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Roman *Piscinae* and Sea-Level Reconstruction in the Southern Levant:

Reexamining a rock-cut installation at Tel Dor, Israel using aerial photography and ground-level photogrammetry

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SUMMARY OF THE RESEARCH

Paleoclimatologists have used archaeological remains in coastal areas as a sea-level proxy for investigating changes in sea-level over time. However, in many circumstances the coastal installations themselves are difficult to date using conventional methods due to constant erosion and corrosion, increased sediment deposition, and vertical tectonic movement common in coastal, intertidal and near-shore environments. The present study proposes a reverse of past techniques to help determine the likely use-period (when a structure could have been used) of a pair of *piscinae*, or fish-ponds, at the site of Tel Dor on the Mediterranean coast of Israel using a local sea-level curve. To take accurate elevation measurements of relevant features, photogrammetric datasets produced from air and ground photography were combined to produce a high-resolution, georeferenced Digital Elevation Model (or DEM, Figure 5). The maximum and minimum elevations of the relevant features (points in Figure 5) were compared with the local paleo sea-level during various points in time (Figure 6) to determine when the local sea-level would have facilitated use of the *piscinae*.

CRITERIA FOR APPLICATION

- **Coastal structure's function is identified in order to determine certain features' vertical relationship with sea-level.**
- **A paleo sea-level curve for the area has been independently established (without using the structure being investigated as a proxy) to avoid a circular argument for dating.**
- **The region has been tectonically inactive since the structure's oldest possible use, or the rate of tectonism is known and quantifiable**

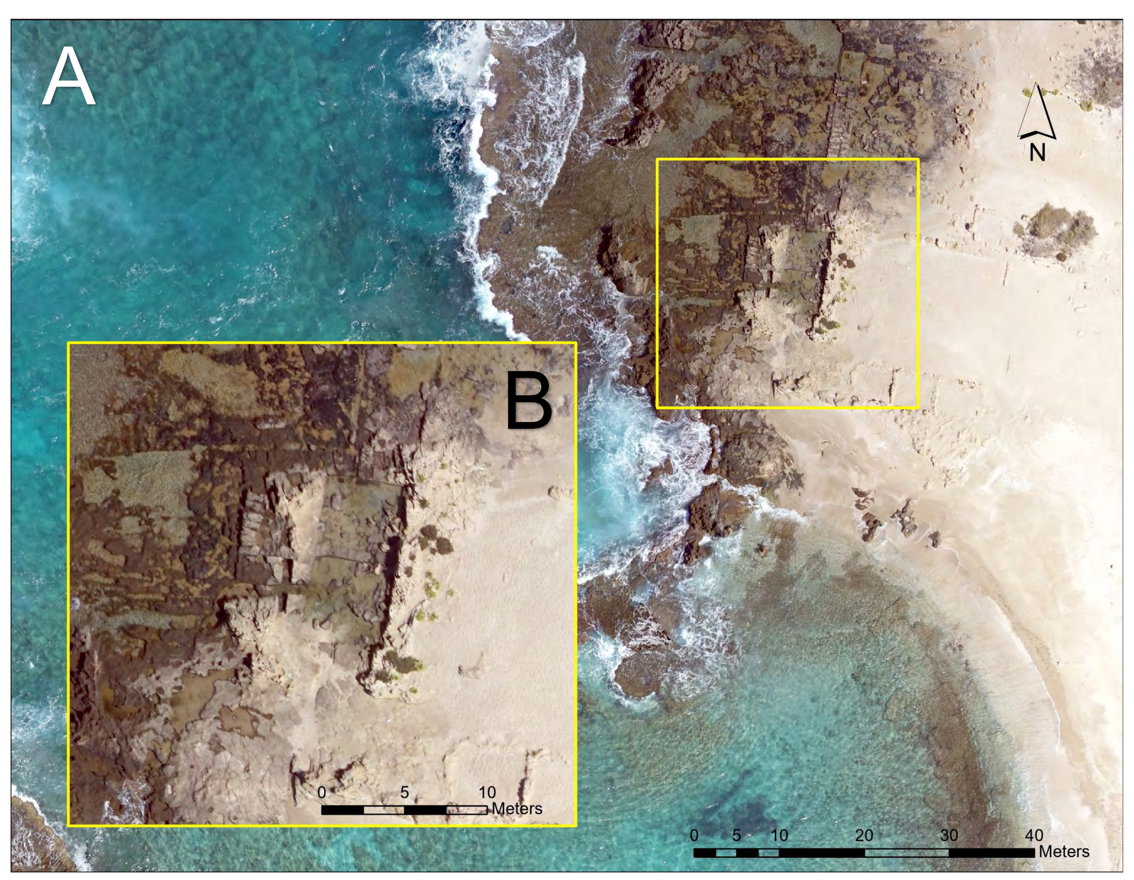

Figure 1) ***Aerial Photography***: This orthophoto-mosaic (A) was produced using a DJI Phantom 4 drone with a stock 1-inch 20-megapixel camera with a polarized lens. 90 low-altitude aerial photographs (LAAPs) were taken during a single flight at low tide to minimize error and increase coverage. The photos were then uploaded into Agisoft Metashape Professional and processed on high specifications to produce the mosaic. The two connected *piscinae* can be seen in the inset (B). Figure 1 was produced from photos taken in the summer of 2017, while the same process was used to produce a georeferenced mosaic (Figure 3) from photos taken in the winter of 2019 when there was less sand coverage.

Figure 2) The two rock-cut *piscinae* at Dor's industrial complex, seen from the NE at low tide in the summer (A) and from the SE during a winter storm event (B). *Piscinae* are common throughout the Mediterranean during the Hellenistic and Roman periods as an integral part of aquacultural activities. Continuous circulation of water via the semi-diurnal tides was essential for breeding aquatic life.

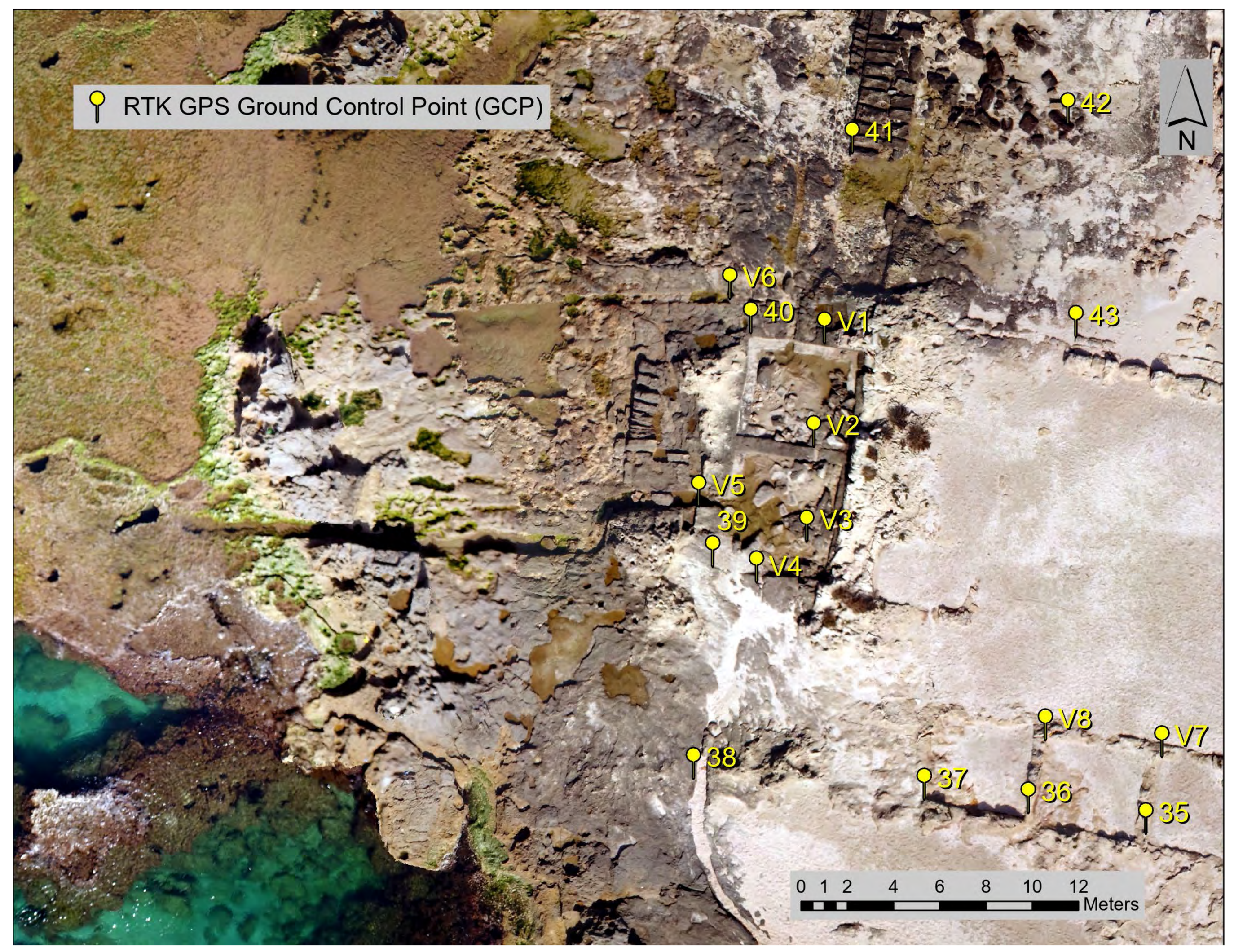

Figure 3) ***Georeferencing using an Aerial Orthophoto***: An orthophoto-mosaic produced from LAAPs taken by drone. Ground control points (GCPs) providing x/y/z coordinate data were taken using a Real-Time Kinematic Global Positioning System (RTK GPS) during the same season as the LAAPs used in the mosaic. Once the mosaic was georeferenced, additional virtual GCPs (those with a "V" label) were taken in Agisoft Metashape to provide better georeferencing of the area of interest. This orthophoto-mosaic, the DEM below, and the DEM above right are georeferenced in the Israeli Transverse Mercator (ITM) projected coordinated system with 3cm/pixel accuracy.

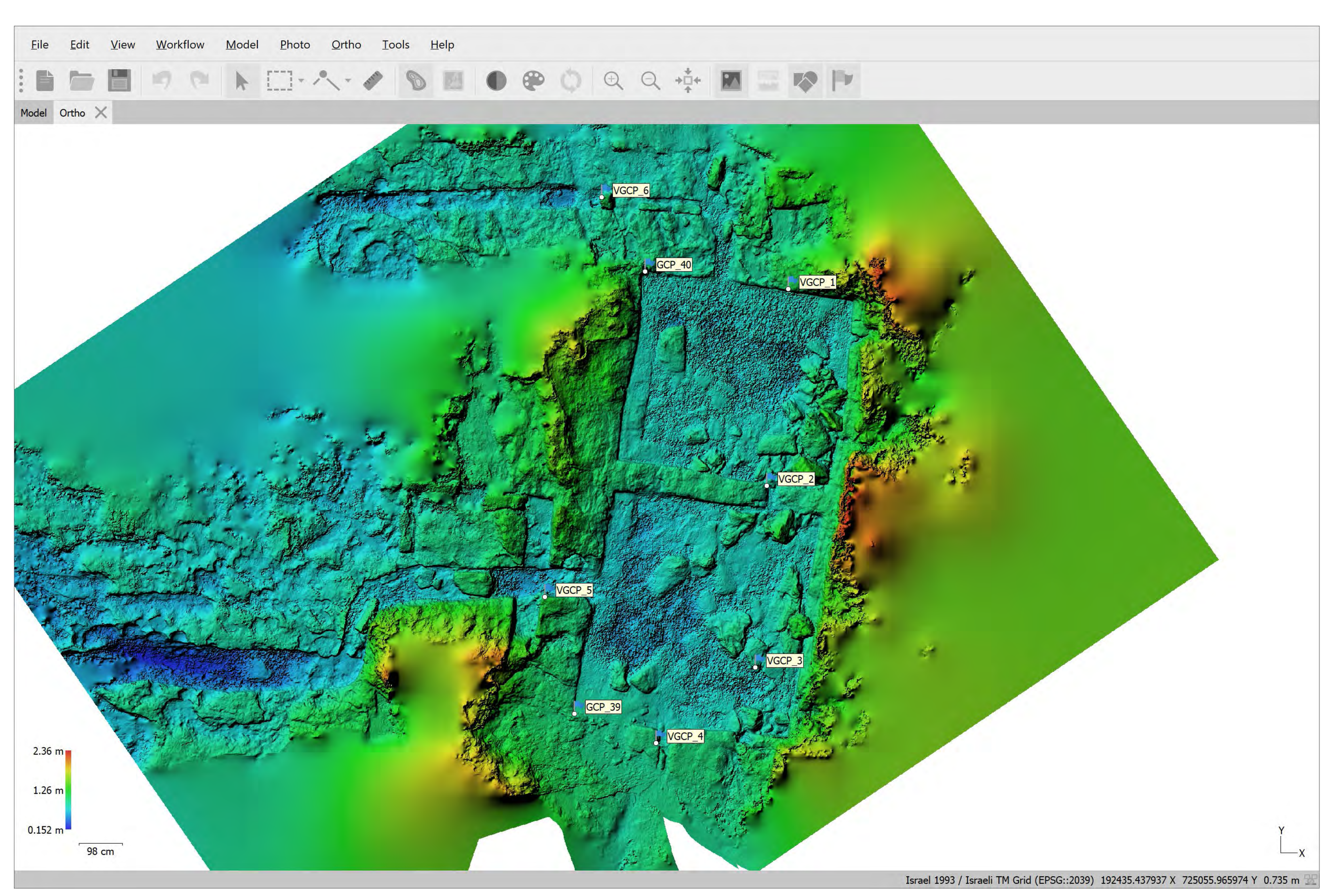

Figure 4) A screenshot of Agisoft Metashape Professional showing the DEM produced from ground photography. This DEM was constructed using 460 images taken by hand with a Sony a5000 20.1-megapixel camera. The photos were processed in Agisoft Metashape Professional on high specifications to make a dense cloud and then a DEM. Note that the GCPs and virtual GCPs from the aerial orthophoto-mosaic (Figure 3 above) have been placed around the pools to best geo-reference the model.

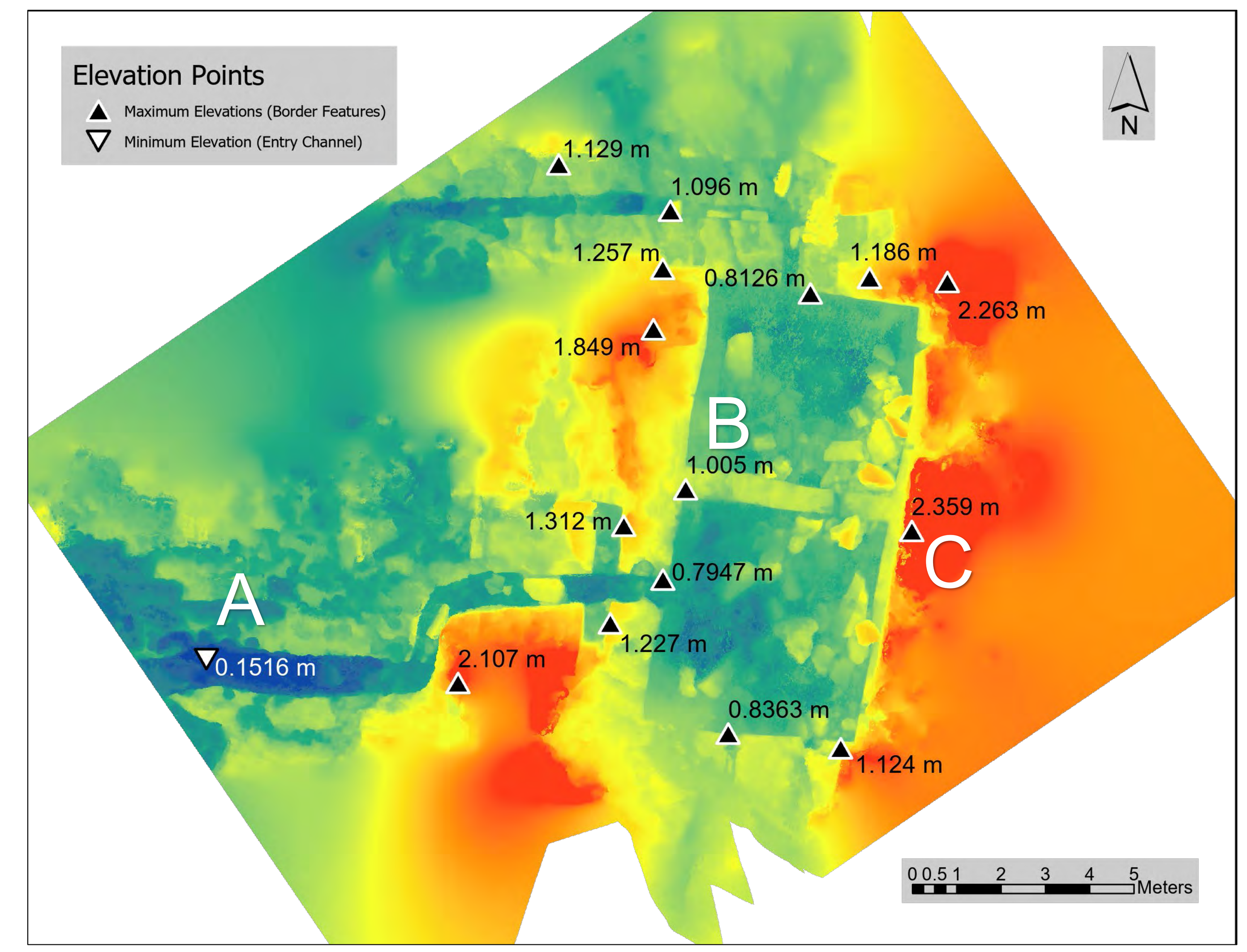

Figure 5) ***DEM Production and Elevation Analysis***: The *piscinae* DEM with maximum and minimum points plotted in x/y/z coordinate space. After georeferencing, the DEM (Figure 4) was exported as a .tif file and loaded into ArcGIS Pro. Using the "Zonal Statistics" tool, maximum and minimum elevations were taken of features known to have a specific vertical relationship with the sea-level for the *piscinae* to function properly. For example, channel openings (point A) must be lower than the minimum sea-level for water to flow in and out of the system. Walkways (point B) and retaining walls (point C) must remain above the maximum sea-level for maintenance and to keep fish in the pools (see Auriemma et al. 2009). Due to sand coverage and calcareous accretions at the time of survey, it is assumed that the channel depth is uniform throughout, equal to the maximum depth in the west near the sea. Maximum pool depth could not be accurately measured due to sand cover and in-filling from collapse.

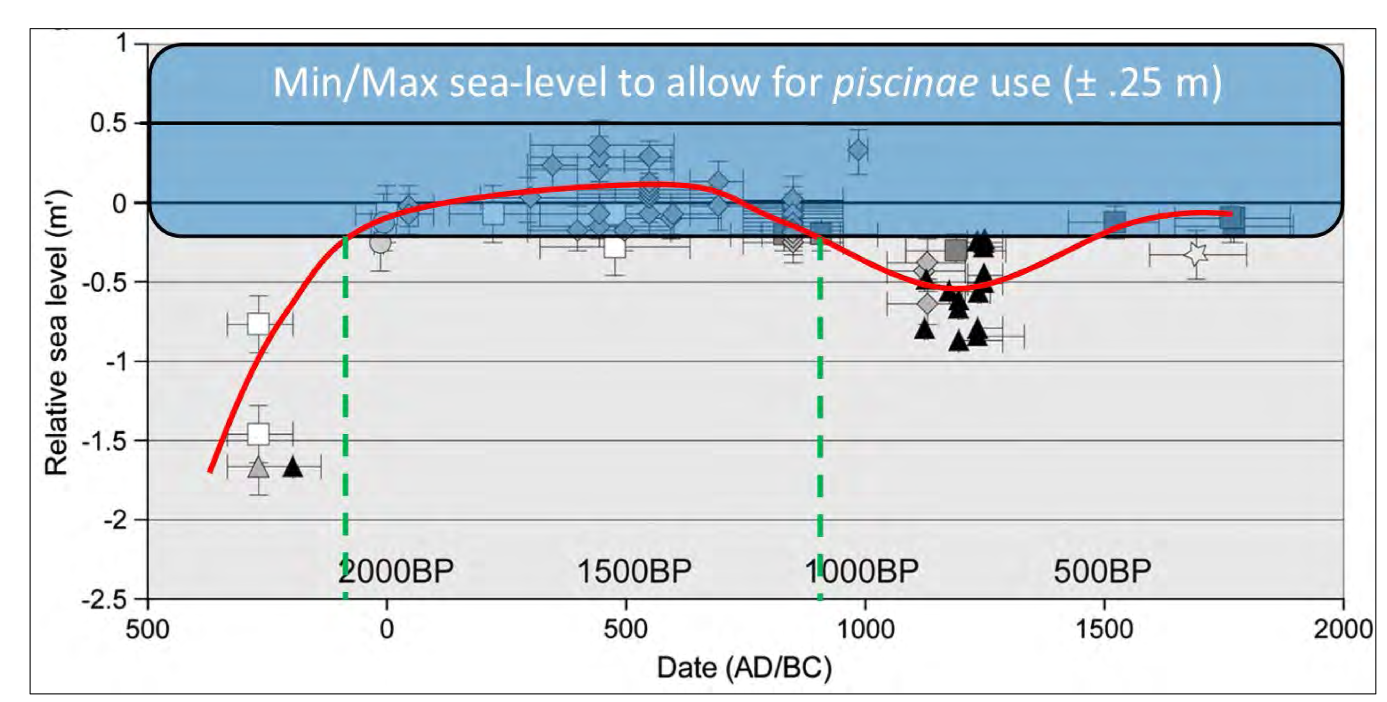

Figure 6) Sea-level curve (red line) of the Mediterranean coast from 2500 years before present (BP) to the present, constructed from archaeological features of known date (plotted on a graph from Toker et al. 2012, one of the few studies of this area that **does not** use the Dor *piscinae* as a proxy for determing paleo sea-level). Note the sharp increase in sea-level prior to the period of the Roman Empire (ca. 2000 BP). The blue area represents the minimum and maximum sea-level necessary for using the Dor *piscinae*, calculated from the minimum and maximum elevations of certain features identified by Auriemma et al. (2009) as useful proxies for paleo sea-levels. The maximum/minimum depth comparison indicates that the use-period for the *piscinae* (green dashed lines) was approximately from the 1st c. BCE – 8th c. CE.

Tel Dor in Context

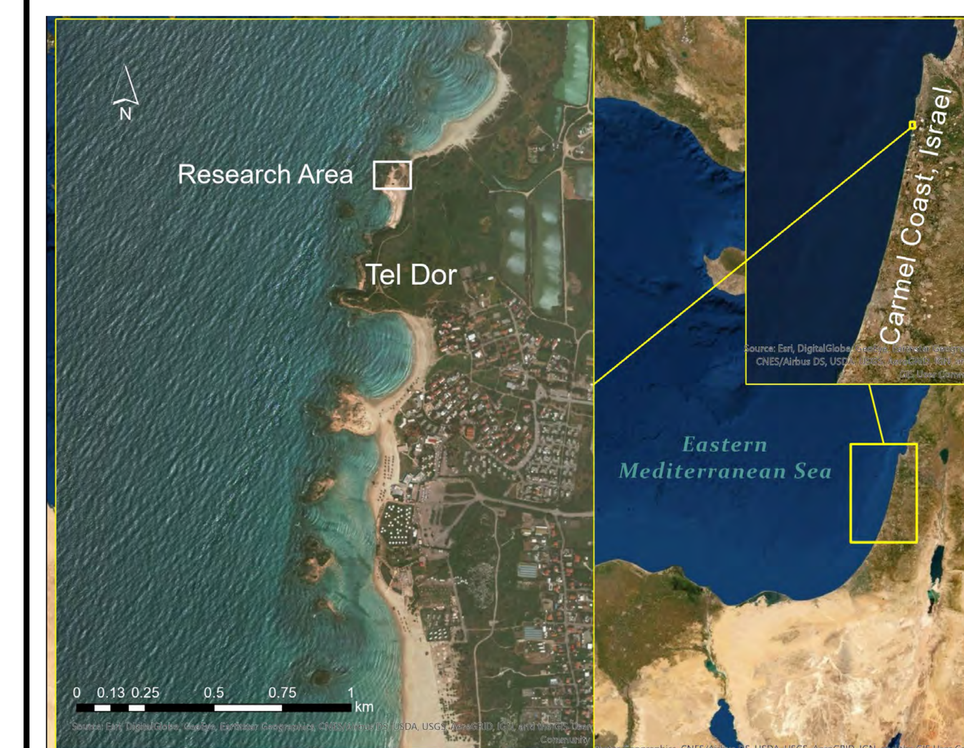

Figure 7) Map of Tel Dor's location on the Mediterranean coast of Israel

- Tel Dor was inhabited from the Late Bronze Age to the Crusader period (ca. 1300 BCE - ca. 1300 CE).
- The site was well-known for its aquacultural industries (esp. purple-dye production and fishing).
- Architectural remains nearby indicate this part of the Carmel Coast has been **tectonically inactive** over the past 2000 years.
- The coastal installation and associated *piscinae* are located to the north of the tel, in an area that has been interpreted as a coastal industrial area.

PRELIMINARY RESULTS

- When compared with the local sea-level curve, the maximum/minimum elevations of features indicate that the use-period of the Dor *piscinae* was **ca. 1st c. BCE – ca. 8th c. CE**.
  - Before and after this period the *piscinae* would have been too far above local sea-level for necessary water circulation to occur.
- Elevation analysis via a DEM can be more comprehensive than collecting min/max elevation points with a total station or RTK GPS survey because calcareous accretion and in-fill, daily/seasonal tides, and human error make it difficult to measure the "bottom" and "top" of features in the field.
  - However, use-period resolution depends on the exposure of the coastal feature and preservation of the top plane of features.
  - Similarly, resolution is directly proportional to the resolution and the rate of change of the local sea-level curve.
- Results can be improved by clearing in-fill to expose the bottom of the *piscinae* before taking additional photographs.

ONGOING AND FUTURE WORK

- This method of analysis alone cannot be applied to date a coastal structure. Rather, it is useful for defining a structure's use-period – when it **could have been** used. Additional relevant archaeological data must be investigated to see what other factors might have led to a site's construction, use, or decline.
- Dating should be refined as future improvements are made to the local paleo sea-level curve, and with further investigation of relevant archaeological data:
  - e.g. Documents from the late 3rd c. CE indicate Roman Dor was no longer inhabited, thus limiting the likely use-period to the 1st c. BCE – 3rd c. CE.
- Similarly, dating can be further refined with an analysis of changes in tidal magnitude during spring and neap tides, as well as storm seasons. Modern storms flood the *piscinae* system (see Figure 2B), rendering it periodically useless during winter storm months.

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