

Interspecies comparisons of Mg/Ca ratios in limpet shells

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Abstract

This study provides a short reassessment of the use of Magnesium to Calcium (Mg/Ca) ratios in Atlantic limpet shells to determine past sea surface temperatures. While *Patella vulgata* along the Spanish shoreline has since then repeatedly produced reliable correlations between sea surface temperature and Mg/Ca ratios, this is not the case for other patelloid species. *Patella vulgata* and *Nacella deaureata* have been studied using Mg/Ca with mixed or contrary results. In this study, we present elemental maps of various such species together with stable oxygen isotope values for some of the specimens. Our dataset also includes specimens that were previously unsuccessful in providing significant correlations between ^{18}O and Mg/Ca ratios. By reassessing these previous specimens and including a wider range of modern and archaeological samples from three patelloid species (*P. vulgata*, *N. deaureata*, and *N. magellanica*) we further add to the growing set of evidence for the reliable use of Mg/Ca ratios to detect palaeotemperature change and serve as a means to determine ontogenetic age and season of capture as well as to reveal locations of interest within the growth record (i.e. annual temperature minima and maxima) for the targeted analysis using ^{18}O or clumped oxygen isotope analysis.

Keywords: Sclerochronology, Limpets, Elemental Ratio, Mg/Ca

1. Introduction

Limpet shells are commonly found within archaeological sites and and past shorelines due to their robust carbonate structure and the long-term use of limpets as a marine food source. They have successfully been studied in the past in the context of coastal subsistence economies, site occupation on seasonal (Shackleton, 1973; Parker et al., 2018; Bosch et al., 2018) or long-term scale (Ortiz et al., 2015), as well as palaeotemperature (Fenger et al., 2007; Surge and Barrett, 2012; Wang et al., 2012; Colonese et al., 2012; Ferguson et al., 2011). Determining past sea surface temperature (SST) change largely relies on the measurement of ^{18}O -values within the calcitic parts of the shell, but attempts have been made to also use elemental ratios, such as magnesium to calcium (Mg/Ca), to have an alternative measure, that potentially provides a more accurate SST estimate than ^{18}O -values, which are also affected by changes in salinity. In addition, the data acquisition of elemental ratios — either through laser-ablation-isotope-ratio-mass-spectrometry (LA-ICP-MS) or laser induced breakdown spectroscopy (LIBS), can be much faster and cost-effective, increasing the number of specimens that can be studied overall (Durham et al., 2017; Hausmann et al., 2023).

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Problematically, links between Mg/Ca ratios and SST changes in limpets have also been shown to be unreliable (Graniero et al., 2015) and even where they were successful, anomalous patterns in some specimens had to be filtered out, reducing the overall robustness of the results of those successful studies (Ferguson et al., 2011).

While recent research particularly of *Patella* sp. in the Mediterranean and Southwest Europe have provided promising results (Hausmann et al., 2019; García-Escárcaga et al., 2015, 2018). There remains unclarity for Atlantic limpet species, particularly since it was last shown here, that they are not reliable recorders of palaeotemperature (Graniero et al., 2015).

In this study we will repeat and expand the analysis of Atlantic limpets to determine the reliability of Mg/Ca ratios as palaeotemperature proxies. To do this, we sampled a set of previously published and unpublished limpet specimens dating to modern and archaeological contexts using LIBS. LIBS allows us to carry out 2D imaging of entire shell sections, which helps us to navigate the complex elemental structure of the shell and better separate the external, temperature-related changes from the internal and less understood factors that influence the Mg/Ca ratio.

Relying and adding onto published datasets, allowed us to simultaneously avoid costs for new high-resolution ^{18}O -data, use real-world examples, and also provide pilot-data for areas of existing research interest. Generally establishing the usefulness and reliability of Mg/Ca as SST proxy in limpets should help to provide a platform for future research and an important stepping stone to better understand elemental ratios in other marine mollusc shells.

2. Materials and Methods

2.1. Limpet specimens

2.1.1. Modern specimens

The analysed specimens, their origin and respective studies with research background information can be found in Table 1. Here we will briefly summarise their contextual information, which can be accessed in more detail at the respective studies (Nicastro et al., 2020; Surge and Barrett, 2012; Graniero et al., 2017). While those studies also included other specimens, their accessibility or state of preservation did not all lend them to be re-analysed.

Table 1: Overview of the modern and archaeological limpet specimens analysed in this study.

Context	Study	Species	Location	Sample ID	Previous analyses
Modern	(Nicastro et al., 2020)	<i>N. deaureata</i>	Cambaceres Bay - Tierra del Fuego (AR)	ND-1016-3	Stable oxygen and carbon isotope analysis
				ND-1016-4	
		<i>N. magellanica</i>		NM-1016-1	
	(Graniero et al., 2017)	<i>P. vulgata</i>	Rack Wick Bay - Westray (UK)	NM-1016-3 ORK-LT5	Stable oxygen and carbon isotope analysis; Mg, Li, Sr, Ca,.

Context	Study	Species	Location	Sample ID	Previous analyses
Archaeological	(Surge and Barrett, 2012)	<i>P. vulgata</i>	Rack Wick Bay - Westray (UK)	QG1-7188-1	Stable oxygen and carbon isotope analysis
				QG1-7189-2	
				QG2-1061-1	
				QG2-1064-1	
				QG2-7180-1	
				QG2-7180-2	
	This study	<i>N. magellanica</i>	Heshkaia 35 in Moat Bay - Tierra del Fuego (AR)	QG1-7246-1	none
				Heshkaia_35-1	
				Heshkaia_35-2	
				Heshkaia_35-3	
		<i>N. deaureata</i>		Heshkaia_35-4	
				Heshkaia_35-5	
				Heshkaia_35-6	
				Heshkaia_35-7	
		<i>N. magellanica</i>		Heshkaia_35-8	
				Heshkaia_35-9	

There are two main locations that we sourced specimens from: the Beagle Channel in Tierra del Fuego (Argentina) and the island of West Ray in Orkney (UK). Four specimens were collected from the Beagle Channel in Cambaceres Bay. The area receives around 570 mm precipitation but the channel waters are predominantly influenced by marine currents stayed around 30.7 ± 0.7 psu (Nicastro et al., 2020). SSTs range from 4.7°C in August to 10°C in February.

On Westray one modern shell (ORK-LT5) was collected in Rack Wick Bay in August 2009. Westray lies about 70 km north of the Scottish mainland and experiences virtually no freshwater input. The annual SST ranges from 6.3°C in March to 13.8°C in August (Figure 1).

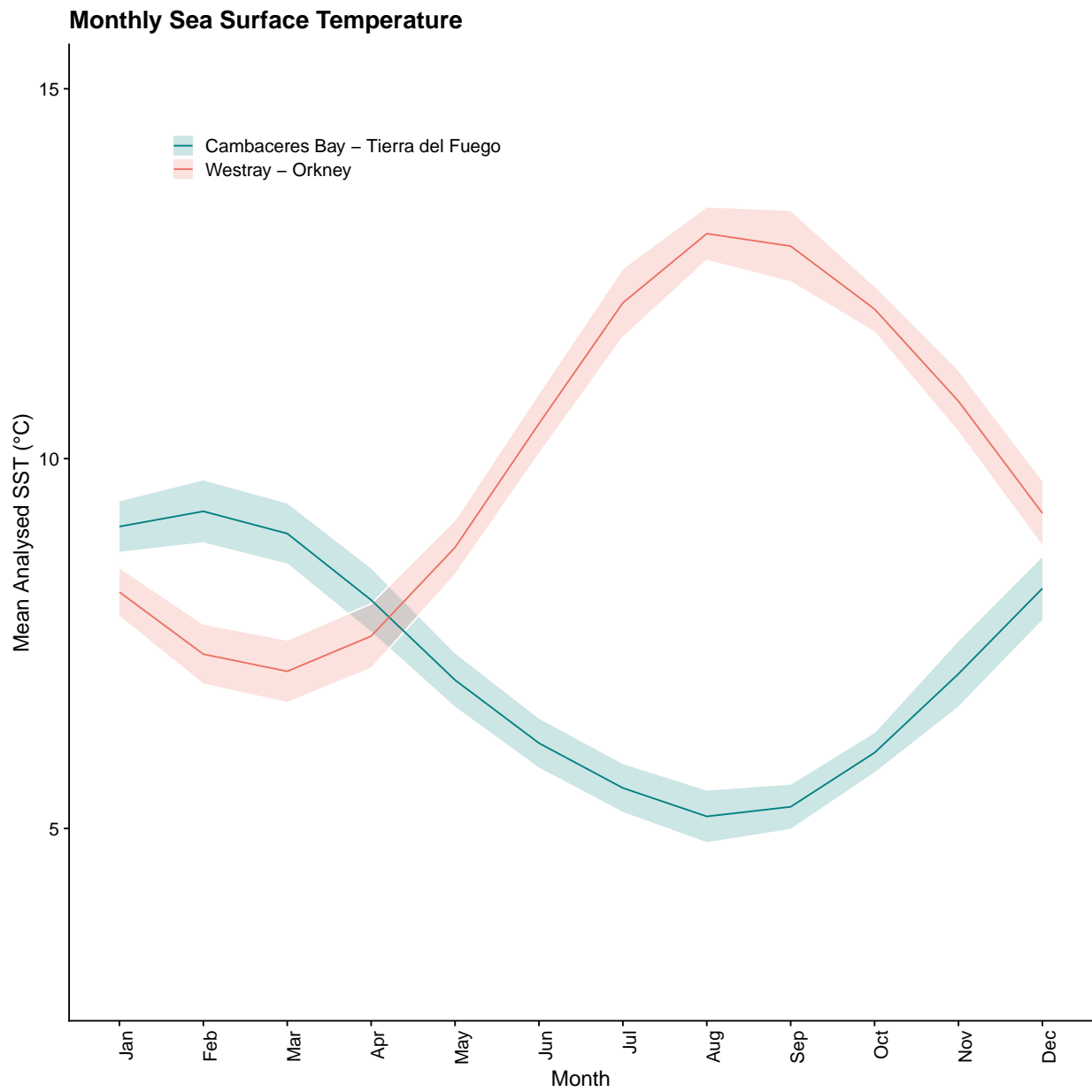


Figure 1: SST values averaged from years. SST values were sourced from ([European Union-Copernicus Marine Service, 2015](#))

2.1.2. Archaeological specimens

2.2. Oxygen isotopes

2.3. Mg/Ca ratios

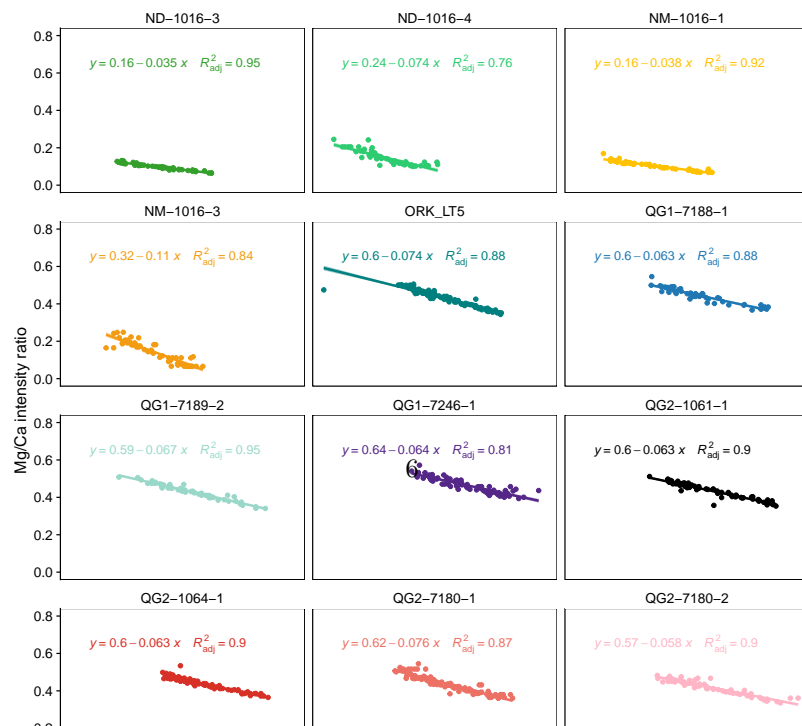
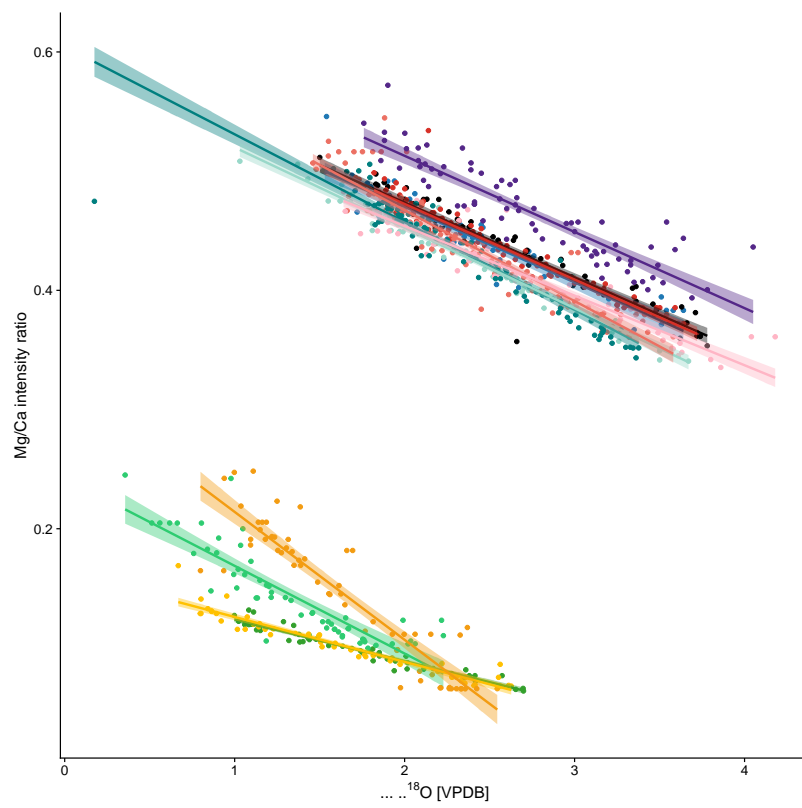
3. Results

3.1. *Patella vulgata*

3.2. *Nacella deaureata*

3.3. *Nacella magellanica*

4.



5. Discussion

5.1. Other correlations

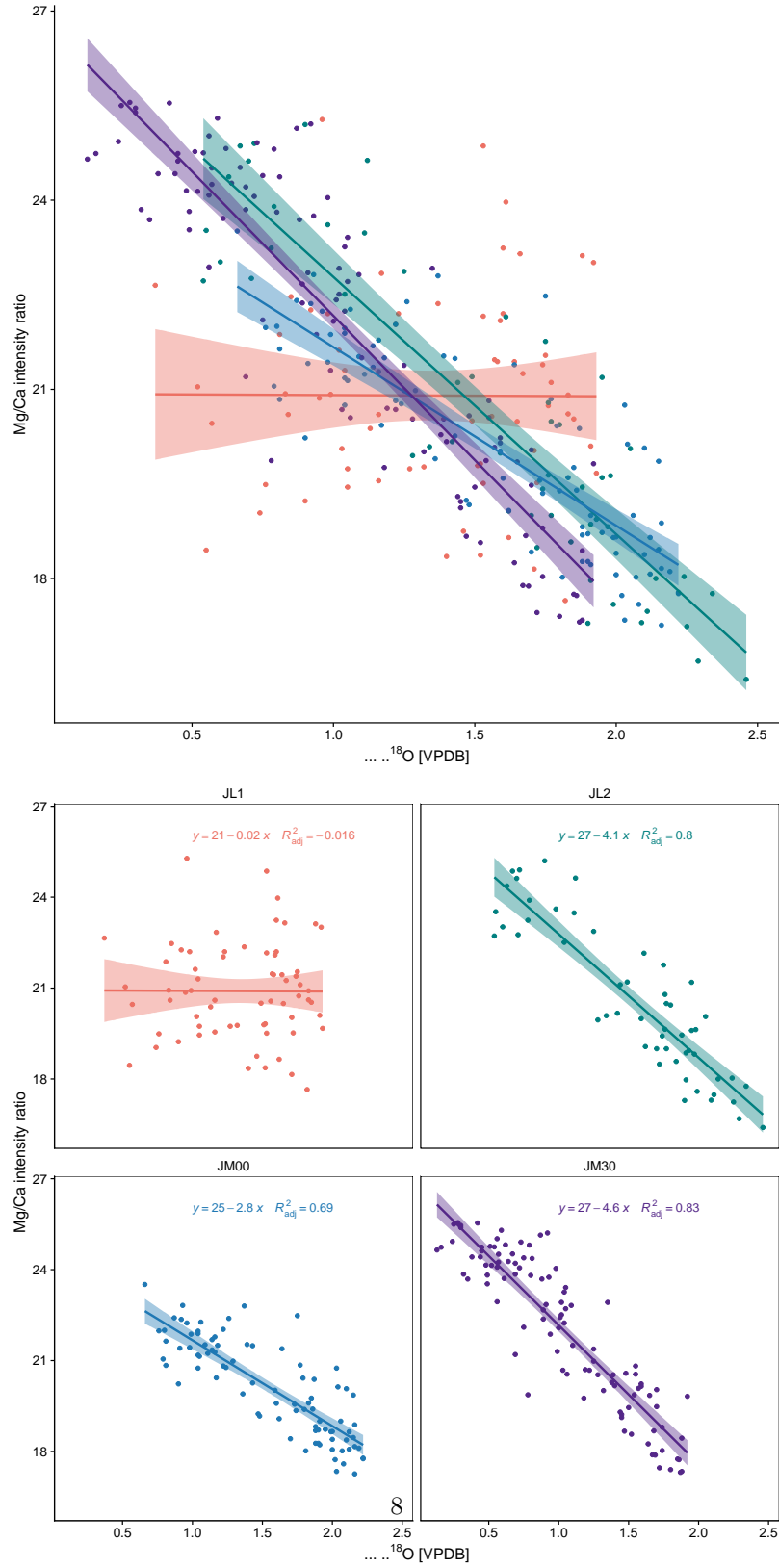


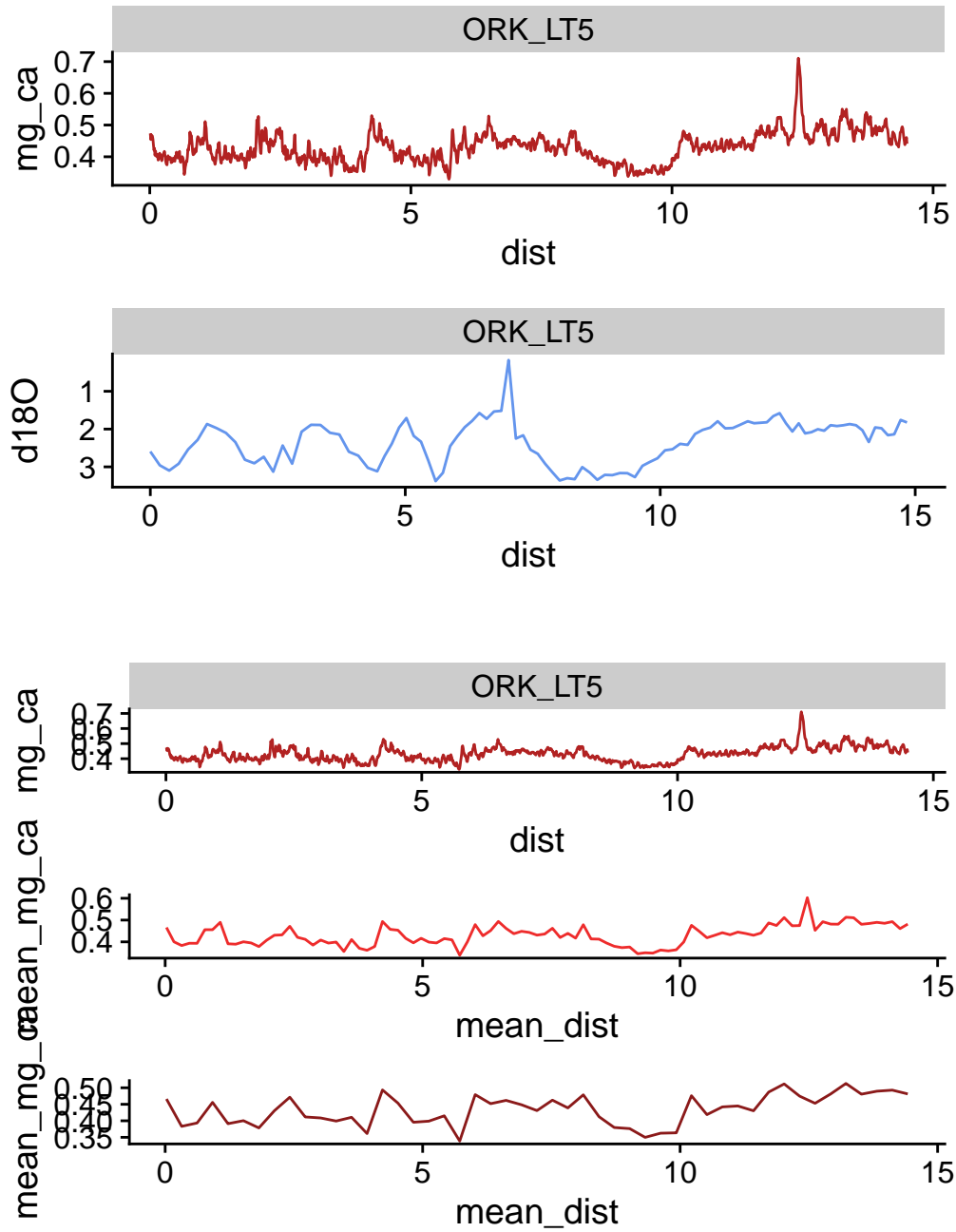
Figure 3: Correlation graphs for Ferguson et al. specimens

Table 2: Table 2: Overview of comparative correlations {#tab:correlations}

Species	Locality	Specimen	Correlation R ²	Study
<i>P. depressa</i>	Northern Spain	LAN541	0.87	(García-Escárzaga et al., 2021)
		LAN545	0.86	
		LAN554	0.78	
		LAN559	0.82	
<i>P. caerulea</i>	Croatia	ISTPC1	0.9	(Hausmann et al., 2019)
		ISTPC2	0.84	
	Crete	AF1911A	0.91 ¹	
		AF3003A	0.92 ²	
	Israel	AKKPC2	0.96	(Ferguson et al., 2011)
		AKKPC3	0.89	
		FRMPC1	0.84	
		FRMPC2	0.96	
	Libya	MO31A	0.83	
		MP64A	0.33	
		MP67A	0.96	
		MP68A	0.81	
	Malta	MA10	0.82	
	Tunisia	TUNPC1	0.81	
		TUNPC2	0.78	
	Turkey	ANTPC1	0.95	
		ANTPC2	0.93	
		KIZPC1	0.94	
		KIZPC2	0.86	
<i>P. rustica</i>	Gibraltar	JL1	0.02	
		JL2	0.8 (0.79)	(Graniero et al., 2017) and this study
<i>P. caerulea</i>	Gibraltar	JM00	0.69 (0.79)	
		JM30	0.83 (0.79)	
<i>P. vulgata</i>	Orkney	ORK-LT5	not reported, here 0.88	

¹SST only, no other geochemical data available²SST only, no geochemical data available

5.2. Comparison of ORK-LT5



References

Bosch, M.D., Mannino, M.A., Prendergast, A.L., Wesselingh, F.P., O'Connell, T.C., Hublin, J.J., 2018. Year-round shellfish exploitation in the levant and implications for upper palaeolithic hunter-gatherer subsistence. *Journal of Archaeological Science: Reports* 21, 1198–1214. doi:[10.1016/j.jasrep.2017.08.014](https://doi.org/10.1016/j.jasrep.2017.08.014).

- Colonese, A.C., Verdún-Castelló, E., Álvarez, M., Briz i Godino, I., Zurro, D., Salvatelli, L., 2012. Oxygen isotopic composition of limpet shells from the beagle channel: implications for seasonal studies in shell middens of tierra del fuego. *J. Archaeol. Sci.* 39, 1738–1748. doi:[10.1016/j.jas.2012.01.012](https://doi.org/10.1016/j.jas.2012.01.012).
- Durham, S.R., Gillikin, D.P., Goodwin, D.H., Dietl, G.P., 2017. Rapid determination of oyster lifespans and growth rates using LA-ICP-MS line scans of shell Mg/Ca ratios. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* 485, 201–209. doi:[10.1016/j.palaeo.2017.06.013](https://doi.org/10.1016/j.palaeo.2017.06.013).
- European Union-Copernicus Marine Service, 2015. Global ocean ostia sea surface temperature and sea ice analysis. URL: https://resources.marine.copernicus.eu/product-detail/SST_GLO_SST_L4_NRT_OBSERVATIONS_010_001/INFORMATION, doi:[10.48670/MOI-00165](https://doi.org/10.48670/MOI-00165).
- Fenger, T., Surge, D., Schöne, B., Milner, N., 2007. Sclerochronology and geochemical variation in limpet shells (*patella vulgata*): A new archive to reconstruct coastal sea surface temperature. *Geochim. Geophys. Geosyst.* 8.
- Ferguson, J.E., Henderson, G.M., Fa, D.A., Finlayson, J.C., Charnley, N.R., 2011. Increased seasonality in the western mediterranean during the last glacial from limpet shell geochemistry. *Earth Planet. Sci. Lett.* 308, 325–333. doi:[10.1016/j.epsl.2011.05.054](https://doi.org/10.1016/j.epsl.2011.05.054).
- García-Escárcaga, A., Clarke, L.J., Gutiérrez-Zugasti, I., González-Morales, M.R., Martínez, M., López-Higuera, J.M., Cobo, A., 2018. Mg/Ca profiles within archaeological mollusc (*patella vulgata*) shells: Laser-Induced breakdown spectroscopy compared to inductively coupled Plasma-Optical emission spectrometry. *Spectrochim. Acta Part B At. Spectrosc.* 148, 8–15. doi:[10.1016/j.sab.2018.05.026](https://doi.org/10.1016/j.sab.2018.05.026).
- García-Escárcaga, A., Moncayo, S., Gutiérrez-Zugasti, I., González-Morales, M.R., Martín-Chivelet, J., Cáceres, J.O., 2015. Mg/Ca ratios measured by laser induced breakdown spectroscopy (LIBS): a new approach to decipher environmental conditions. *J. Anal. At. Spectrom.* 30, 1913–1919. doi:[10.1039/C5JA00168D](https://doi.org/10.1039/C5JA00168D).
- García-Escárcaga, A., Martínez-Mincheró, M., Cobo, A., Gutiérrez-Zugasti, I., Arizabalaga, A., Roberts, P., 2021. Using mg/ca ratios from the limpet *patella depressa* pennant, 1777 measured by laser-induced breakdown spectroscopy (libs) to reconstruct paleoclimate. *Applied Sciences* 11, 2959. URL: <http://dx.doi.org/10.3390/app11072959>, doi:[10.3390/app11072959](https://doi.org/10.3390/app11072959).
- Graniero, L., Surge, D., Gillikin, D., 2015. Assessing the utility of elemental ratios as a paleotemperature proxy in shells of patelloid limpets, in: EGU General Assembly Conference Abstracts, adsabs.harvard.edu.
- Graniero, L.E., Surge, D., Gillikin, D.P., Briz i Godino, I., Álvarez, M., 2017. Assessing elemental ratios as a paleotemperature proxy in the calcite shells of patelloid limpets. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* 465, Part B, 376–385. doi:[10.1016/j.palaeo.2016.10.021](https://doi.org/10.1016/j.palaeo.2016.10.021).
- Hausmann, N., Prendergast, A.L., Lemonis, A., Zech, J., Roberts, P., Siozos, P., Anglos, D., 2019. Extensive elemental mapping unlocks Mg/Ca ratios as climate proxy in seasonal records of mediterranean limpets. *Scientific Reports* 9, 3698. doi:[10.1038/s41598-019-39959-9](https://doi.org/10.1038/s41598-019-39959-9).
- Hausmann, N., Theodoraki, D., Piñon, V., Siozos, P., Lemonis, A., Anglos, D., 2023. Applying laser induced breakdown spectroscopy (LIBS) and elemental imaging on marine shells for archaeological and environmental research. *Sci. Rep.* 13, 19812. doi:[10.1038/s41598-023-46453-w](https://doi.org/10.1038/s41598-023-46453-w).
- Nicastro, A., Surge, D., Briz i Godino, I., Álvarez, M., Schöne, B.R., Bas, M., 2020. High-resolution records of growth temperature and life history of two nacella limpet species, tierra del fuego, argentina. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* 540, 109526. doi:[10.1016/j.palaeo.2019.109526](https://doi.org/10.1016/j.palaeo.2019.109526).
- Ortiz, J.E., Gutiérrez-Zugasti, I., Torres, T., González-Morales, M., Sánchez-Palencia, Y., 2015. Protein diagenesis in patella shells: Implications for amino acid racemisation dating. *Quat. Geochronol.* 27, 105–118. doi:[10.1016/j.quageo.2015.02.008](https://doi.org/10.1016/j.quageo.2015.02.008).
- Parker, W., Yanes, Y., Mesa Hernández, E., Hernández Marrero, J.C., Pais, J., Soto Contreras, N., Surge, D., 2018. Shellfish exploitation in the western canary islands over the last two millennia. *Environ. Archaeol.* , 1–23doi:[10.1080/14614103.2018.1497821](https://doi.org/10.1080/14614103.2018.1497821).
- Shackleton, N.J., 1973. Oxygen isotope analysis as a means of determining season of occupation of prehistoric midden sites. *Archaeometry* 15, 133–141. URL: <http://dx.doi.org/10.1111/j.1475-4754.1973.tb00082.x>, doi:[10.1111/j.1475-4754.1973.tb00082.x](https://doi.org/10.1111/j.1475-4754.1973.tb00082.x).
- Surge, D., Barrett, J.H., 2012. Marine climatic seasonality during medieval times (10th to 12th centuries) based on isotopic records in viking age shells from orkney, scotland. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* 350–352, 236–246. doi:[10.1016/j.palaeo.2012.07.003](https://doi.org/10.1016/j.palaeo.2012.07.003).
- Wang, T., Surge, D., Mithen, S., 2012. Seasonal temperature variability of the neoglacial (3300–2500 BP) and roman warm period (2500–1600 BP) reconstructed from oxygen isotope ratios of limpet shells (*patella vulgata*), northwest scotland. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* 317, 104–113.