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Preliminary Results of Rock-cut Fish Tanks Evidence Along the Tyre Coast of Lebanon. Implication for Ancient Sea-level Reconstruction

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*'Circum-Mediterranean' human occupation in antiquity has left a rich heritage of archaeological remains along the coastline. Tight relationships between sea-level and coastal structures elevation during construction (especially fish tanks) allow accurate tracking of sea-level variations through ages. Building upon field work conducted by Jean-Baptiste Yon and Pierre-Louis Gatier (*Mission archéologique de Tyr - *HiSoMa), and funded by the Honor Frost Foundation, this study aims to revisit former relative sea-level rise (RSL) estimates, based on the recent discovery of two fish tanks on the shoreline near Tyre. There, archaeological, chronological and topographic data lead us to propose that the RSL have increased 0.6 m since Roman times.*

Keywords: sea-level, ancient fish tank, Tyre.

Introduction

Sea-level variations are induced by eustatic factors (expansion and shrinking of ice caps and mountain glaciers, ocean water volume change resulting from modifications in water temperature; isostatic, flexural ground uplift and subsidence due to Earth's mantle flow under the loading and unloading of ice and water over continents and oceans), and tectonic determinants (contraction or stretching of the Earth's crust, and mantle convection) (Flemming 1969: 10; Waelbroek *et al*. 2002: 297; Lambeck *et al*. 2004a: 1567; Pirazzoli 2005: 1990). In tectonically active regions, such as the eastern shore of the Mediterranean Sea (Morhange *et al*. 2006: 99; Anzidei *et al*. 2010: 14), the understanding of both eustatic and tectonic processes is essential to comprehend the origin and spatial variability in relative sea-level changes. Archaeological findings (Pirazzoli 1976; Caputo and Pieri 1976: 5787; Rovere *et al*. 2011: 2) can track relative sea-level alterations with great accuracy over historical times, especially where the amplitude of the tidal range is small, such as in the case of the eastern Mediterranean Sea. In such settings, coastal structures are designed such as to function properly under a restricted range of sea-level elevation (Antonioli *et al*. 2007: 2471). Therefore, regional past sea-levels can be revealed by a careful analysis of harbour architectural elements, such as docks, slipways, quarries, fish tanks and water supply channels. The well-studied fish tanks of the central Mediterranean area have been mostly found along the Tyrrhenian shoreline of Italy (Schmeidt 1972: Appendix-Part 1; Lambeck *et al*. 2004b: 564; Evelpidou *et al*. 2012: 261). Fewer fish tanks have been formally explored in the western (Morhange *et al*.

2013: 364) and the eastern (Mourtzas 2012a; 885, b: 2394) Mediterranean basin. Fish tanks were adapted to the local morphology, coastal current dynamics and the type of fish breeding (Evelpidou *et al*. 2012, 260). Channels connected the tanks to the open sea by canals that ensured constant water recharge; they are particularly useful to define past sea-level.

This paper provides preliminary estimates of relative sea-level variations rendered by these recently discovered rock-cut fish tanks (**fig. 1**). It was conducted under the supervision and technical assistance of Jean-Baptiste Yon and Pierre-Louis Gatier, within the frame of the *Mission archéologique de Tyr* (MAT–HiSoMa), and funded by the MAT and the Honor Frost Foundation. The results are then compared to previous sea-level reconstructions in this area (Morhange *et al*. 2003: 83; Mariner *et al*. 2006: 1), which had documented +2 m and + 3.5 m of RSL rise respectively. We discuss these discrepancies by considering the strength and limitations of the methods used in each study. Here, our reconstruction is based on two major assumptions. In the absence of constraints on the timing of construction, we presume that the fish tanks were built throughout the latest Roman or early Byzantine period, when such maritime structures were popular, commonly called *piscinae* and described by the Latin author Columella (Darembert and Saglio 1873). This hypothesis is supported by P. L. Gatier, J-B. Yon and J. Abdul Massih's oral communications, and by the fact that the coastline of Tyre reached its greatest concentration of maritime constructions during the Hellenistic, Roman and Byzantine eras.

We suppose that, to ensure water refilling of the tanks, the feeding channels had to be at sea level when erected. They are, therefore, reliable archaeological indicators to determine past sea-level variations.

Methodological Approach

Surveys of fish tank morphological features were performed employing Differential GPS Trimble providing high altitudinal accuracy (within a centimetre). Measurements of the sea-level were conducted regularly at low and high tide, in the absence of wind and swell. The raw GPS data were projected onto a universal geoid (based on EGM 96 gravity model). Altimetric elevations were then corrected to match the General Levelling of Lebanon (GLN) datum using nearby archaeological sites already correlated to that datum. To achieve this, and relying on our field observations, we assumed that the GLN sea level at these archaeological sites corresponds to the biological sea-level. Thus, following (Pérès and Picard 1964: 7), we used this marker, which is also present at the fish tanks, to calibrate the height of the fish tanks relative to these archaeological sites. The biological sea-level coincides with the limit between the infralittoral (subtidal) and intertidal zones, that is,

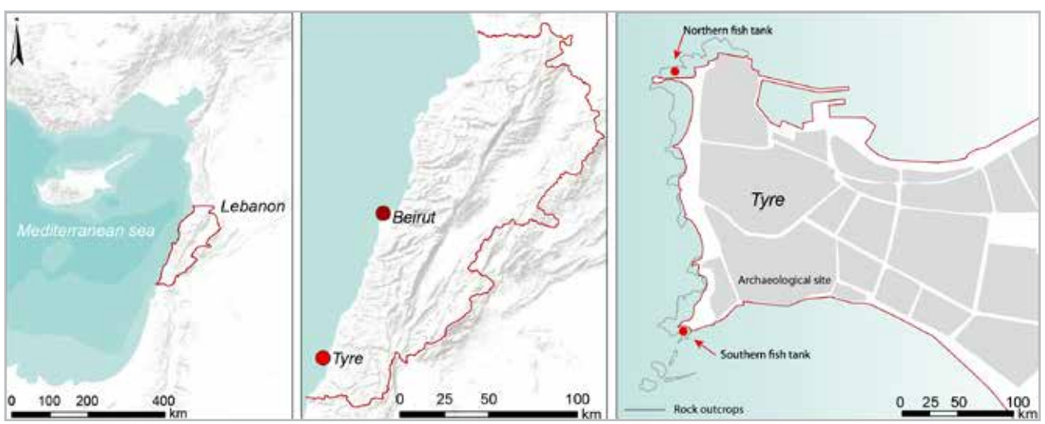

Fig. 1- Location map of Tyre at different scales and position of the recently discovered fish tanks along the western coast of Tyre.

the top of the constantly immersed environment. Functional heights–i.e. architectural elements elevation related to the biological sea-level (BSL) were then finally established after previous approaches (Anzidei *et al*. 2010: 4; Antonioli *et al*. 2007: 2468; Auriemma and Solinas 2009: 135).

Dating is based on preliminary archaeological interpretations of the fish tanks construction's period.

Preliminary Results and Interpretations

Fieldwork conducted in October 2017 revealed two rock-cut fish tanks (northern and southern), along the western coast of Tyre (**fig. 2** and **3**). The tanks were conveniently opened into the floors of pre-existing stone quarries cut to sea-level (Badawi 2016: 144). The flat floors of the quarries provide adequate service areas around the tanks, while relics of rock knobs act as sea walls, probably protecting workers and fish tanks from sea swells (Frost, 1971).

Northern Fish Tank

The northern fish tank retains critical features for the estimation of sea level, especially U-shaped channel (**fig. 2c**) linked to the sea that allows water renewal within the tanks, and fringing feet walks. The fish tank is subrectangular, 13 m wide and 20–21 m long. It connects to the sea through a 14 m-long U-shaped canal, of 1.2 m wide and 0.4 m deep upon arrival into the tank. The biological sea level currently stands at the elevation of the channel ledge. On the south-western side, a second channel is clogged with mortar. The original floor of the tank, cut into the bedrock, is exposed at a depth of 0.90 m below BSL. Remains of rock-cut and constructed partitions divide the fish tank into three or four compartments (**fig. 2a** and **b**).

Southern Fish Tank

The southern fish tank possesses an elongated U-shaped channel for water supply; its meridional wall displays a distinctive succession of concave arcuate grooves (**fig. 3**). The fish tank is rectangular, 17 m long and 7 m wide. It connects to the sea by a 30 m-long U-shaped channel, of 0.8 m wide and 0.3 m deep upon arrival into the tank. There too, the biological sea level currently reaches the elevation of the channel ledge. The fish tank is naturally protected by sea walls along its south-western section. Remains of mortar are still visible on the sea wall side. The floor of the fish tank is at a depth of 0.90 m below the BSL.

First Sea-level Estimation

We posit that, at the time of usage, high tide levels cannot have overflown the ledges of the fish tanks. Since the local tide range reaches 60 cm, the biological sea-level when in use must have lied 0.60 m below the present-day one (**fig. 4**). Under such circumstances, supply channels would drain away at low tide and refill at high tide, because their floor is 0.40 m beneath the fish tank edges. Neither us, nor any specialist presented with the sites could evidence remnants of former pavements over the quarry floor, or of the raised tank margins, that could have been lain down at the time of use. We therefore consider that current ledges represent the functional tank levels and document an RSL increase of 0.60 m since construction.

Fig. 2- Significant features of the northern fish tank. The white arrows indicate remains of constructed partitions.

Obviously, another fundamental question that should be resolved is the chronological range over which fish tanks have been used. Preliminary archaeological investigations suggest that construction took place during Roman or Byzantine times (P. L. Gatier, J.- B. Yon and J. Abdul-Massih's oral communication). Global, eustatic sea-level change's reconstructions for the eastern Mediterranean (Lambeck and Purcell 2005) predict an RSL rise of 0.60 m along the coastline of Tyre since Antiquity. This result indicates that the entirety of the sea-level expansion at the fish tanks occurs from global, eustatic sea-level rise, with no added contribution of local tectonic ground subsidence. Note that this result is at odds with earlier,

Fig. 3- Significant features of the southern fish tank.

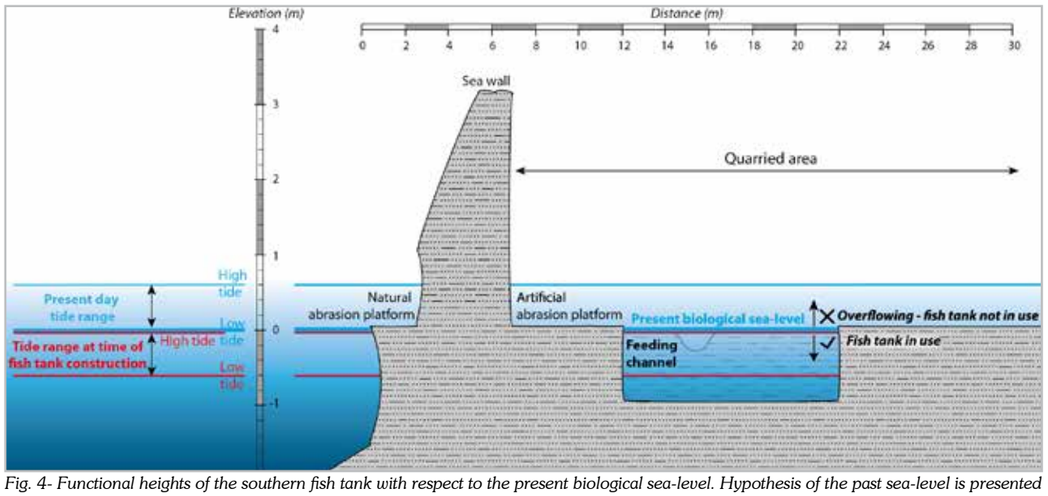

Fig. 4- Functional heights of the southern fish tank with respect to the present biological sea-level. Hypothesis of the past sea-level is presented in red.

substantially larger estimates of sea-level rise. In the same region, El-Amouri *et al*. 2005 and Marriner *et al*. 2006, interpreted quarry floors now submerged at two metres BSL, harbour moles affected by 2.5 m of relative ground subsidence, and breakwaters immersed up to 3.5 m 'since Antiquity'. Marriner *et al*. 2008, after Morhange *et al*. 2006, ascribe Late Roman age to these structures. Finally, Morhange *et al*. 2013, revise this estimate two metres, based on the coastal quarry floor's submergence depths, thought to have been cut above sea level. Accordingly, these studies require substantial amounts of ground subsidence to meet such high values of RSL.

Conclusion

The present article describes the first observations ever reported on two fish tanks recently discovered along the Tyre coastline. Precise field measurements of structures unambiguously closely tied to former sea levels suggest that no more than 0.6 m of RSL rise has taken place from the period of their construction. These new data differ from previous studies conducted in the same area (Morhange *et al*. 2003: 283; Mariner *et al*. 2006: 1), which had reported RSL rise of 2m-3.5m since past times.

Despite the lack of chronological constraints on fish tank usage, the results demonstrate the potential to re-evaluate the former RSL along the Tyre coastline. These recent estimates enable reliable reconstruction of ancient sea-level, bridging some gaps in the understanding of landscape history, shoreline evolution and anthropogenic impacts. Indeed, a better knowledge of sea-level variations will help comprehend the development of Tyre's northern harbour (Poidebard, 1937, 1939). It can also assist in designing new strategies for discovering the southern harbour. At the broader, regional scale, a similar strategy can be used to reassess the RSL along the coastline and determine the location of future archaeological excavations.

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