation discussed above [30]. Varying degrees of these adaptations were apparent in all of the species examined during this research and it is apparent that the species of the intertidal in the western Arabian Gulf are phylogenetically adapted to cope with the extremes of the region. However the exact tolerance level for each species in relation to temperature, salinity, exposure and desiccation is not yet understood and will only be known with further physiological experiments in the laboratory when the true species specific limit mortis will be discovered.

Table4. *Anosim results comparing intertidal levels and sites in relation to live species. Global R): 0.59 Significance level of sample statistic: 0.1%. Results in bold represents the significant differences.*

Sites x Levels	R - Statistic	Significance Level %
High levels		
Al-Wakra X Al-Khor	0.209	6.1
Al-Wakra X Umm-Bab	**1**	**0.1**
Al-Khor X Umm-Bab	**0.881**	**0.1**
Middle levels		
Al-Wakra X Al-Khor	**0.932**	**0.1**
Al-Wakra X Zekreet	**1**	**0.1**
Al-Wakra X Umm-Bab	**1**	**0.1**
Al-Khor X Zekreet	0.479	0.2
Al-Khor X Umm-Bab	**0.525**	**0.3**
Zekreet X Umm-Bab	0	100
Low levels		
Al-Wakra X Al-Khor	**0.682**	**0.1**
Al-Wakra X Zekreet	**0.637**	**0.1**
Al-Wakra X Umm-Bab	**0.588**	**0.1**
Al-Khor X Zekreet	**0.681**	**0.1**
Al-Khor X Umm-Bab	**0.727**	**0.1**
Zekreet X Umm-Bab	-0.056	71
Al-Wakra		
High X Middle	**0.678**	**0.1**
High X Low	**0.915**	**0.1**
Middle X Low	**0.925**	**0.1**
Al-Khor		
High X Middle	0.265	2
High X Low	**0.754**	**0.1**
Middle X Low	**0.789**	**0.1**
Zekreet		
Middle X Low	0.163	3.4
Umm-Bab		
High X Middle	0.178	2
High X Low	0.473	0.3
Middle X Low	0.263	3.4

5. CONCLUSION

The Rapid Assessment Survey using random quadrat sampling has been shown to be a simple yet effective tool for monitoring the challenging coastal environments in the western Arabian Gulf. It is capable when properly applied of highlighting differences in biodiversity in relation to abiotic factors. The study concurs with the findings of Smith (2005) [19] that gastropods are habitat specialists [11] and ideal candidates for identifying and comparing differences between intertidal sites in regards to physiochemical, seasonal and anthropogenic influences. The research has presented the first baseline data list for gastropod target species which can be used for monitoring protocols (table 1). The dominance of C. conica has been identified as a key indicator of extreme high salinity.

The study revealed that an understanding of the temperature and salinity management abilities expressed by these species can be one of the main drivers for further studies of the intertidal ecosystem in Qatar. Further investigations like the one undertaken in this research should be carried out as a matter of urgency as the region presents conditions that provide an insight into possible environmental changes in the future as global temperatures continue to rise. An understanding of the ecological variations and adaptations of species from the region will allow for the early identification that a global warming scenario may present in the future.

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