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Lichen communities responses to a changing environment: A case study of Ħaġar Qim and Mnajdra Temples

Introduction

The megalithic temples of Ħaġar Qim and Mnajdra are considered to be amongst the oldest surviving examples of archaeological remains in the world, dating back to the 4th millennium BC. These temples represent a highly innovative and sophisticated architecture for the Neolithic period making them a fundamental reference point in architectural history.[1] Their value as archaeological remains has also been recognised by the United Nations Educational, Scientific and Cultural Organization (UNESCO) and in 1992 these were inscribed on the UNESCO World Heritage List.

In addition to their paramount significance for local and international archaeology, a number of stone features making up these Neolithic temples provide several habitats where biological communities may develop. Lichens[2] in particular are considered to be an important feature colonising both horizontal and vertical stone surfaces at the temples of Ħaġar Qim and Mnajdra. Their presence is mostly valued because a number of species have the ability to protect the underlying stone substrate by acting as a buffer against elemental deterioration which would have taken its toll throughout the years.[3]

Since their excavation, in the 19th century these Neolithic temples have been subjected to weathering by atmospheric elements including precipitation and sharp thermal fluctuations causing extensive deterioration within the sites.[4] The temples of Ħaġar Qim and Mnajdra are built from local bedrock. Most of the megalithic structures were built using lower Globigerina Limestone, a relatively soft stone, with the exception of the outer walls of Mnajdra Temples which were built using Lower Coralline Limestone[5]. Accelerated deterioration of stone is particularly noticeable in those parts that were built from the softer Globigerina Limestone.

In an effort to better conserve these temples and to slow down the deterioration, temporary protective sheltering structures were put up over the two temples in 2009 (Fig 1). This decision was taken by the Scientific Committee which was set up following an international meeting of experts held in Malta in 1999 to identify the way forward for the conservation of the Megalithic Temples. The

Fig. 1 Protective shelter over Ħaġar Qim main temples

Fig. 2 Major horizontal community types; Yellow orange community dominated by *Caloplaca* species (left) and blackish community dominated by *Verrucaria nigrescens* (right).

shelters were constructed in a manner to ensure that the existing hygrothermal balance would not be drastically modified by the intervention.[6]

Colonization and distribution of lichen flora on stone is influenced by a number of habitat and environmental characteristics including water availability, temperature, light intensity and wind[7]. In addition, the restricted microclimatic requirements of lichens make these species vulnerable to a range of environmental alterations[8]. Consequently, changes in annual temperature fluctuations, moisture availability and illumination brought about by the sheltering installations were expected to have significant effects on the lichen flora present within Ħaġar Qim and Mnajdra temples.

Biological monitoring studies are carried periodically by Heritage Malta in an effort to identify tendencies of biological colonization on stone and to contribute further towards a better understanding of lichen communities within these vulnerable habitats. To date two biological monitoring campaigns have been conducted. The first comprehensive survey was carried out in 2008 in exposed conditions and the second survey was conducted in 2013 after a four year period in sheltered conditions. This paper gives an overview of the responses of major lichen communities in the Neolithic temples of Ħaġar Qim, Mnajdra and an exposed control site, Ħaġar Qim North temples, by comparing lichen community composition and abundance between the two biological surveys together with changes in monitored environmental parameters.

First Biological Survey

The first comprehensive biological survey was carried out seasonally between November 2007 and August 2008 by Gómez Bolea et al. (2008) with the participation of the author. The survey's aims were to carry out detailed mapping and characterization of phanerogamic[9] and cryptogamic[10] plant communities occupying the stone substrate, soil floorings and infills present[11]. The survey was carried out in three temple remains: Ħaġar Qim main temples, Mnajdra temples and Ħaġar Qim North temple which lies a few meters north from Ħaġar Qim main temples. Ħaġar Qim North temple was included in the surveys with the intention to act as a control in future biomonitoring studies since these remains were not covered by the shelter, therefore enabling comparison of lichen community changes between exposed and sheltered conditions.

Fig. 3 Major vertical community types; Greyish community dominated by mature *Dirina massiliensis* (left), endolithic community of *Opegrapha calcarea* (centre), and reddish brown community of *Lecania spadicea* (right)

Lichen community types characterization

During this first biological campaign lichen flora was found to be a prominent feature on the stone substrate. Amongst the lichen species present five predominant lichen community types were identified which were later described in Llop et al. (2013). During the first survey in 2008 detailed maps of three *relevés* for each of the five identified lichen communities were made with the aim to be used as sampling points for long term biomonitoring campaigns within the temples. Three quadrants measuring 15 by 10 cm each were mapped for each lichen community. The methodology adopted for mapping and analyzing lichens followed Llop & Gómez-Bolea 2008.

On horizontal surfaces two distinct communities were characterized; a community made up predominantly of *Caloplaca* species and another community made up mostly of *Verrucaria nigrescens* (Fig 2). In shaded conditions, vertical stone surfaces were found to be colonized by three distinct communities, a community of *Dirina massiliensis*, an endolithic community of *Opegrapha calcarea* and a community of *Lecania spadicea*, with the last two communities being only present at Mnajdra temples (Fig 3).

Second Biological Survey

A post sheltering survey was carried out during the winter season between 2013 and 2014[12]. Changes in species were estimated using the previously mapped quadrants from the 2008 survey. The methodology adopted for analyzing lichen species richness and percentage cover followed Llop & Gómez-Bolea 2008. Species determination was carried out in the field and sampling operations have been avoided as much as possible for conservation reasons. In case of dubious species, specimens were collected from rubble walls in the vicinity and identified in the laboratory.

Data analysis

Biological and environmental data was first analysed for normality using Shapiro-Wilk Test. Due to non-normality in data distribution non-parametric tests have been used. Statistical analysis was carried out using SPSS Ver.19 (IBM Corp, 2010). Differences in lichen community percentage cover between exposed and sheltered conditions were explored using Kruskall-Wallis analyses of variance. Changes in cover for individual lichen species within community types and environmental parameters were assessed by pair-wise comparisons using Wilcoxon matched-pairs test. Local environmental

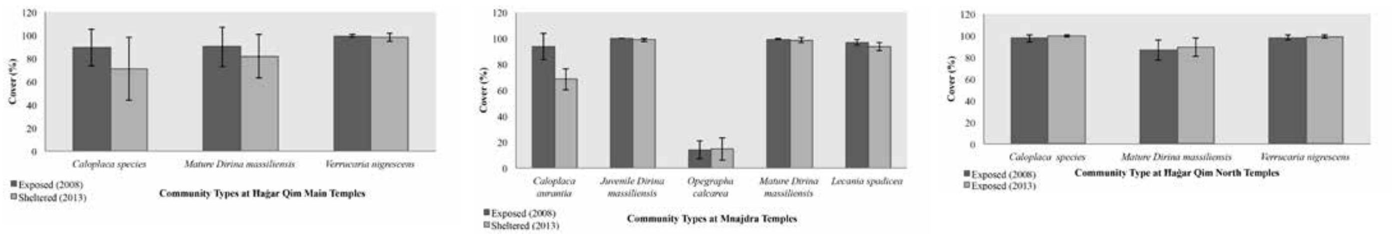


Fig 4 Evaluation of Mean cover (%) for major lichen community types between 2008 and 2013 at Ħaġar Qim main temples, Mnajdra Temples and exposed Ħaġar Qim North Temple. Kruskall-Wallis analysis of variance measured statistically significant reduction in cover for *Caloplaca* dominated community between exposed and sheltered conditions at Ħaġar Qim main temples (cover: $p = 0.003$) and Mnajdra temples (cover: $p < 0.0001$). Vertical error bars represent standard error of the mean ($n = 3$)

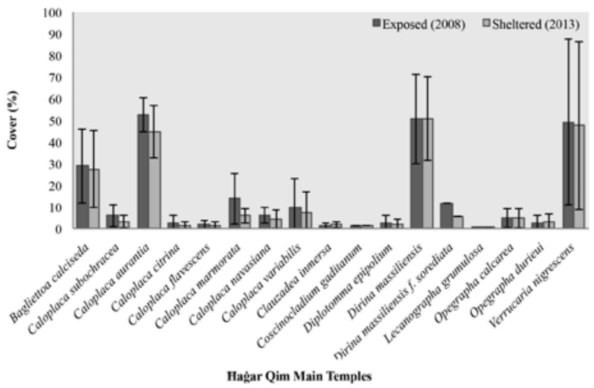
parameters including temperature (°C), relative humidity (%), radiation (KW/m^2), wind speed (m/s), and rainfall (mm) were explored to evaluate significant differences in daily means of environmental variables before and after sheltering installations. Such environmental data were provided by Heritage Malta's Preventive Conservation Unit[13].

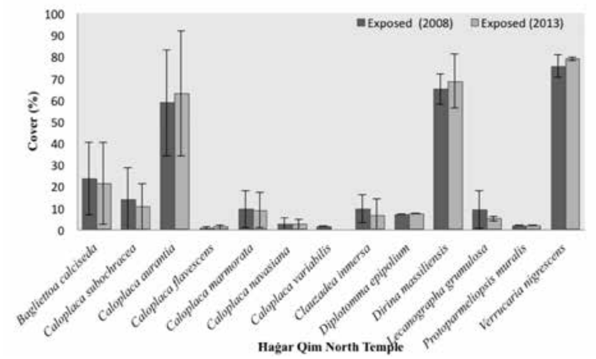
Results and Discussion

A comparison of lichen community cover data before and after sheltering conditions at Ħaġar Qim main temples and Mnajdra temples showed a general reduction in cover by all community types between the two study periods. In contrast there was a marginal increase in cover for lichen communities at the exposed Ħaġar Qim North temples between 2008 and 2013 (Fig 4). This supports the initial hypothesis that the new microclimatic conditions under the shelter would affect the lichen communities. It was also found that different lichen communities responded differently to the new microclimatic conditions, which indicates that the communities present have different magnitudes of response for the increased aridity within the temples.

Communities dominated by *Caloplaca* species on horizontal surfaces suffered the most significant reduction in cover in response to sheltering installations both at Ħaġar Qim main temples and Mnajdra temples (Fig 4). Pairwise comparisons between individual lichen species showed that there was a statistically significant decline in cover in a number of species belonging to the *Caloplaca* dominated community including *Bagliettoa calcarea* and *Caloplaca navasiana* followed by less but still significant reductions in *Caloplaca citrina*, *Clauzadea inmersa* and *Protoparmeliopsis muralis* (Fig 5). As expected, lichen species with a higher affinity for sun exposure and rainwater suffered the most in sheltering conditions.

Lichen communities which prefer diffuse sunlight and are confined to shady areas appear to have a higher tolerance to sheltering installations in contrast to species which favour direct solar exposure. This could be seen from the minimal decline in cover for community types dominated by *Dirina massiliensis*, *Verrucaria nigrescens* and *Lecania spadicea* under the shelters both at Ħaġar Qim and Mnajdra temples. In the case of communities dominated by *Dirina massiliensis* and *Lecania spadicea* the insignificant decline in cover may be attributed to the morphological and physiological adaptations of chlorolichens[14]. Chlorolichens have the ability to tolerate desiccation whilst undergoing minimal shrinkage thereby





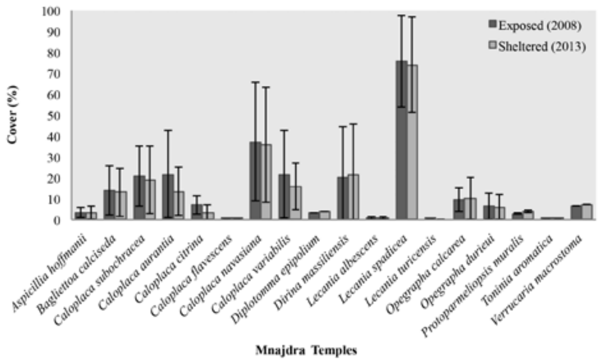


Fig. 5 Evaluation of Mean cover (%) for individual lichen species present in different temples between 2008 and 2013. Vertical error bars represent standard error of the mean. Pairwise comparison of individual lichen species resulted in statistically significant reductions for species of *Bagliettoa calcarea* (p = 0.001), *Caloplaca citrina* (p = 0.03), *Caloplaca navasiana* (p = 0.005), *Clauzadea inmersa* (p = 0.046) and *Protoparmeliopsis muralis* (p = 0.03) at Mnajdra and Ħaġar Qim main Temples following sheltering installations. Changes in percentage cover for these species at Ħaġar Qim North temples were statistically insignificant. Insignificant percentage cover changes (p > 0.05) resulted for other species within the temples of Mnajdra, Ħaġar Qim main temples and Ħaġar Qim North Temples between 2008 and 2013.

remaining relatively unaltered[15]. The relatively small change in community cover for species of *Opegrapha calcarea*, *Verrucaria nigrescens* and other endolithic lichens may be attributed to their efficiency in water absorption[16]. Endolithic lichens are rather efficient in absorbing water due to their small biomass which enables them to use dew and water vapour as moisture to reach hydration, in contrast to epilithic lichens which require higher levels of water for hydration [17].

Considering the environmental parameters including temperature, relative humidity, wind speed and irradiance, the study supports findings by Cassar et al. (2010) that sheltering installations brought about significantly lower daily variability in relative humidity and air temperature in sheltered conditions. Environmental data comparisons have also shown a significant increase in aridity and decline in wind forces under the shelter (Table 1). Although this study has not explored the effect of environmental variables on lichen communities it is thought that a reduced frequency of thermo-hygrometric cycles within the temples brought about by a reduction in variability of air temperature could have a negative impact on lichen communities since water availability in form of dew and vapour would be drastically reduced. Furthermore, the reduction in wind speed and increased aridity under the shelter may have an indirect influence on the decline of lichen communities occupying horizontal surfaces. Whereas in exposed conditions dust deposited on stone was previously washed away by rain and blown away by wind, in sheltered conditions it is less likely to be removed. In addition, considering the significant reduction in several species lying horizontally on stones in the community

Study Site	Environmental variable	Exposed (2008)	Sheltered (2013)	Z -value	P-value
Ħaġar Qim Main Temples					
	Average annual mean temperature (°C)	18.58 + 5.78	19.07 ± 4.23	-12.438	**< 0.0001**
	Percentage average relative humidity (%)	63.13 ± 47.15	65.87 ± 6.54	-12.723	**< 0.0001**
	Wind speed (m/s)	4.07 ± 2.28	0.56 ± 0.74	-43.401	**< 0.0001**
	Irradiance (KW/m²)	232.07	28.65	-36.624	**< 0.0001**
	Precipitation (mm)	0.750 ±0.85	0	-9.811	**< 0.0001**
Mnajdra Temples					
	Average annual mean temperature (°C)	18.90 ± 6.05	19.12 ±4.85	-3.877	**< 0.0001**
	Percentage average relative humidity (%)	70.63 ± 13.17	73.22 ±9.60	-8.157	**< 0.0001**
	Wind speed (m/s)	5.14 ±25.84	0.47 ±0.68	-43.504	**< 0.0001**
	Irradiance (W/m²)	213.13	27.5	-33.645	**< 0.0001**
	Precipitation (mm)	0.30 ±0.23	0	-8.346	**< 0.0001**
Ħaġar Qim North Temple					
	Average annual mean temperature (°C)	18.58 ± 5.78	18.16 ± 5.23	-0.150	0.881
	Percentage average relative humidity (%)	63.13 ± 47.15	64.92 ± 49.37	-2.296	0.022
	Wind Speed (m/s)	4.07 ± 2.28	3.98 ±2.25	-0.75	0.940
	Irradiance (W/m²)	232.07	225.98	-1.406	0.160
	Precipitation (mm)	0.750 ± 0.85	0.340 ± 0.82	-4.645	**0.0000**

Table 1: Mean annual daily environmental variables (±SD) for the three study sites (Ħaġar Qim main temple, Mnajdra temples and Ħaġar Qim North temple) and analyses of means of environmental parameters. P-values for the Wilcoxon-matched pairs test applied to the three study sites for pair wise comparisons. (N=365)

dominated by *Caloplaca* it may be that the dust settling on stone may be blocking light from reaching the lichen surface. This in turn hinders the photobiont[18] partner in lichens from carrying out photosynthesis which may cause the lichen to die and deteriorate in time.

Conclusion

This study provides evidence that the newly established microclimatic conditions brought about by sheltering installations are affecting lichen communities. Morphological analyses have shown that lichen species inhabiting horizontal surfaces especially those that have a higher affinity for sun exposure and rainwater such as those belonging to the *Caloplaca* dominated community are likely to perish under the shelter in time. Also, in view of the fact that the majority of lichens did not show significant morphological change it may be that morphological assessment of lichen communities within the temples may not be resolute enough to quantify the magnitude of response for all lichen species. Consequently physiological assessments of lichen communities may also be included in the biomonitoring programs as a more resolute monitoring technique. Finally, in order to be able to correlate the changes in lichen communities to the newly established microclimate conditions, additional environmental parameters may be taken into consideration in future biomonitoring studies particularly stone surface temperature, stone surface wetness as well as dust deposition, as these may provide more insight to the significant environmental factors affecting lichen communities.

Notes

1 Cassar, et al., (2011), Shelters over the Megalithic Temples of Malta: debate, design and implementation. *Environmental Earth Sciences*, 63(7-8): 1849-1860.

2 A lichen is a composite oragism made up of an algae or cyanobacterium *or both (living among filamentous fungi in a symbiotic relationship.

3 Llop et al., 2013

4 Cassar et al., 2010

5 Cassar, 2002

6 Cassar et al., 2010

7 Miller et al., 2012

8 Insarov and Schroeter, 2002

9 A phanerogam is a plant that produces seeds.

10 A cryptogam is a plant that reproduces by spores, without flowers or seeds.

11 Details of the survey can be found in Gómez-Bolea A., et al . (2008) Environmental Monitoring at *Ħaġar* Qim and Mnajdra Temples. October 2008. Report presented to Heritage Malta: p. 41.

12 Details of the survey can be found in Sammut, S. (2014) Biological Monitoring at *Ħaġar* Qim and Mnajdra Temples. September 2014. Report presented to Heritage Malta: p. 33.

13 Environmental data measurements have been registered as hourly average readings and data analysis was based on average daily values of two years, one for each sampling period.

14 Lichens which have a green algal photobiont.

15 Kranner et al., 2008

16 Endolithic lichens live inside rocks or in pores between mineral grains.

17 Epilithic lichens live on the surface of the stone. (Tretiach, 1995)

18 The photosynthetic component of a lichen which may either be an algae or a cyanobacterium.

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Acknowledgements

Stroud, Katya – Senior Curator within the Prehistoric Sites Department, Heritage Malta, and Esteve Llop Vallverdú – Professor at the Department of Vegetal Biology, Faculty of Biology, University of Barcelona.