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"BESS" Pocket Beach Management & Remote Surveillance System

Anton Micallef, Emanuele Colica, Luciano Galone, Sebastiano D’Amico,
Stefania Lanza, Anthony Zammit, Agostino Tomasello, Francesco Italiano, Giovanni Randazzo

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IL Sileno Edizioni

L-Università ta' Malta

In Collaboration with Project Partners

MINISTRY FOR GOZO

ISTITUTO NAZIONALE DI GEOFISICA E VULCANOLOGIA

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Cover: Orthomosaic of Gnejna Bay.
The survey was carried out in May 2019

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Scientific and Cultural Association “Il Sileno”, VAT 03716380781
Via Piave, 3/A, 87035 - Lago (CS), Italy
and
Department of Geosciences, University of Malta,
Msida MSD 2080, MALTA

Index

1. The Project “BESS”

“BESS” Pocket Beach Management & Remote Surveillance System is a project co-funded by the European Union, lasting 30 months; it is coordinated by Prof. Salvatore Cuzzocrea, Rector from University of Messina (MIFT-UNIME). This project brings together two Maltese partners (the Ministry of Gozo and the University of Malta, the latter represented by the Euro-Mediterranean Centre on Insular Coastal Dynamics (ICoD)) together with three Sicilian partners, the University of Messina, the University of Palermo and the Italian National Institute of Geophysics and Volcanology (INGV).

Pocket beaches (hereafter PBs) are literally “**pocket-shaped**”, generally small and limited by natural headlands jutting into the sea. Along the Maltese and Sicilian coasts there are several PBs, which depending on their isolation and level of exposure, preserve ecological niches of great value, and thus represent relic deposits, formed under different conditions from those currently experienced, suggesting a response naturally resilient to the effects of climatic changes.

These beaches are prized by tourist but often suffer the impact of human pressure and trigger risks to the safety of the same users.
It is proposed to map all the PBs in Malta and Sicily to create a remotely sensed monitoring platform (fix and satellite), based on the identification of specific geomorphological and sedimentological indices, in order to preserve these erosion sensitive environmental niches and ensuring continued tourist use. The project will equip Public Administrations with an erosion predictive instrument, and its subsequent management will be the responsibility of those who produced it, and who can provide on-demand support.

The project involves sharing with stakeholders of all its phases and will end with the production of a beach management manual and the drafting of two management plans on two sample locations. The MIFT-UniMe and ICoD provide experts on coastal geomorphology and development of the abiotic components of the project, while DiSTeM-Unipa will address those aspects related to biotic components, with particular reference to the analysis of the contribution of seagrass to the production of detritus accumulations on the coasts. INGV will integrate the product in its surveillance system network and the Ministry for Gozo will cover the communication aspects.

The BESS Project is funded under the EU’s INTERREG ITALIA-MALTA Programme. It is part-financed by the European Union’s European Regional Development Fund (ERDF), co-financing rate: 85%/75% EU Funds; 15%/25% National Funds.

2. The Geographical Setting

The Maltese archipelago, consisting of the three main islands of Malta, Gozo and Comino and a number of other minor islands and rocks, trends in a north-westerly to south-easterly fashion and is circa 44km long (House et al., 1961; Ransley, 1974). The islands support a permanent population of over 514,564 (National Statistics Office, 10th July 2020) with Malta, the largest of the three main islands. Malta is 27.3 km long by 14.5 km wide and has a surface area of 246sq.km. Its sister island Gozo, lying north-west of Malta is 14.45 km long by 6.4 km wide and has a surface area of approximately 67sq.km. Of the smaller islands (Comino, Kemmunett, St.Paul's Islands, Filfla and Fungus Rock), only Comino is inhabited, having a surface area of about 2.5 sq. km. (Ransley, 1974; Planning Services Division, 1990). From the above statistics, it can be calculated that with a total surface area of only 316 km^2, the Maltese islands possess a population density of 1,631 persons/km^2, the highest population density in Europe and the Mediterranean region and according to Mallia & Schembri (1995) one of the highest population densities in the world.

2.1. The Geology of the Maltese Islands

Local geology and climatic characteristics have been crucial to the formation and development of the Maltese Islands.

Since the early works of Spratt & Forbes (1843), Murray (1890), Cooke (1893; 1896) and Rizzo (1932), several authors have reviewed the geology of the Maltese Islands (House et al., 1961; Pedley et al., 1976, 1978; Zammit – Maempel, 1977). Apart from some clays, marls and minor Quaternary deposits, Maltese geology is made up entirely of Tertiary Limestones. The Quaternary deposits dating from the Pleistocene account for the coastal conglomerates, cliff breccias, cave and valley loams, sands and gravels found on the island. The exposed Tertiary succession is entirely of Oligocene and Miocene carbonates ranging in age from Chattian (Late Oligocene) to Early Messinian (Late Miocene) (Carbone et al., 1987). House et al. (1961) and Pedley et al. (1976; 1978) have described the stratigraphy of the main Limestone Formations as being represented by a succession of the Lower Coralline Limestone; Globigerina Limestone; Blue Clay; Greensand and the Upper Coralline Limestone (Figure 1).

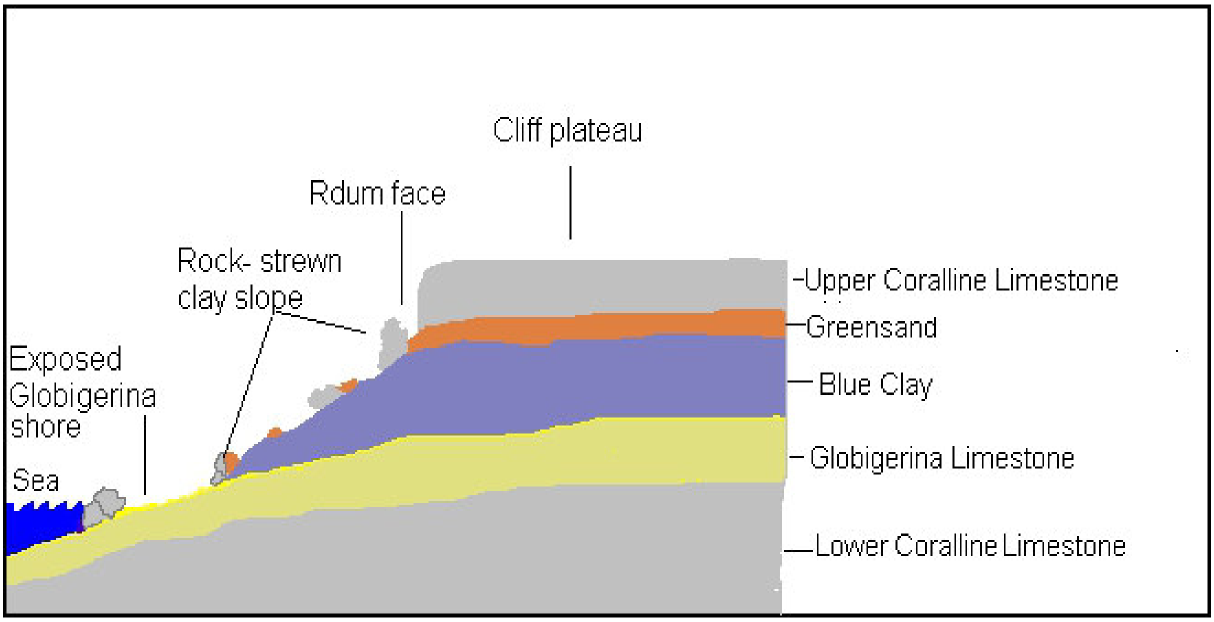


Figure 1: Schematic profile to illustrate the depositional sequence of the five main Limestone Formations forming the Maltese Islands. The illustration also represents a typical rdum coastal slope feature. *(N.B. The thickness of the individual rock strata is not to scale).*

2.2. Coastal Geomorphology

The coastal morphology of the Maltese Islands has been largely determined by tectonic activity primarily in the Holocene period, which has been un-interrupted to present day (Drago, 1991). Apart from that obscured by urban development, the natural coast of the Maltese islands can be best described by its geomorphological characteristics (Table 1) and belongs to either: (i) Low-lying rocky shore, (ii) Plunging cliffs (iii) *rdum* cliffs (iv) Beaches (Planning Services Division, 1990). The generation of such different coastal land-forms may be attributed to tectonic activity and the varying impact of natural erosional forces on the differently resistant bedrock,

Coastal type	**Percentage of overall coastline**	
	Malta	**Gozo & Comino**
Low-lying rocky shore	30 %	16 %
Plunging cliff	22 %	62 %
Rdum cliff *	17 %	14 %
Beach	2 %	2 %
Anthropogenic development	*29 %*	*6 %*

Table 1: Geomorphologic form of the Maltese Coastline - where linear measurements are expressed as percentages of the total coastal length of either Malta or Gozo & Comino. (*Adapted from Planning Services Division, 1990*).

These cliffs appear whenever Globigerina Limestone overlaid with Upper Coralline Limestone is exposed at the coast. The removal of the Globigerina Formation by wave erosion exposes the overriding clay deposits that subsequently spread down the slope forming typical coastal clay taluses, thereby undercutting the overlying Upper Coralline Limestone and Greensand Formations. As a consequence, huge cracks appear at the edge of the Upper Coralline plateau with subsequent crumbling of the *rdum* face forming the typical rock and boulder strewn *rdum* slope. Where such debris is removed by wave action, the eroded Globigerina Limestone is exposed as shore platforms. Due to their poor access and sheltered nature, *rdum* cliffs (Figure 2) are important sites for the establishment and natural protection of many species of local flora and fauna.

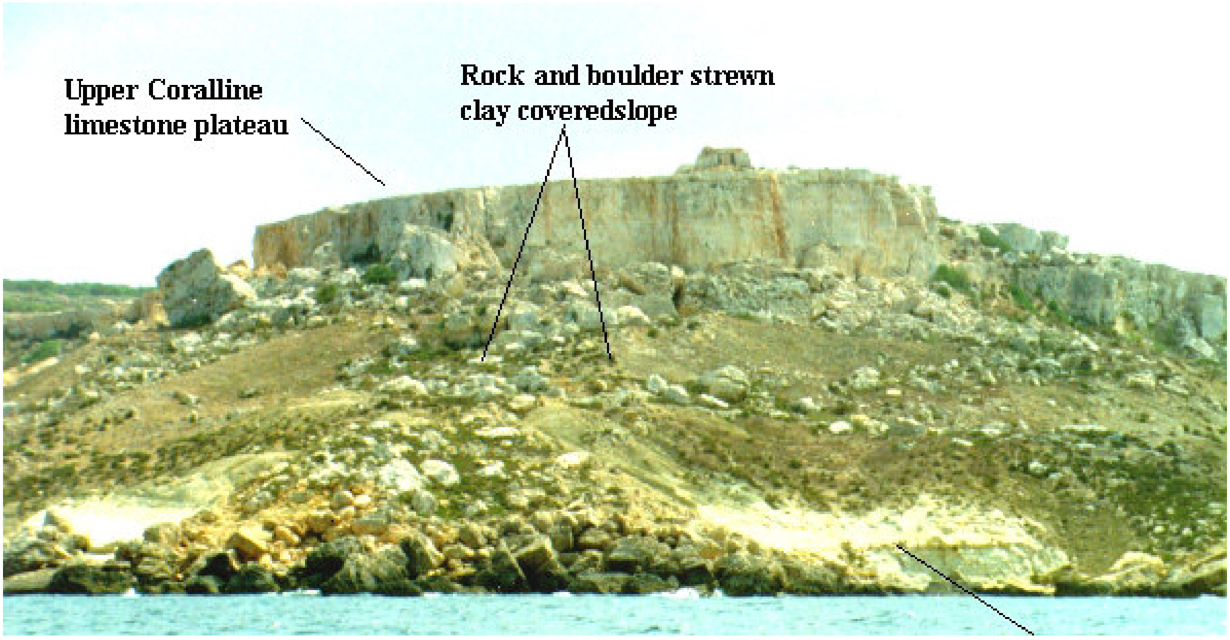


Figure 2: Coastal Rdum formation with underlying clay covered slope feature at Gnejna Bay, south-west coast of Malta.

Paskoff and Sanlaville (1978) have suggested that although it is easy to imagine that such coasts could erode rapidly, the boulder covering of the Rdum slope and particularly of its sea-ward edge, offers sufficient protection to prevent rapid erosion and that this type of cliff erodes at a slower pace than those composed entirely or largely of Globigerina Limestone. Typical examples of *rdum* cliffs may be seen on the north-west coast of Malta between Ras il-Pellegrin and the north-western coast of Mellieha ridge.

2.3. Beaches

While the geology of the islands has been extensively studied, no scientific study has as yet addressed the issue of coastal erosion rates and in particular the very limited coast related recreational facilities in the form of sand beaches and accessible low-lying rocky shore. Such resources are in high demand by both local and incoming tourists and in this connection, Paskoff & Sanlaville (1978) have observed that sediment accumulating coast on the Maltese Islands is very scarce, being mainly represented by Ramla Bay on Gozo and Ghadira Bay and a number of much smaller bays in Malta being situated at the mouth of valley systems in the north of the Island (Figure 3).
The Maltese Islands' coast supports very few and small beaches as a consequence of the limited and fine (and thus non-abrasive) sediment produced by its predominant Limestone Formations (Micallef, 2003). In a few cases where valley deposits and run-off is more significant and Blue Clay and Greensand Formations outcrop together, the beaches are somewhat larger (e.g. Ir-Ramla beach in Gozo), being composed of sand, clay and background silt (Anderson and Schembri, 1989).
Using microscopic and X-ray diffraction analysis, Turi *et al*. (1990) examined the mineralogy and origin of Maltese beach sediments with respect to local Tertiary (Late Oligocene - Miocene) rock formations. This analysis identified an over 90% (largely organic) carbonate beach composition and a very limited extant carbonate production. Such findings and the lack of local river systems, support the indication of limited beach sedimentary sources and strengthen the argument that erosion of Tertiary rock outcroppings within local embayments is of particular importance in providing sediment to local pocket beaches (Micallef, 2003).

2.4. Beach sediment sources

A literature review of works referring to beach sediment mineralogy and origin in the Maltese Islands (Pedley, 1978; Spiteri, 1990; Turi et al., 1990; Schembri & Baldacchino, 1992; Micallef et al., 1994; Zammit-Maempel, *pers. comm*., 1998) suggested that nourishment of present-day beaches in Malta may be attributed to sediments derived from:
Valley alluvial Quaternary deposits particularly during flash-floods caused by high precipitation events.
Sediments eroded from coastal Tertiary rock outcrops mainly in the form of *rdum* cliffs and associated headlands.
Marine sediments of Holocene origin.

In the above context, it is interesting to note that all of the major beaches found in the Maltese Islands (namely those at Ghadira, Gnejna, Ghajn Tuffieha, Golden Sands in Malta and Ramla in Gozo - Figure 3) have associated valley systems and *rdum* cliffs formations. Other less extensive beaches such as that at Marsalforn in Gozo and the now completely eroded beach at Xemxija in Malta (Figure 3), are either representative of drowned valleys where *rdum* cliffs are absent or where large scale coastal urbanisation has reduced *rdum* headlands and where extensive damming of the associated catchment area and road construction across the back of the beach have considerably reduced sediment supply.

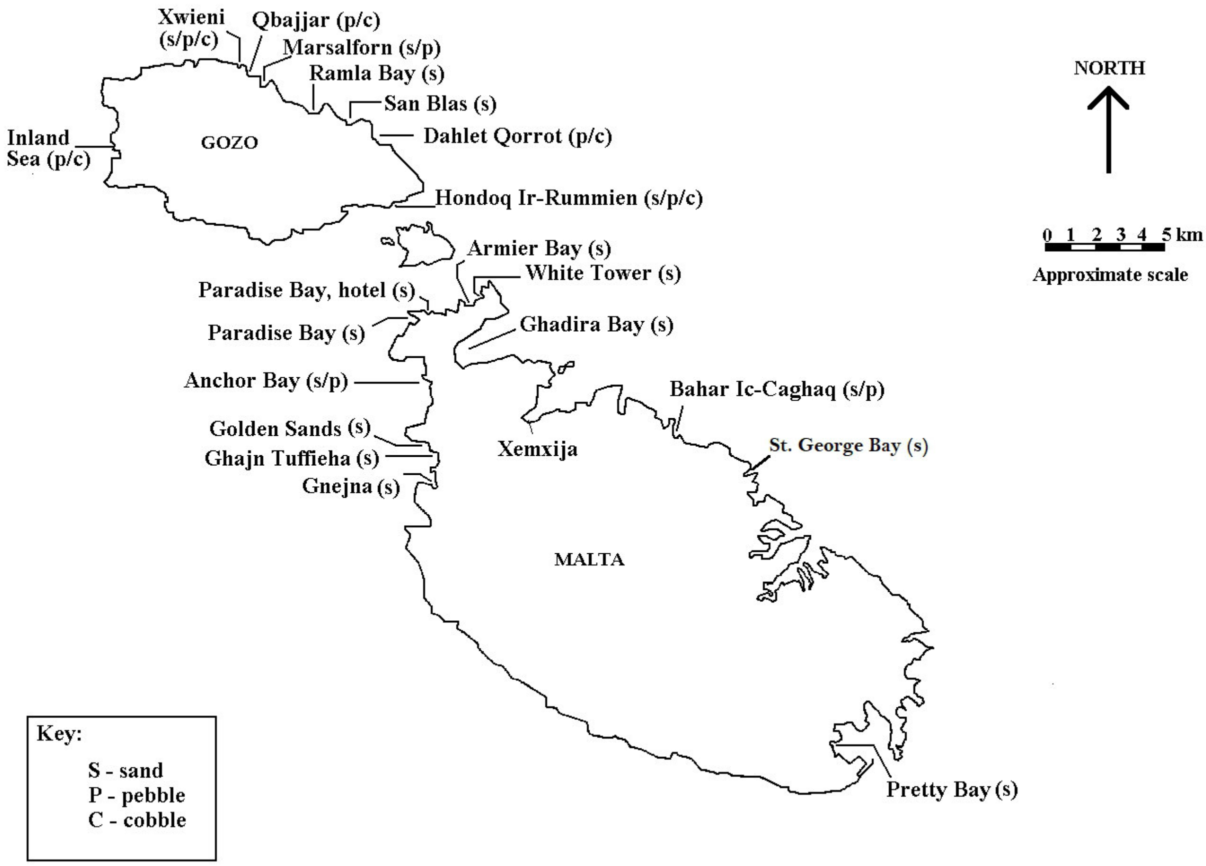


Figure: 3: Beaches in Malta and Gozo.

Ghadira bay on the northern coast of the island, supports the largest beach in Malta. A number of much smaller beaches are located at Armier, White Tower Bay and at Cirkewwa on the north/north-western end of the island (Figure 3). Apart from the artificial beaches at Pretty Bay, Birzebbugia and St George's Bay in St. Julians, other beaches are located on the south-western coast at Gnejna, GhajnTuffieha and Golden Sands (Figure 3; Micallef, 1996). While the beaches on Gozo are even more limited and largely restricted to the northern coast, this smaller island supports the ir-Ramla, one of the more attractive and substantial beach and dune systems of both islands.

A number of much smaller beaches composed of a sand/pebble/cobble (or purely pebble/cobble combination) matrix may be found at the Inland Sea, Marsalforn Bay, Qbajjar and Xwieni Bay in Gozo and BahaIr Ic-Caghaq in Malta (Micallef, 1996); (Figure 3).

The stability status of sand beaches was classified by Fabbri (1990) according to Table 2. While the author did not define beach stability, Bird (1996, p.55) has suggested that a stable beach is one "*where there is no net gains or losses in beach sediments over periods of more than a year or two*". Furthermore, the '*urgent nourishment works'* referred to by Fabbri (1990) for Pretty Bay reflects the highly degraded state of this beach prior to beach nourishment which was undertaken in that same year subsequent to the Fabbri (1990) report.

BEACHES	**STATUS**
Gnejna, Ghajn Tuffieha, Golden Bay, paradise Bay, Mistra Bay and Ramla l-Hamra.	Beaches in a stable state requiring no further intervention.
Armier and White Tower Bays.	Beaches eroding mainly through landward aeolian transport.
Kalkara, Rinella, M'Xlokk, St.George's (B'Bugia), Salina, Spinola, Balluta, Gharid-Dud, Manoel Island and Dwejra.	Sites unsuitable for sand nourishment
M'Scala, St.Thomas, Ramla (Malta), Ghadira, Bahar ic-Caghaq, Xlendi and Marsalforn.	Beaches in need of nourishment following extensive studies.
Pretty Bay, Xemxija, Qalet Marku and St.George's Bay.	Beaches/bays requiring urgent nourishment works.

Table 2: Beach classification according to Fabbri (1990). *Source: Chircop, 1991.*

Factors that influence beaches in the Maltese Islands are several and may include the following:

Climate change. This is mainly considered in respect of the trend in increasing storminess, the influence of which, is expressed as increased wind storm frequency and related wave-scour impact on beaches, increased generation of rip-currents and related sediment movement off-shore and increased precipitation storm events and related damage to sandy beaches and dune systems.
Wave climate as influenced by particularly large fetches to which Maltese beaches are exposed and headland diffraction (generated by pocket beach configuration) of oblique angled waves.
A *limited natural sediment supply* represented by an absence of sediment rich river systems, typical pocket beaches unable to benefit from upstream sediment supplies and a parent geology yielding very limited beach-suitable sediments. The latter are in fact largely fine and either soluble or generated as suspended sediments during and after precipitation storm events.
Attrition and weathering of a largely carbonate beach sediment fraction.

Aeolian sediment transport as evidenced by Ramla beach in Gozo and Ghadira beach on north Malta and according to Fabbri (1990) Armier and White Tower beaches (Figure 2.3). In the Maltese Islands, sediment transport by wind action is particularly apparent on a number of beaches exposed to prevalent north-westerly winds. Ramla beach in Gozo, for example, has a northerly orientation and loses sand to the south-easterly hinterland as a result of strong north-westerly storms to an extent that cultivated fields are discoloured by the orange coloured sand found at this beach. Locally, a further indication of the influence of aeolian transport of sediment from beaches may be observed in the accumulation of sand on and beyond coast-roads following strong wind storms (Figure 4).

Figure 4: Aeolian transport of beach sediment and sea-weed fragments (foreground) beyond an artificial sea-wall (centre - right of the picture) on to the coast-road bordering the back-shore of the beach at Ghadira Bay, north-western coast of Malta.

Extensive *sea-grass meadows* associated with local beaches. The movement and production of coastal sediment material is also influenced by marine organisms such as echinoderms, molluscs and algae, through their burrowing and feeding behaviour and subsequent break-up into shell fragments. Sea-grass meadows (largely represented by *Posidonia oceanica* beds around the Maltese Islands), are also known to play an important role in the stabilisation of sea-bottom sediments by their extensive root systems (*mattes*) which trap sediment. The *Posidonia* meadows further protect the shoreline, and in particular beaches, by effectively lowering the water depth, therefore causing oncoming waves to break prior to reaching the shore. Conversely, Bird (1985; 1996) suggested that the establishment of sea-grass meadows may prevent off-shore sediment from drifting in-shore. In this context, Micallef (1992) identified a 1 - 2m band of coarse shell fragment dominated sediment accumulated outside the mouth of Ghadira Bay (on the north-west coast of Malta – Figure 3) just beyond the seaward edge of a *Posidonia oceanica* meadow within the embayment. Bird (1985; 1996) described examples of beach accretion following the destruction of such sea-bed vegetation on the Danish Island of Kyholm and the Mediterranean coast of Provence.

A locally reduced marine biogenic generation of sediments (Turi et al., 1990).

An increased local coastal urbanisation resulting in reduced sediment supplies from stabilisation of potentially sediment-rich *rdum* systems within coastal embayments.

3. Methodology

This booklet presents three types of results from our study of 16 selected pocket beaches (PBs) in Malta and Gozo (Figure 5): orthomosaics, digital elevation models (DEMs) and bathymetric maps.

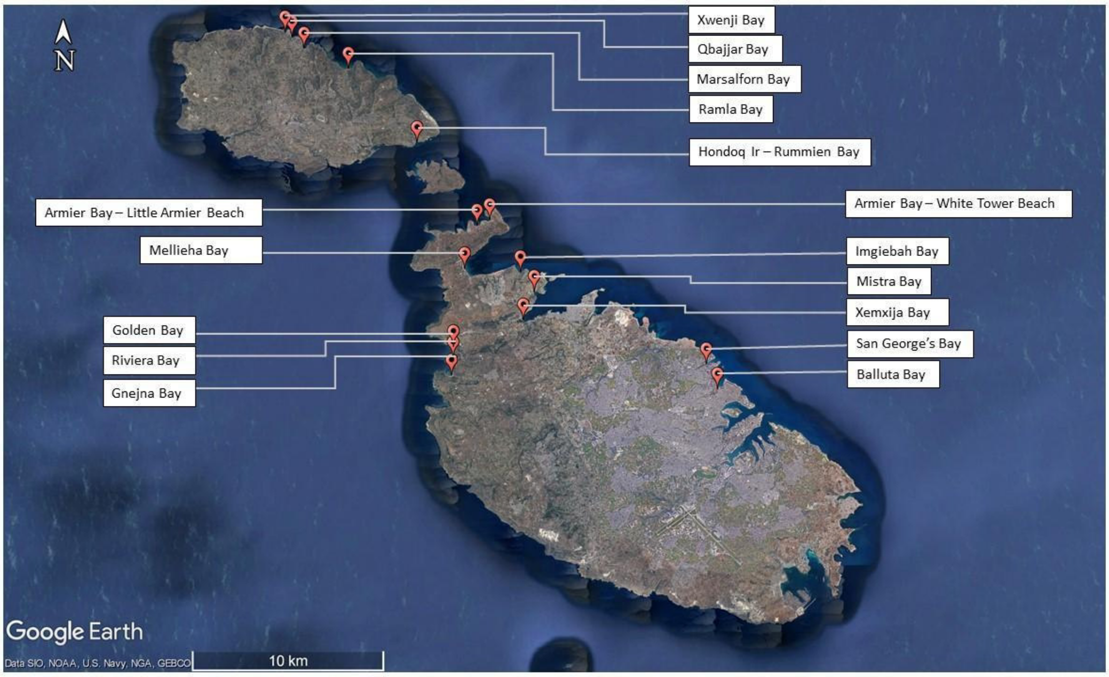


Figure 5: Map of the Maltese Islands showing the selected pocket beaches.

3.1. Aerial photogrammetry methodology

The orthomosaics and digital elevation models were obtained by unmanned aerial vehicles (UAVs) photogrammetry. Different types of UAVs (or drones) and a sophisticated differential global navigation satellite system (GNSS) were used to achieve centimetric accuracy.

During 2019, two surveys were conducted, one in May and one in October, in order to carry out observations for monitoring purposes (all orthomosaics and DEMs are in Appendix I). Obtaining the DEMs and orthomosaics involves a series of sequential steps (Colica et al., 2017) (figure 6):

1. Image acquisition: Images were acquired using a digital camera mounted on a drone. The flights have been performed using flight planning software, ensuring a high degree of overlap between continuous photographs, which is essential to obtain reliable 3D information. In addition, to ensure correct and accurate georeferencing and scaling of the final models, ground control points were used, the coordinates of which were taken with a differential GNSS.

2. Camera alignment: This step consists of searching for common points in the photographs and matching them by using specific software. As a result, a sparse point cloud and a set of camera positions are formed.
3. Dense point cloud reconstruction: The building of a dense point cloud is based on the estimated positions of the cameras and the images themselves. This cloud is similar to the previous one but with a much larger number of points. It can be edited by removing erroneous points before proceeding to the next step.
4. Mesh generation: In this step, software is used to reconstruct a 3D polygonal mesh representing the object surface based on the dense (or sparse) point cloud.
5. Texture building: Once the geometry has been reconstructed, the software is able to generate a texture and complete the 3D model. From this 3D model it is possible to generate both a digital elevation model and an orthomosaic.

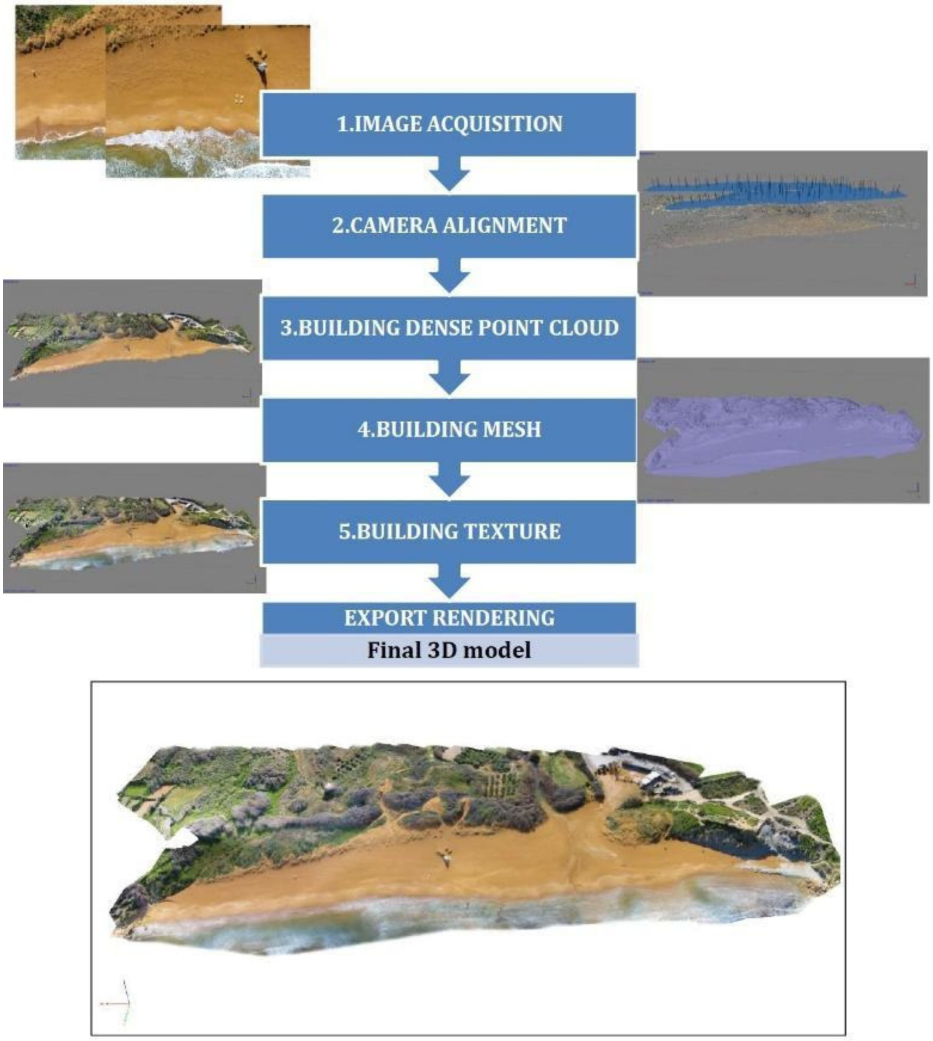


Figure 6: Photogrammetric workflow.

3.2. Bathymetric survey methodology

The bathymetric maps were made with data acquired during the year 2020 (the bathymetric maps for all PBs are in appendix II). Scanning of the seabed was achieved through the use of a single beam echo sounder (SBES) installed on a dinghy and on an underwater remotely operated vehicle (ROV). The echosounder is capable of estimating water depth from the time interval between the emission of a sound pulse and the reception of its reflection on the seabed. Due to that, it needs sound velocity data to make correct depth measurements. Before the acquisition, different parameters of this tool must be calibrated. The SBES was coupled with a high precision GNSS in order to geo-reference the points obtained. The collection of the data was performed by making parallel and orthogonal lines, generating square or rectangular meshes. Finally, the data was processed in a GIS environment, where the point measurements were interpolated to generate an elevation grid. From this, colour maps and contour lines were obtained. This workflow is summarized in figure 7.

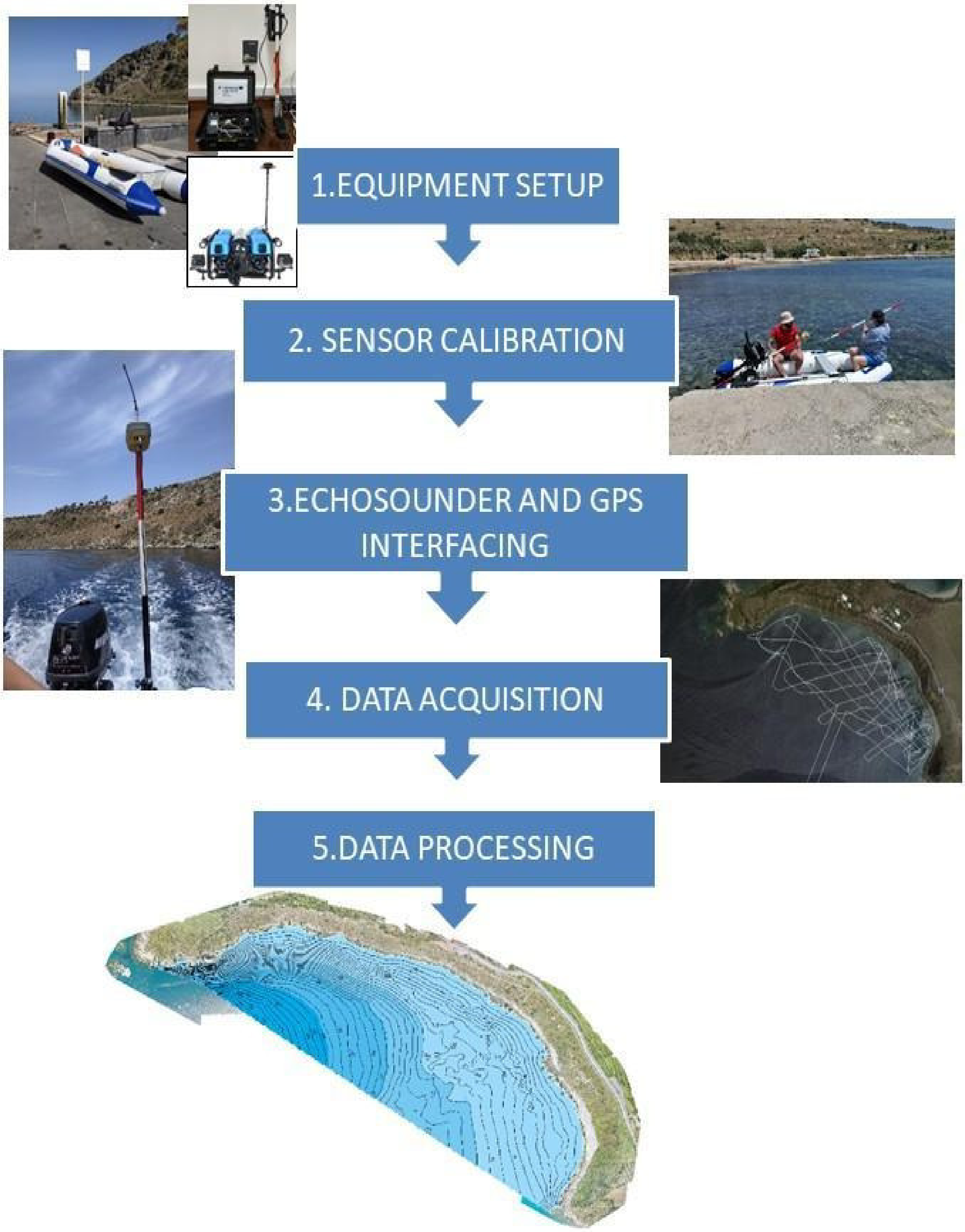
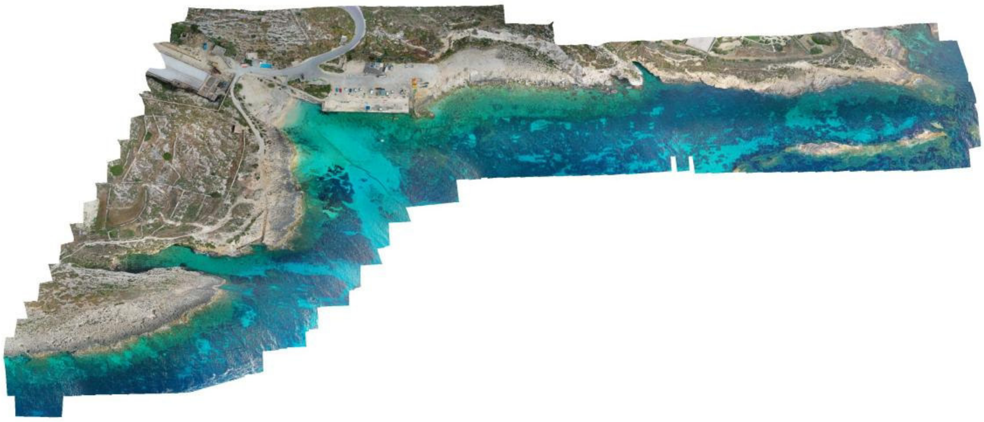


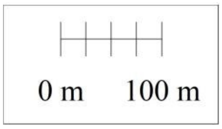
Figure 7: Workflow to obtain the final bathymetric map.

Appendix I : Photogrammetry

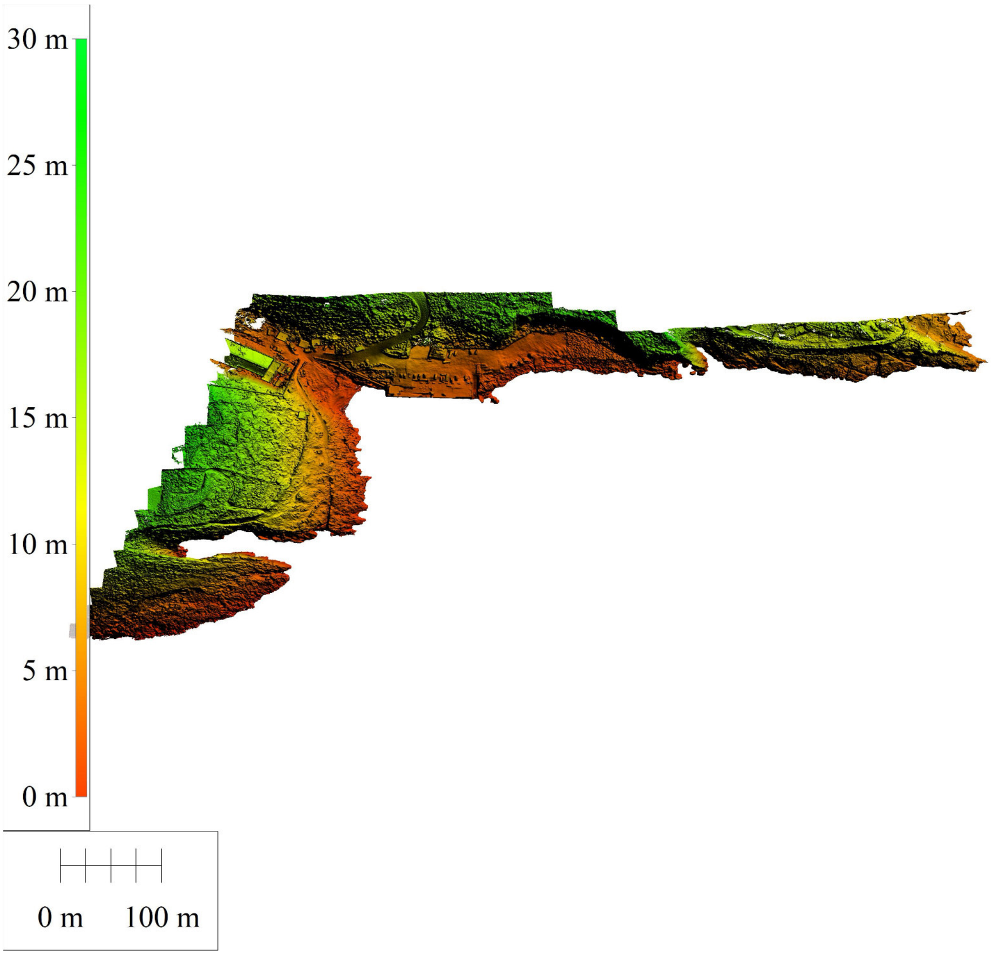
Hondoq Ir – Rummien Bay

Bess Code Gz01

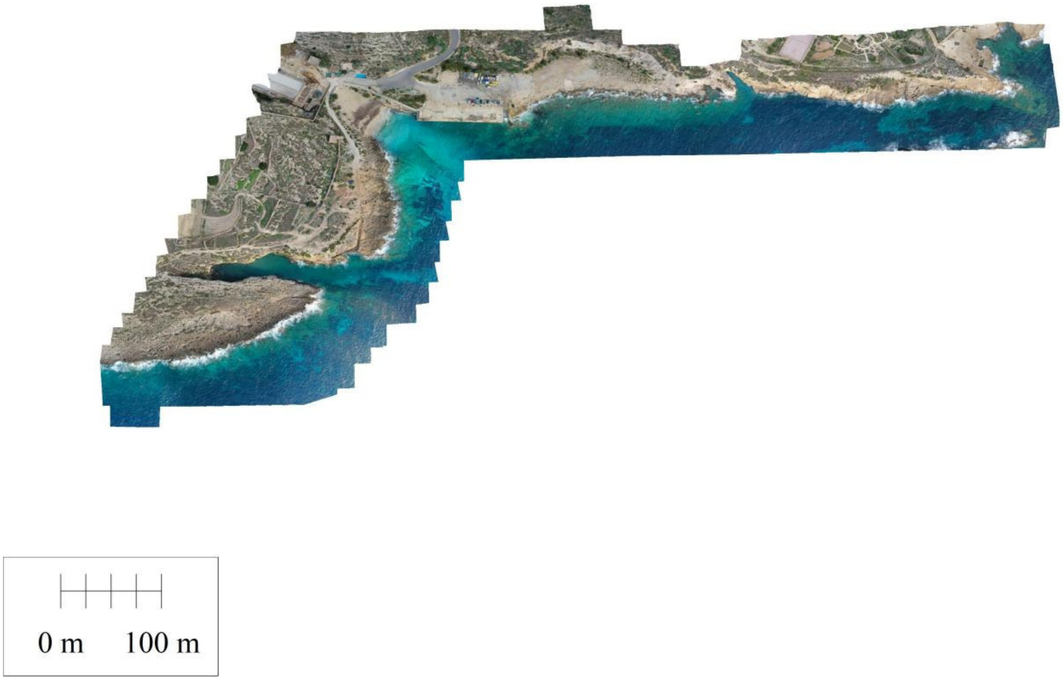




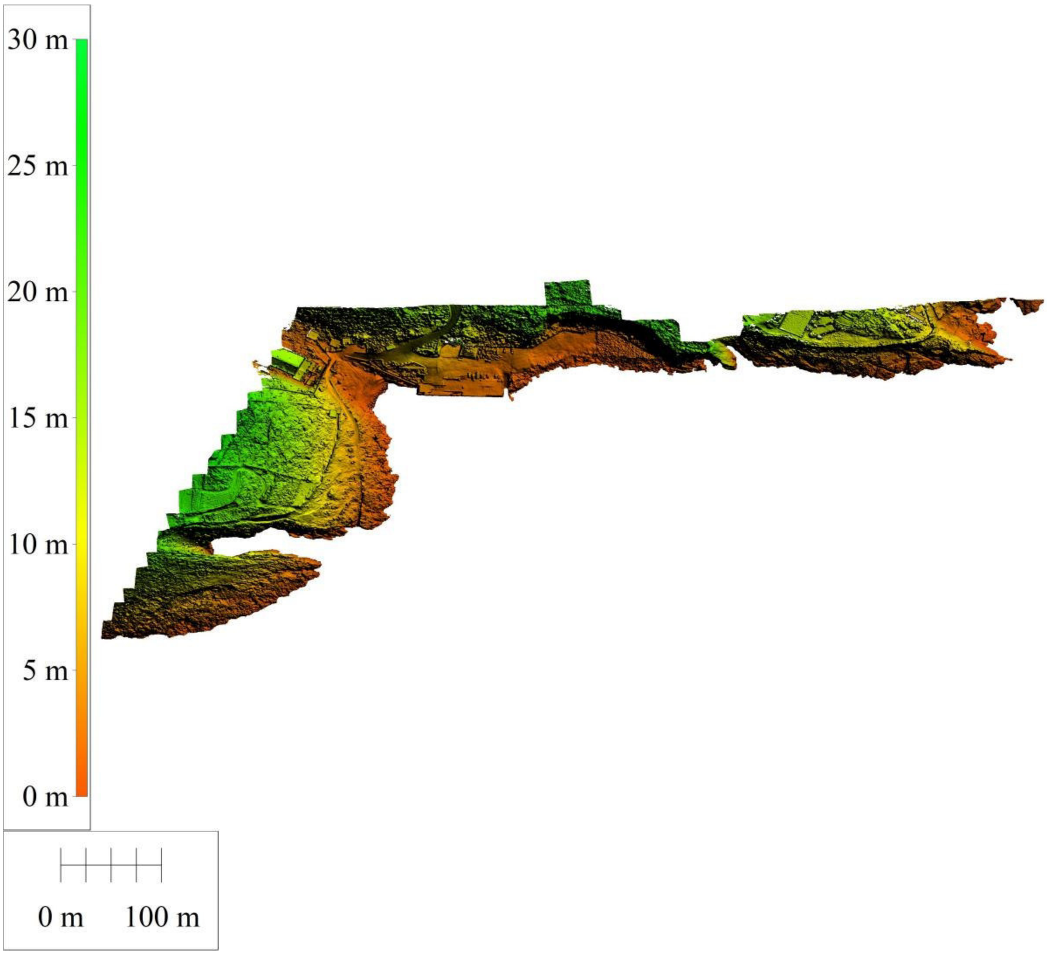
AI.1: Orthomosaic of Hondoq ir-Rummien Bay. The survey was carried out in May 2019.



AI.2: Digital Elevation Model of Hondoq ir - Rummien Bay. The colour scale represents the ground elevation above sea level. The survey was carried out in May 2019.

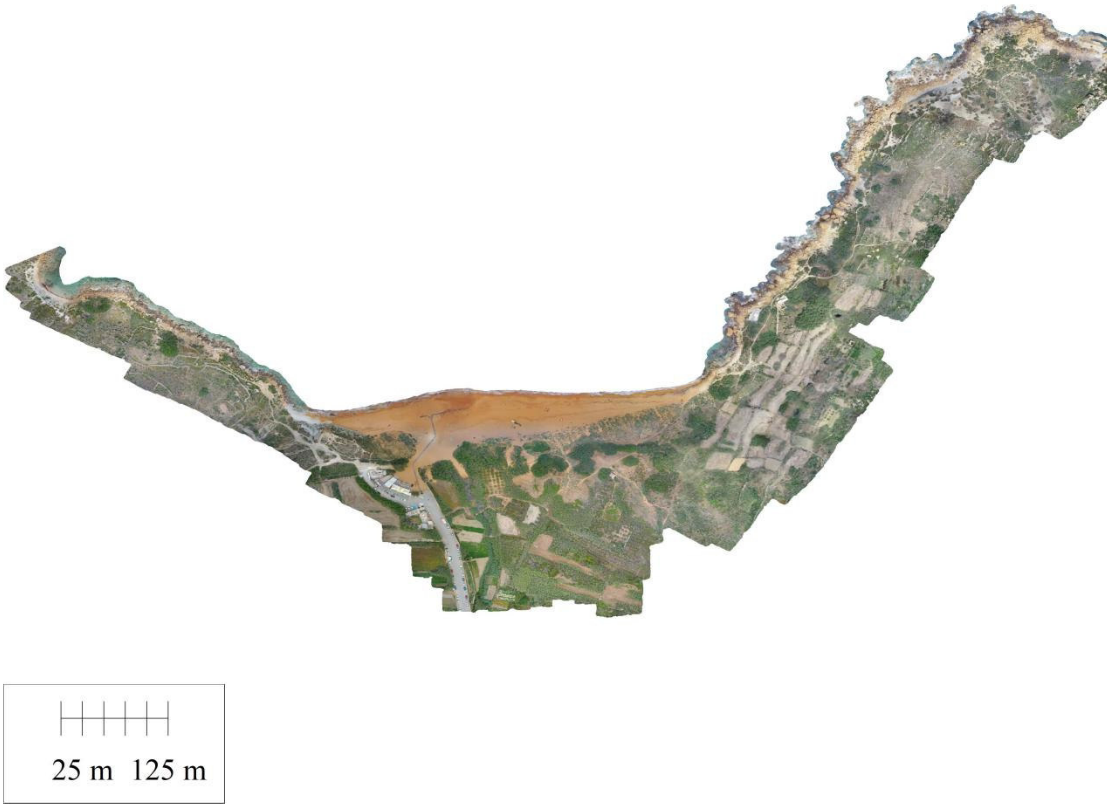


AI.3: Orthomosaic of Hondoq ir-Rummien Bay. The survey was carried out in October 2019

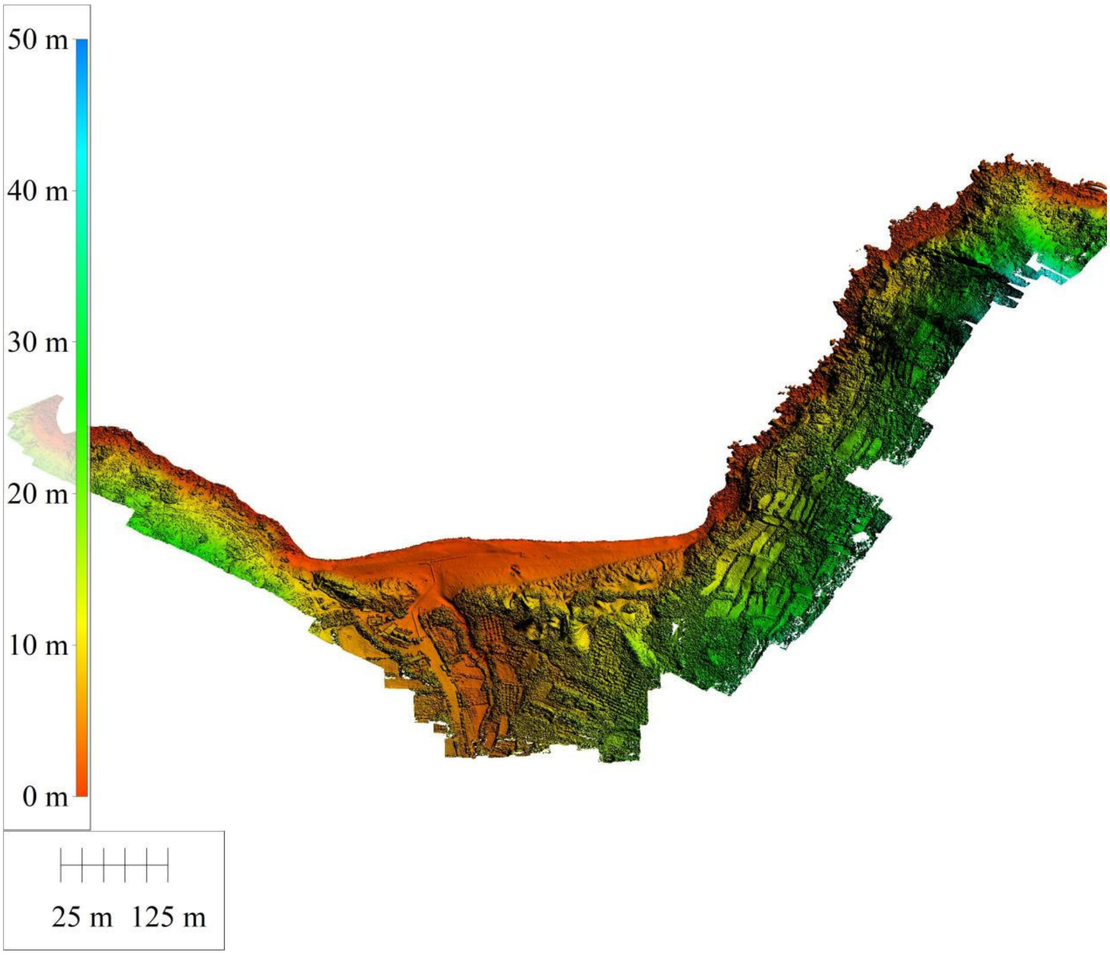


AI.4: Digital Elevation Model of Hondoq ir - Rummien Bay. The colour scale represents the ground elevation above sea level. The survey was carried out in October 2019.

Ramla Bay
Bess Code: GZ02

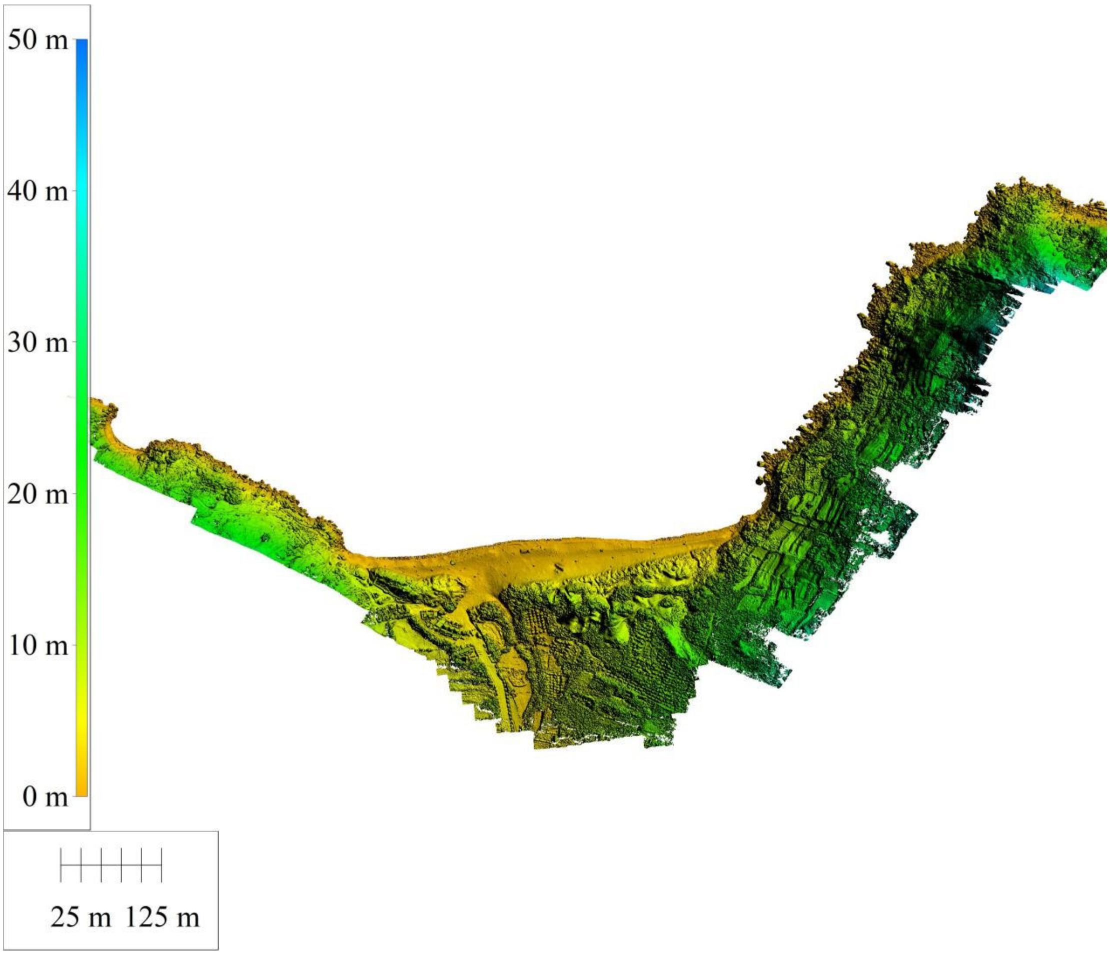


AI.5: Orthomosaic of Ramla Bay. The survey was carried out in May 2019.



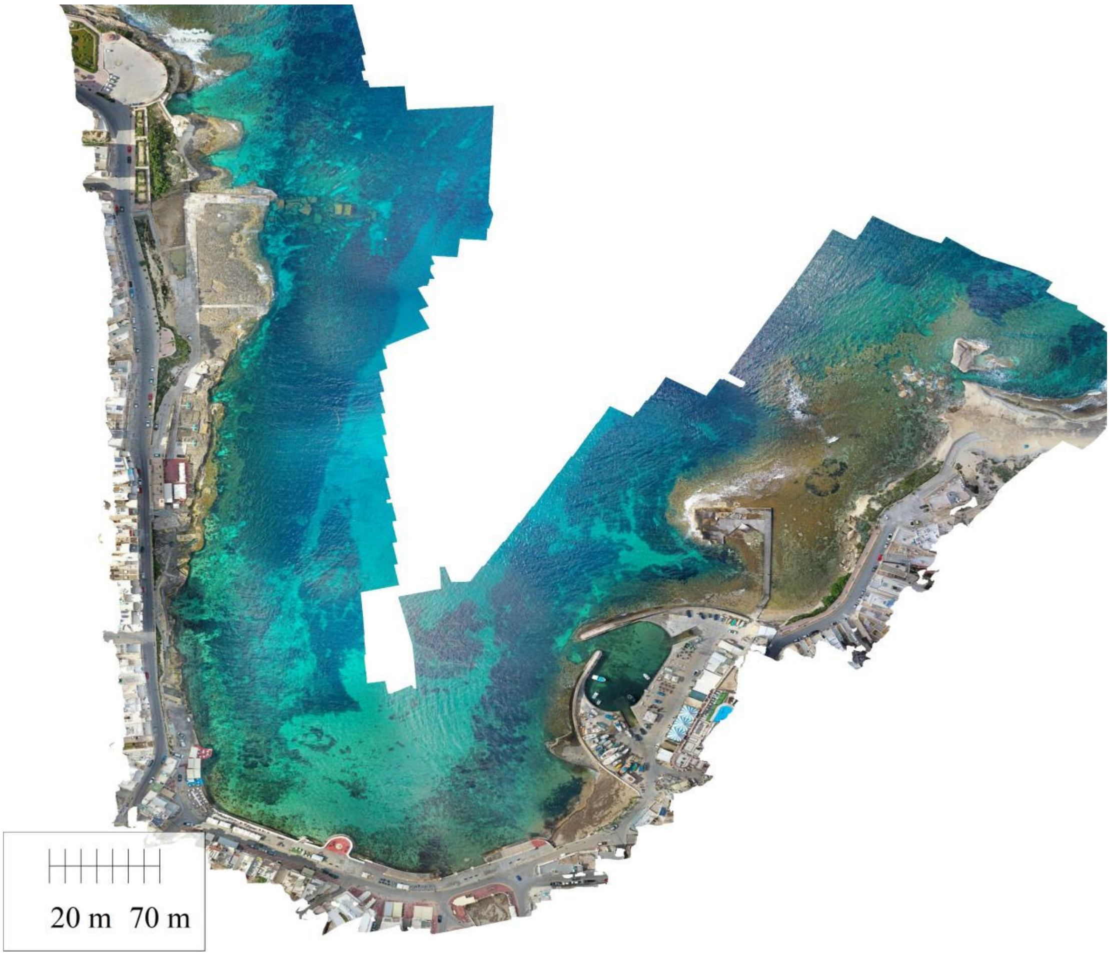
AI.6: Digital Elevation Model of Ramla Bay. The colour scale represents the ground elevation above sea level. The survey was carried out in May 2019.

AI.7: Orthomosaic of Ramla Bay. The survey was carried out in October 2019.

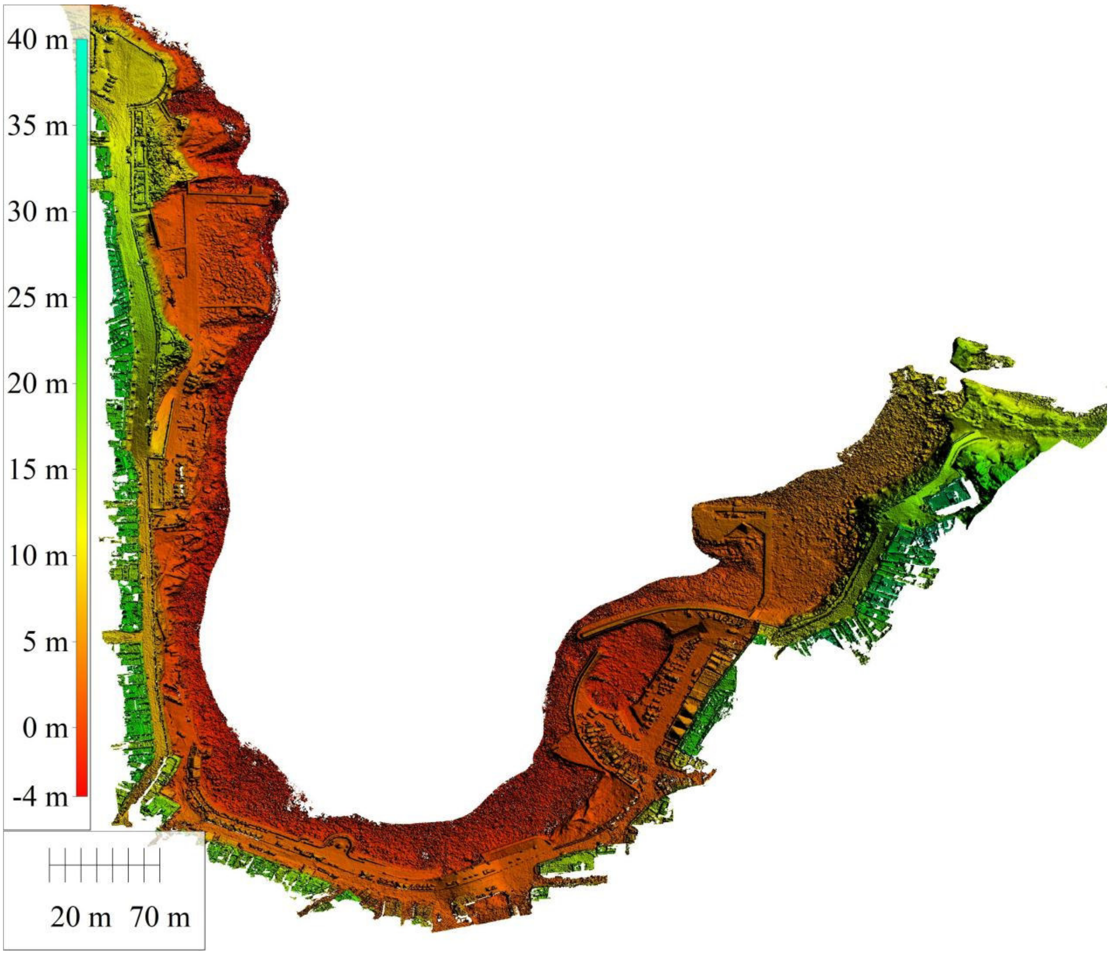


AI.8: Digital Elevation Model of Ramla Bay. The colour scale represents the ground elevation above sea level. The survey was carried out in October 2019.

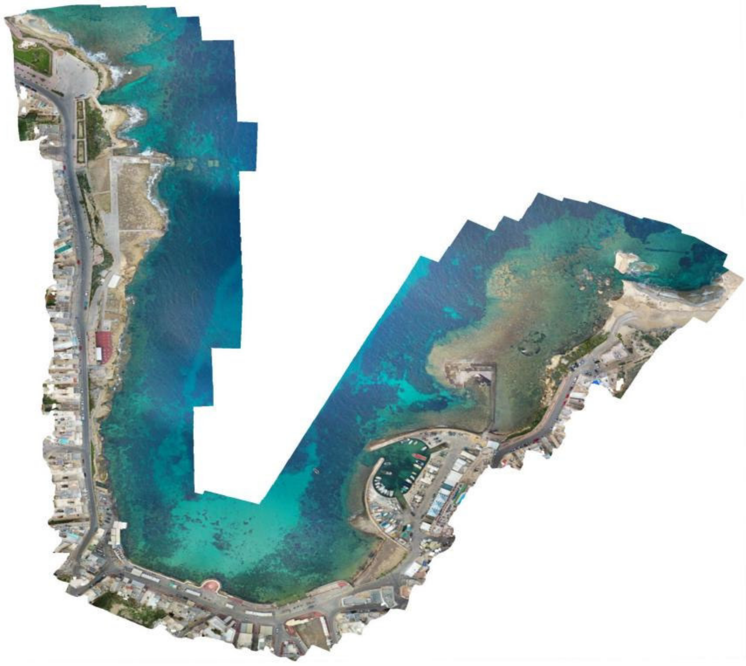
Marsalforn Bay
Bess Code: GZ03

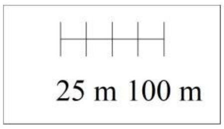


AI.9: Orthomosaic of Marsalrforn Bay. The survey was carried out in May 2019.

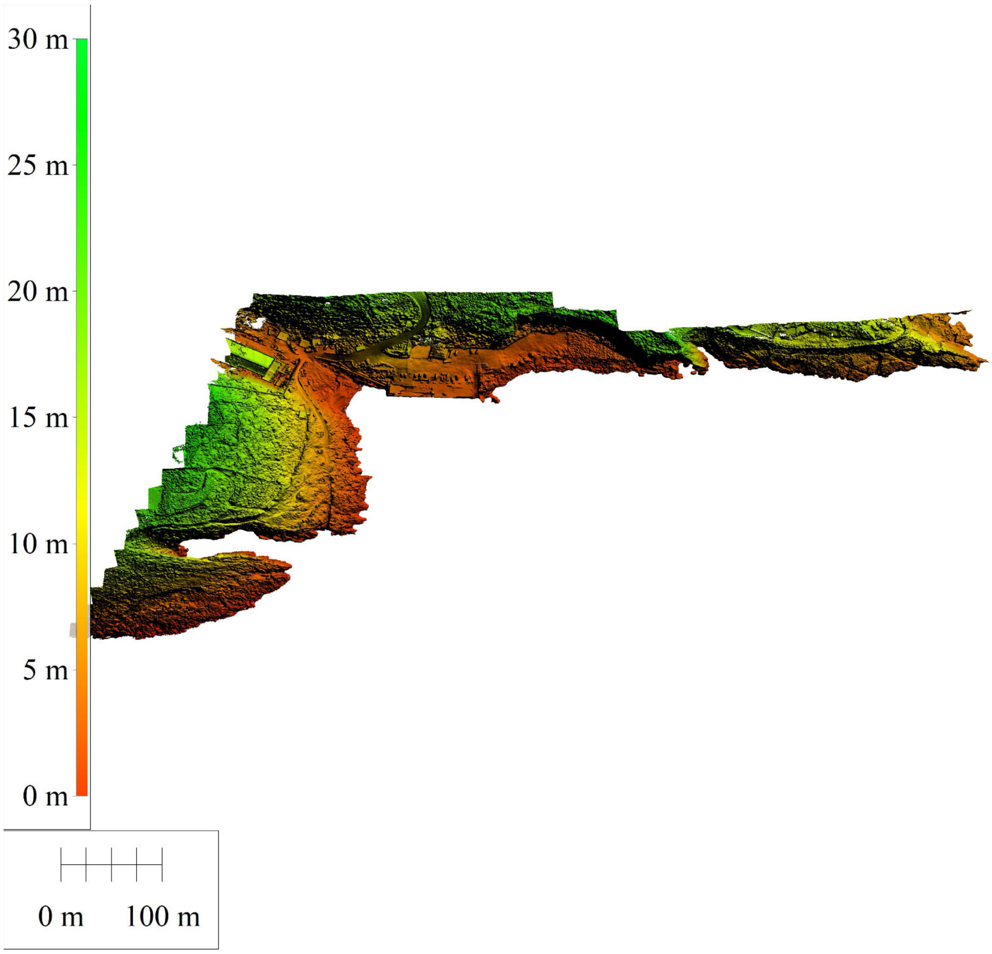


AI.10: Digital Elevation Model of Marsalforn Bay. The colour scale represents the ground elevation above sea level. The survey was carried out in May 2019.





AI.11: Orthomosaic of Marsalrforn Bay. The survey was carried out in October 2019.



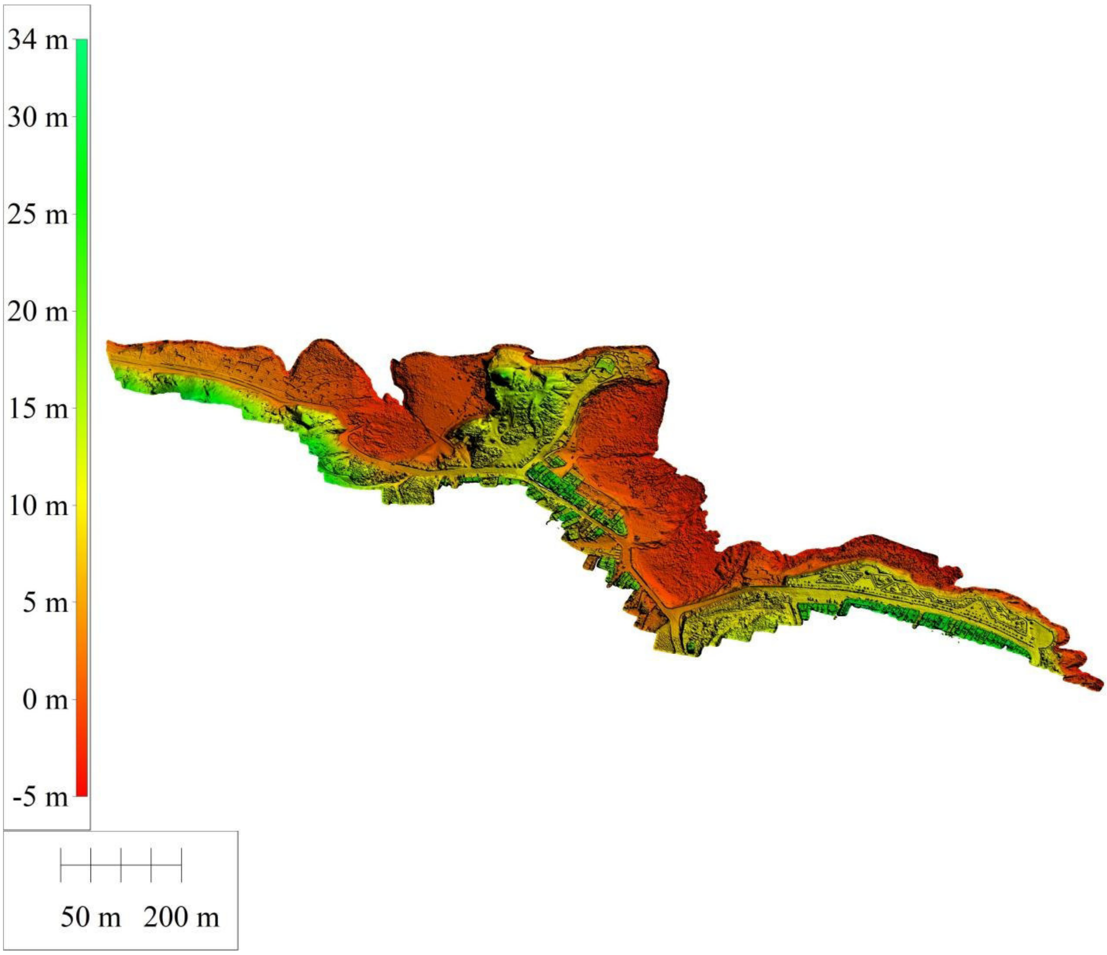
AI.12: Digital Elevation Model of Marsalforn Bay. The colour scale represents the ground elevation above sea level. The survey was carried out in October 2019.

Qbajjar Bay

GZ04

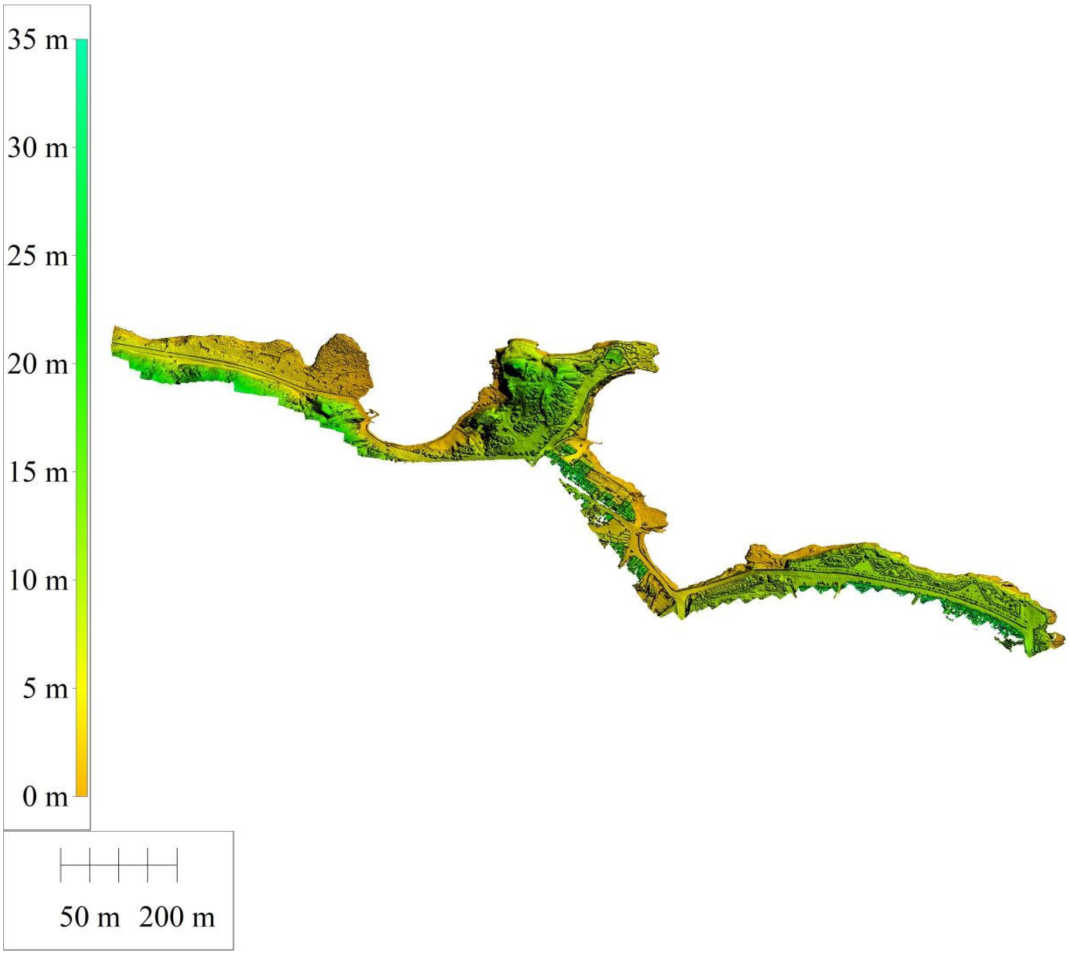
50 m 200 m

AI.13: Orthomosaic of Qbajjar Bay. The survey was carried out in May 2019.



AI.14: Digital Elevation Model of Qbajjar Bay. The colour scale represents the ground elevation above sea level. The survey was carried out in May 2019.

AI.15: Orthomosaic of Qbajjar Bay. The survey was carried out in October 2019.

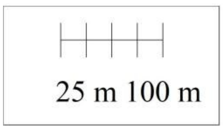


AI.16: Digital Elevation Model of Qbajjar Bay. The colour scale represents the ground elevation above sea level. The survey was carried out in October 2019.

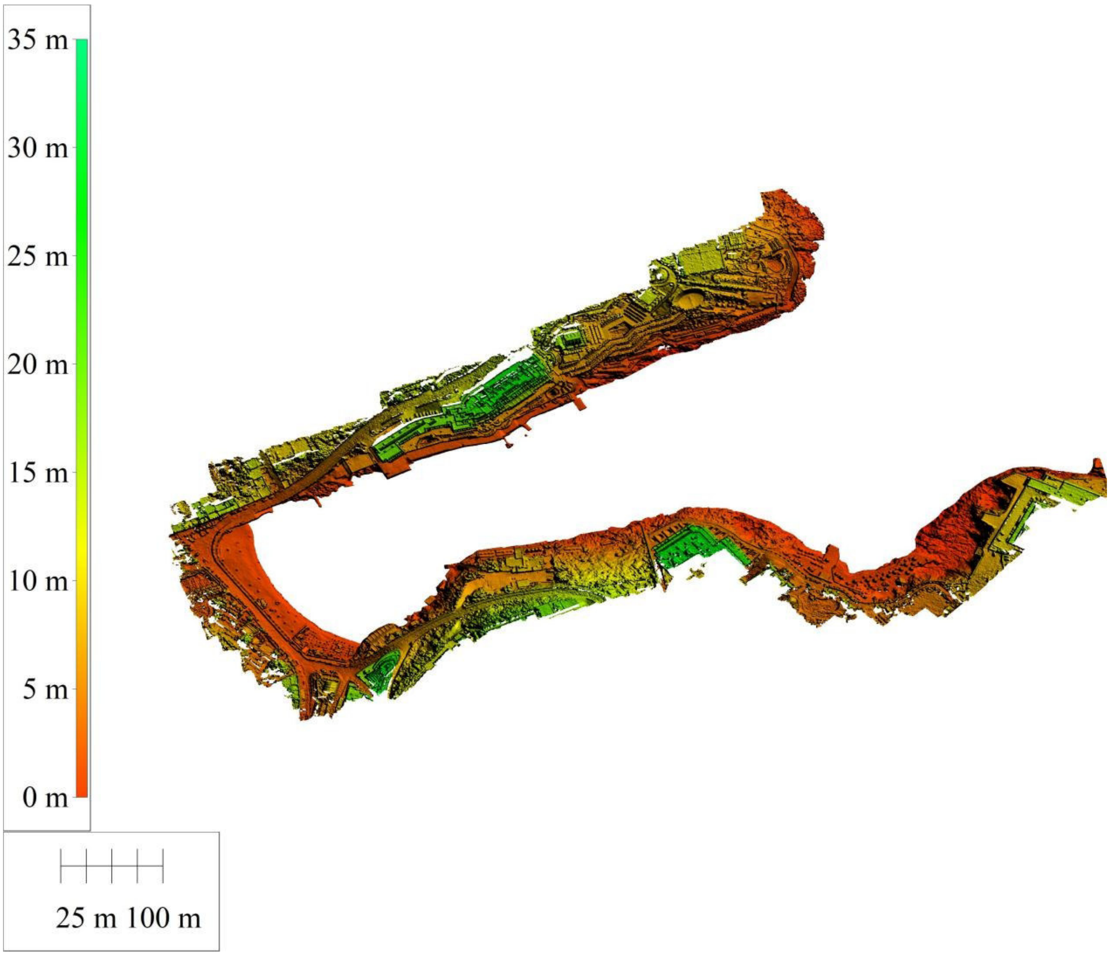
Xwenji Bay

Bess Code : GZ05

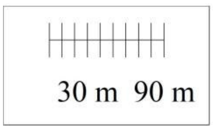
San George´s Bay



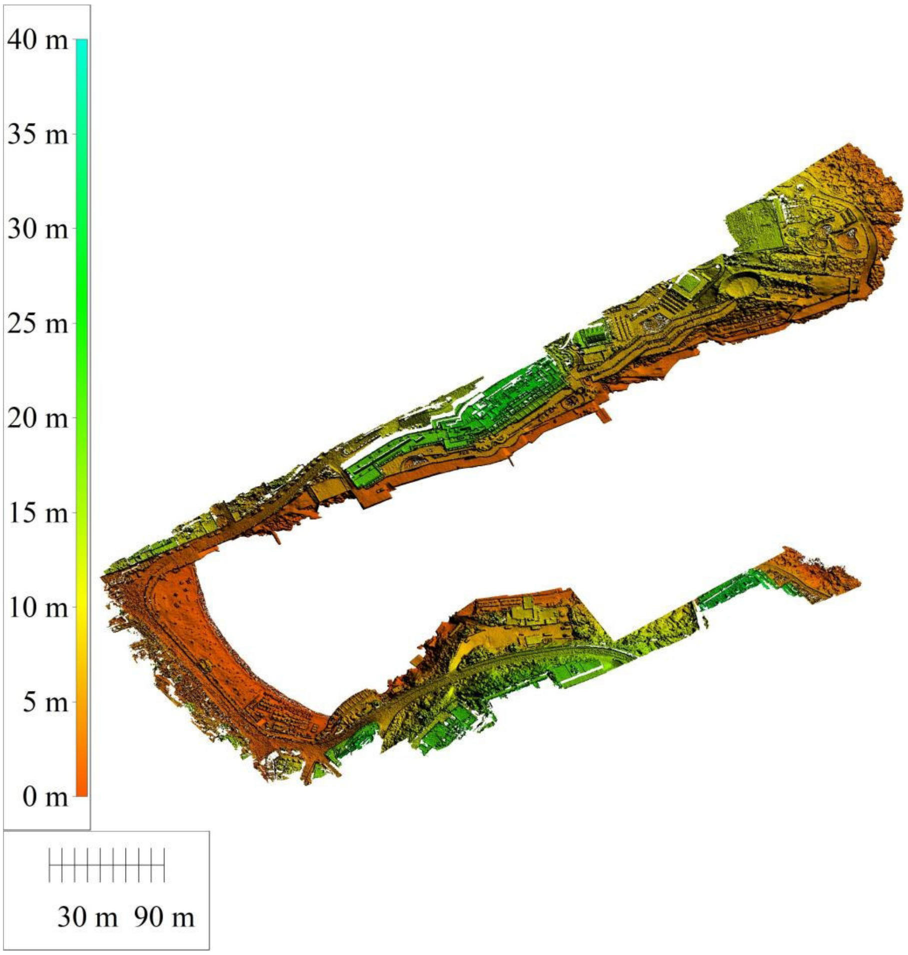
AI.17: Orthomosaic of San George’s Bay. The survey was carried out in May 2019.



AI.18: Digital Elevation Model of San George Bay. The colour scale represents the ground elevation above sea level. The survey was carried out in May 2019.

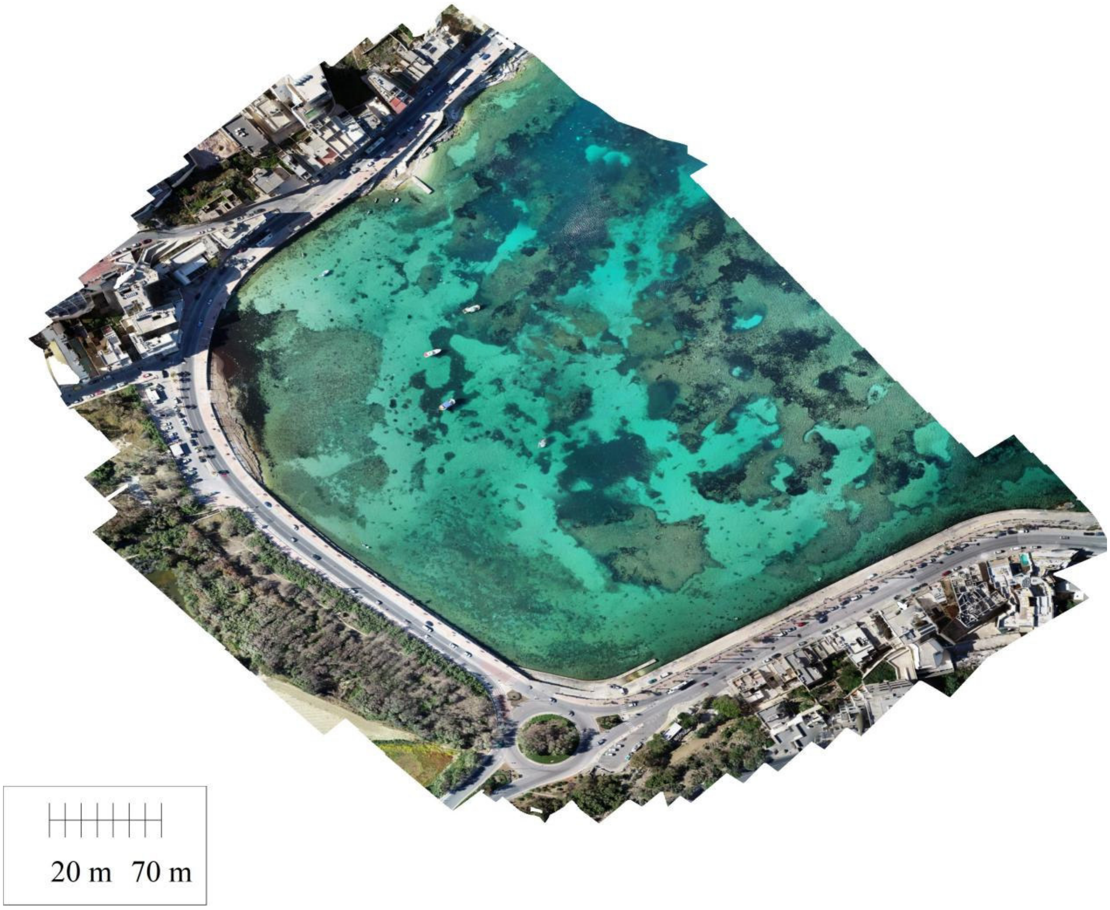


AI.19: Orthomosaic of San George’s Bay. The survey was carried out in October 2019.

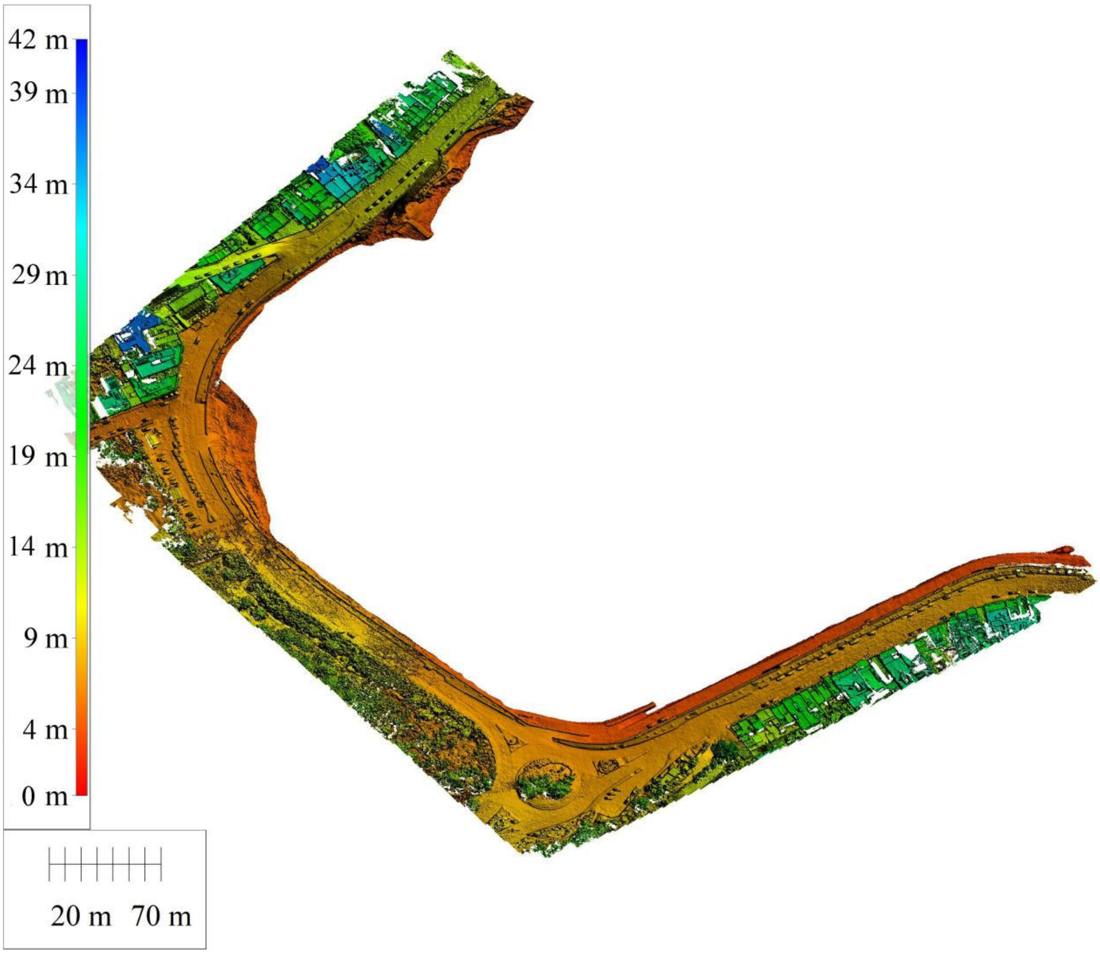


AI.20: Digital Elevation Model of San George Bay. The colour scale represents the ground elevation above sea level. The survey was carried out in October 2019.

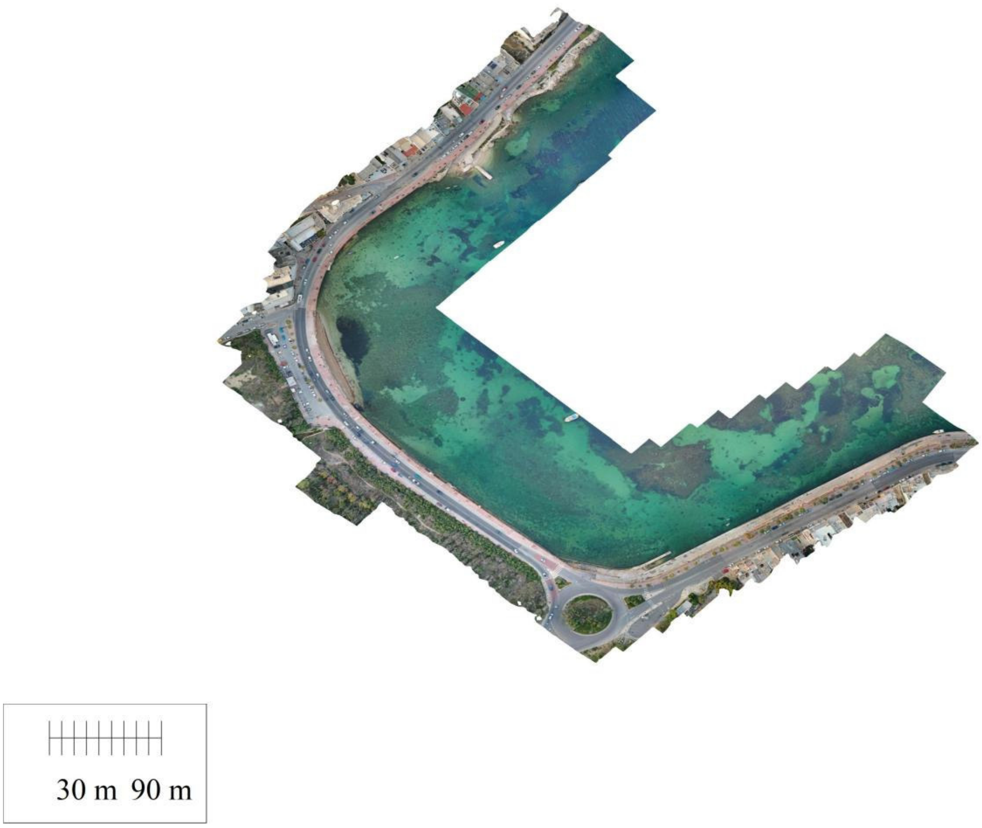
Xemxija Bay



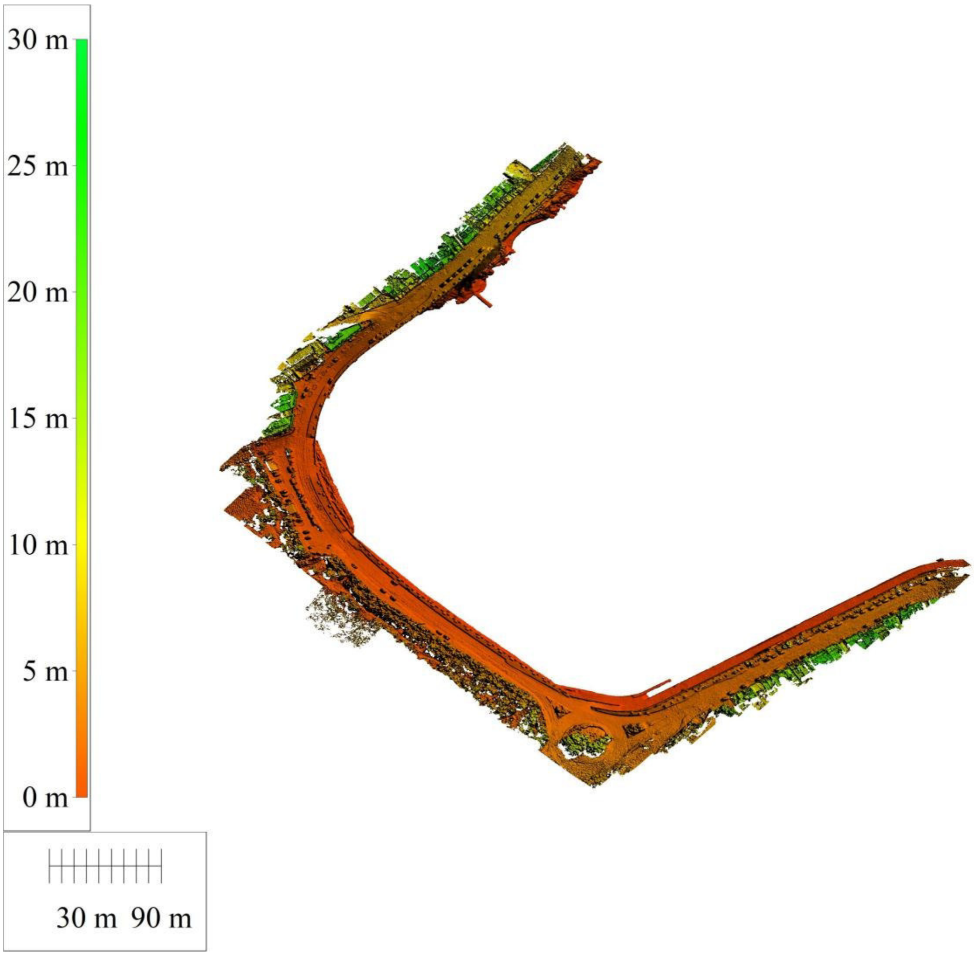
AI.21: Orthomosaic of Xemxija Bay. The survey was carried out in May 2019.



AI.22: Digital Elevation Model of Xemxija Bay. The colour scale represents the ground elevation above sea level. The survey was carried out in May 2019.



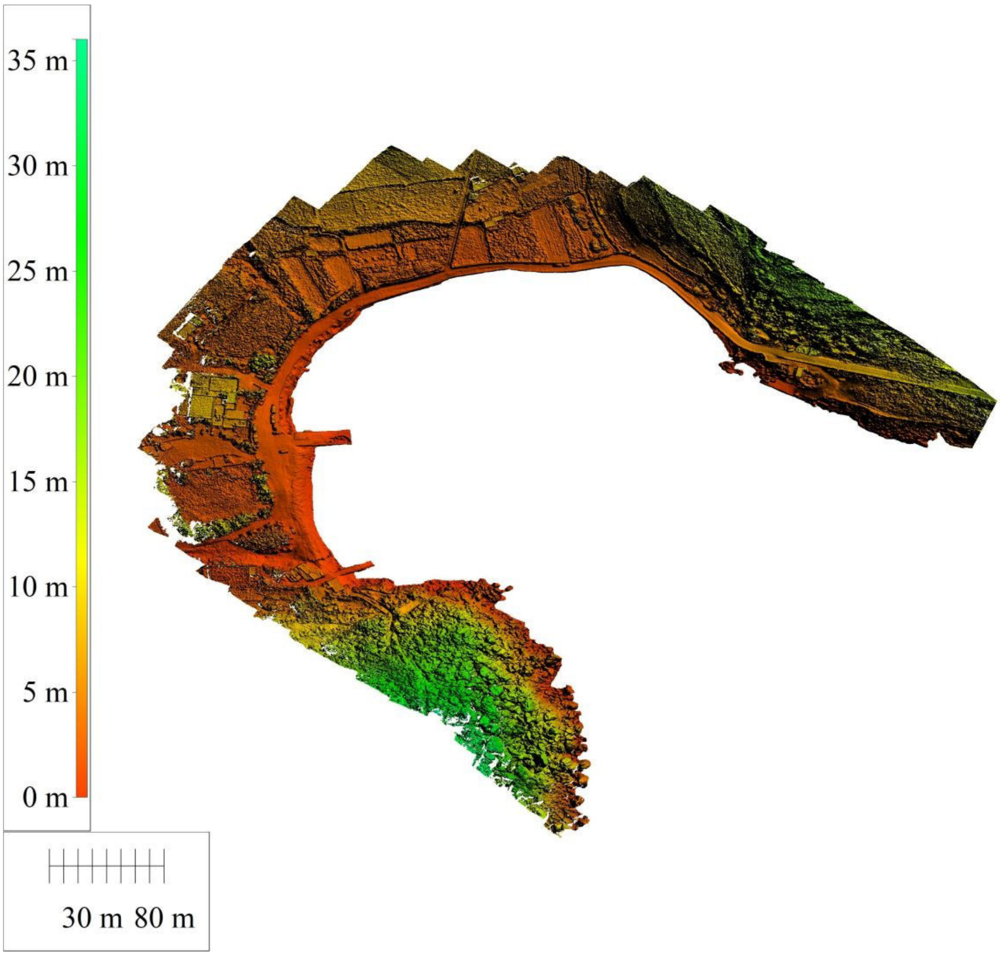
AI.23: Orthomosaic of Xemxija Bay. The survey was carried out in October 2019.



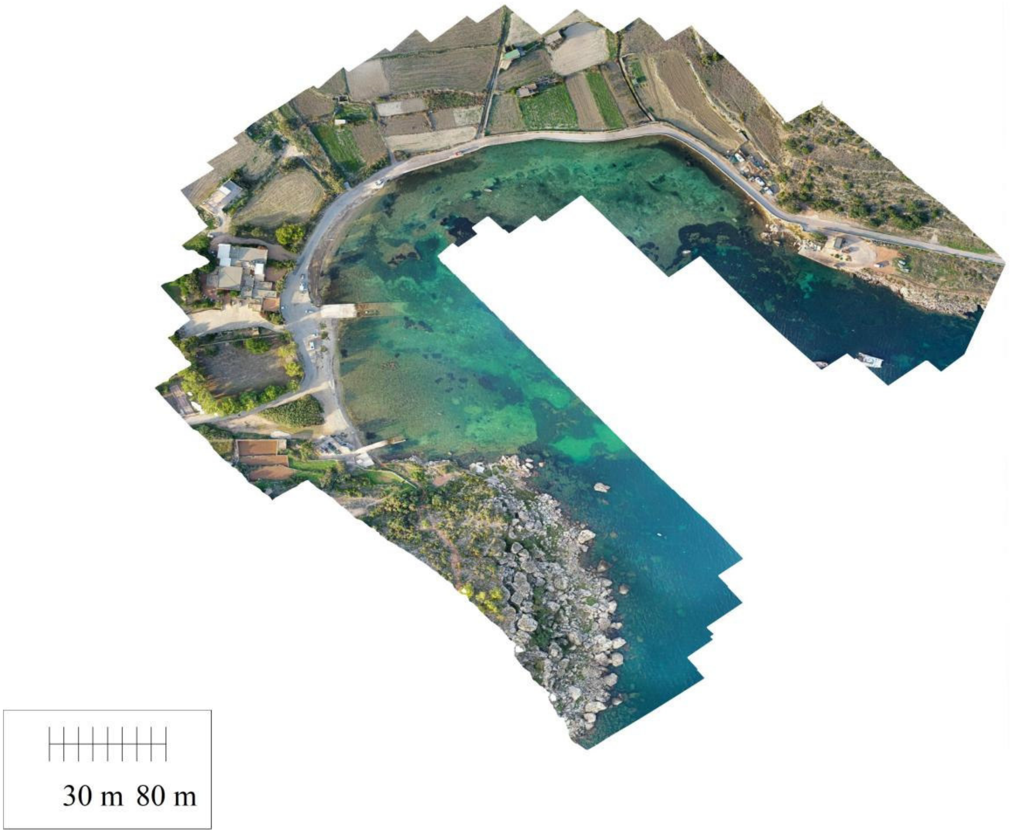
AI.24: Digital Elevation Model of Xemxija Bay. The colour scale represents the ground elevation above sea level. The survey was carried out in October 2019.

Mistra Bay

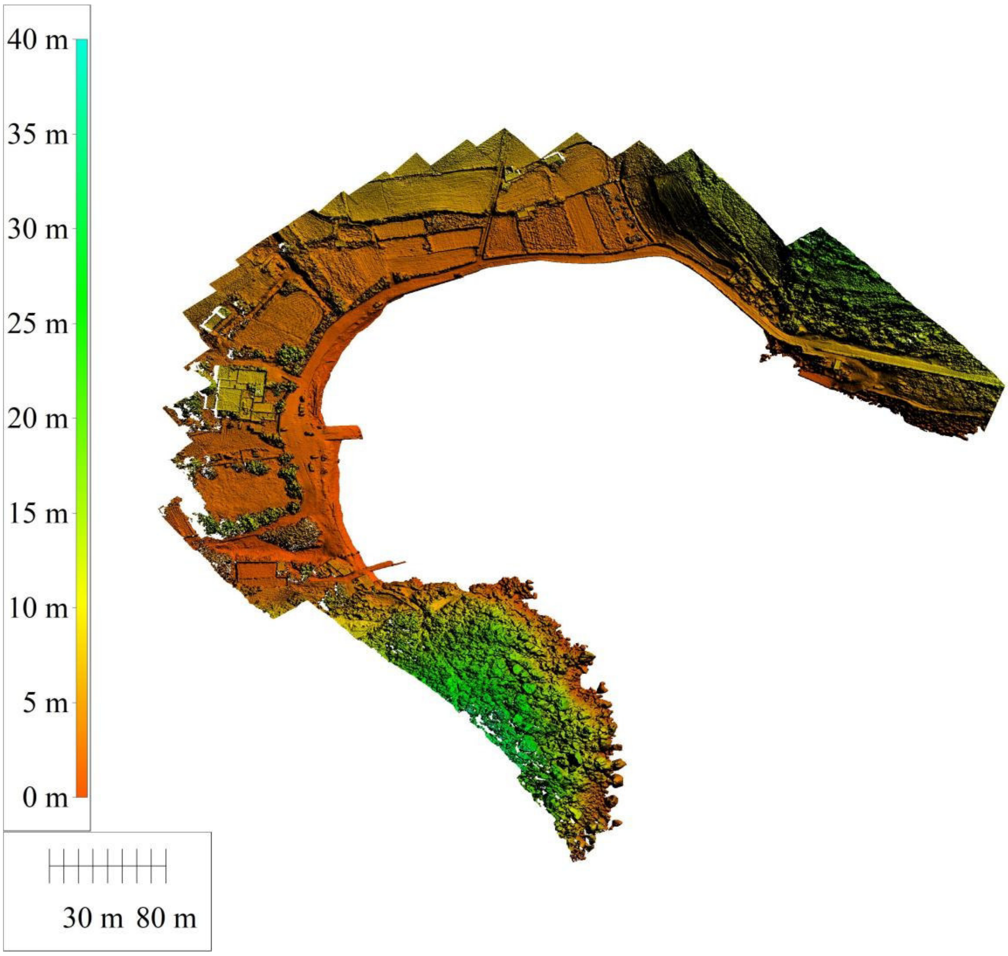
AI.25: Orthomosaic of Mistra Bay. The survey was carried out in May 2019.



AI.26. Digital Elevation Model of Mistra Bay. The colour scale represents the ground elevation above sea level. The survey was carried out in May 2019.

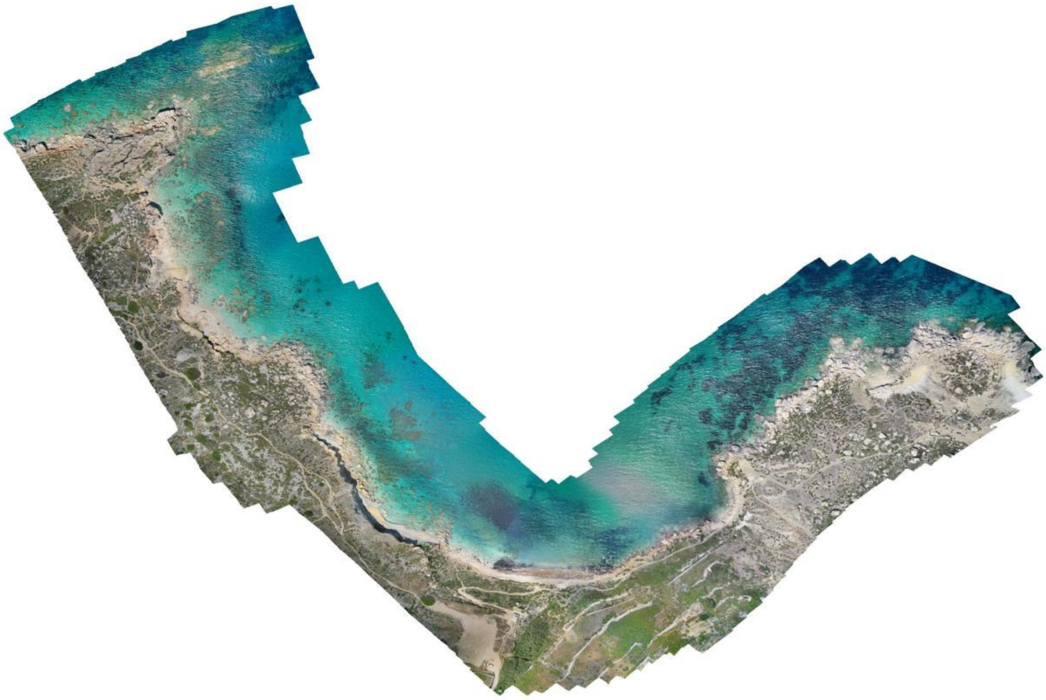


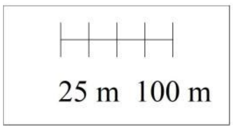
AI.27: Orthomosaic of Mistra Bay. The survey was carried out in October 2019.



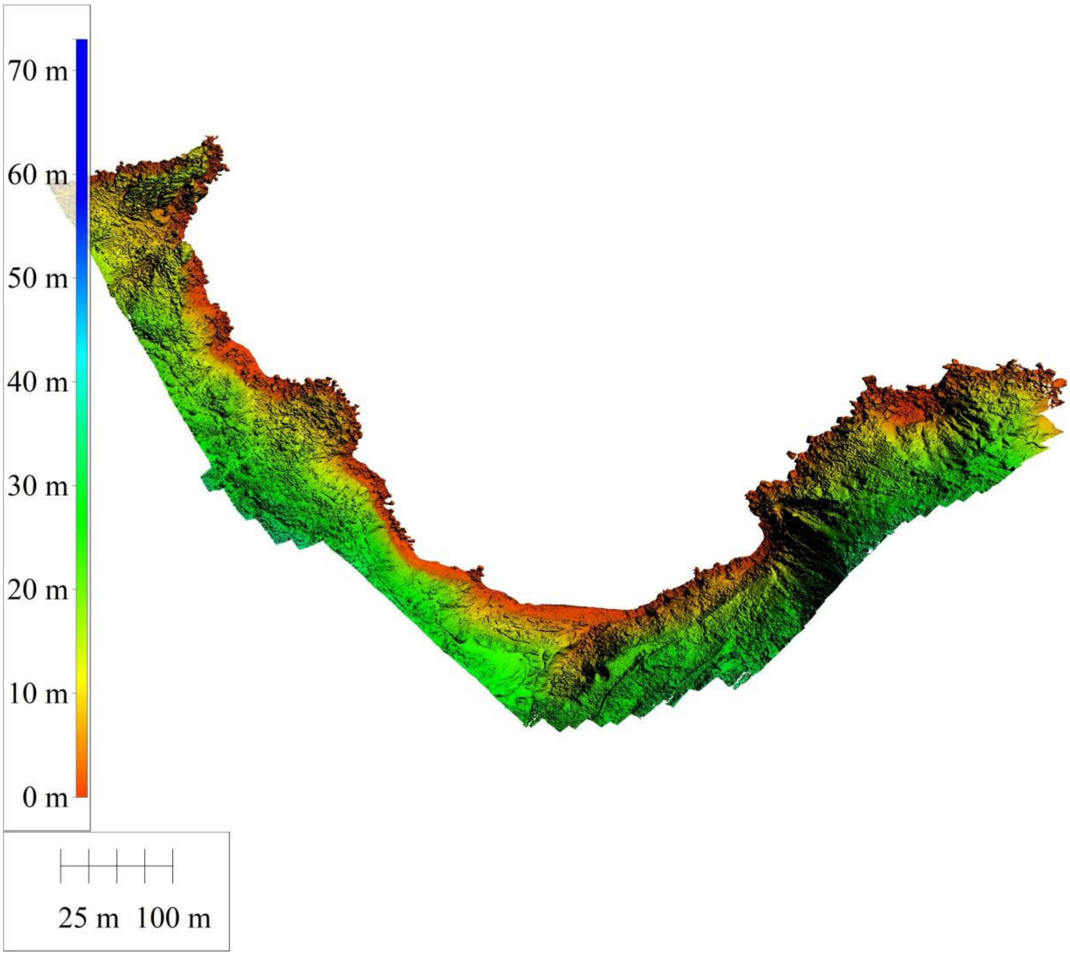
AI.28: Digital Elevation Model of Mistra Bay. The colour scale represents the ground elevation above sea level. The survey was carried out in October 2019.

Imgiebah Bay



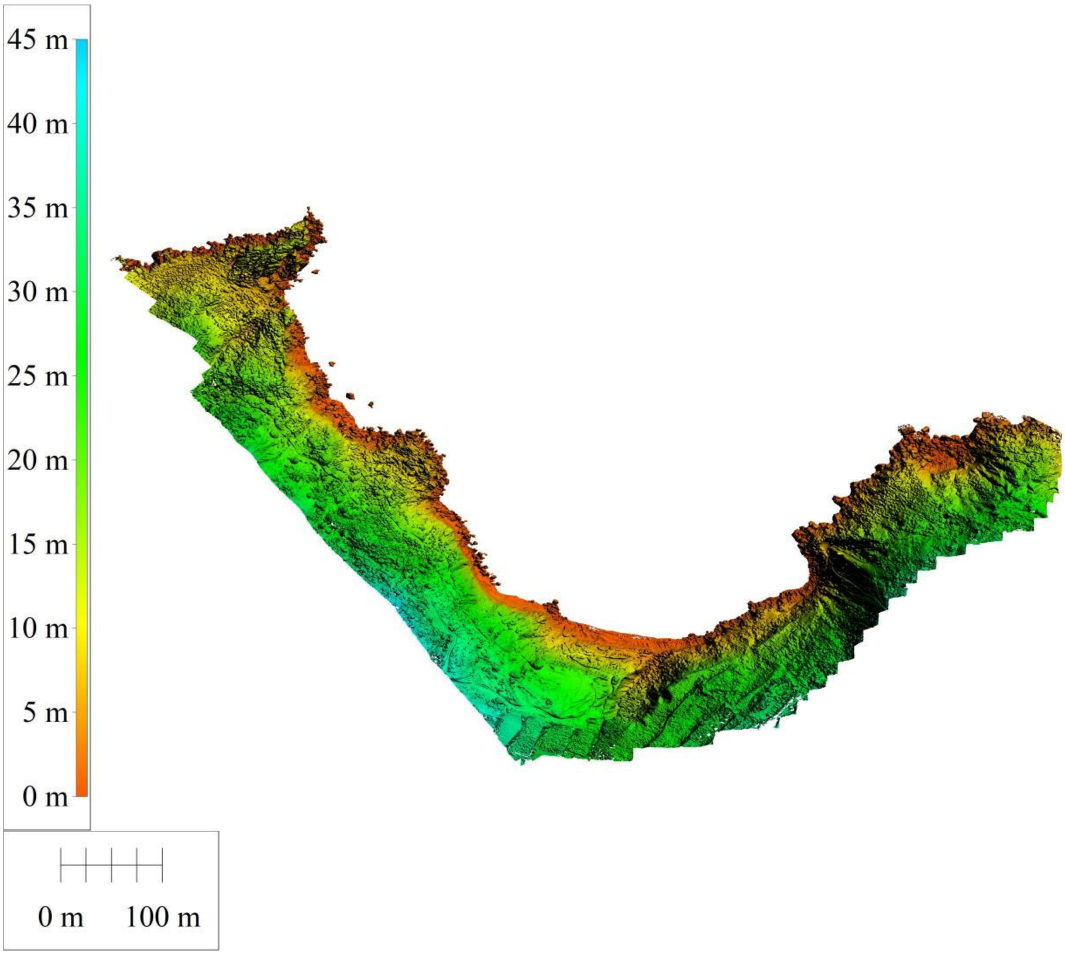


AI.29: Orthomosaic of Imgiebha Bay. The survey was carried out in May 2019.



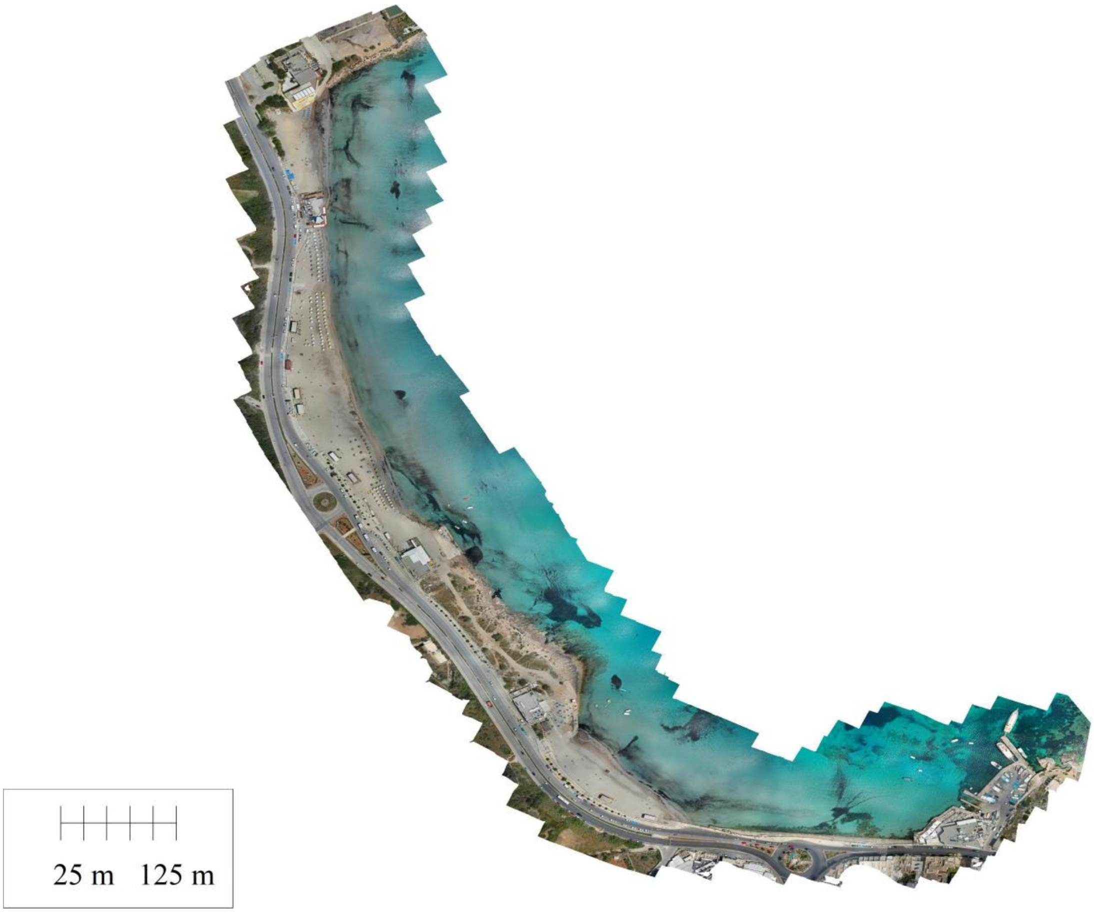
AI.30: Digital Elevation Model of Imgiebha Bay. The colour scale represents the ground elevation above sea level. The survey was carried out in May 2019.

AI.31: Orthomosaic of Imgiebha Bay. The survey was carried out in October 2019

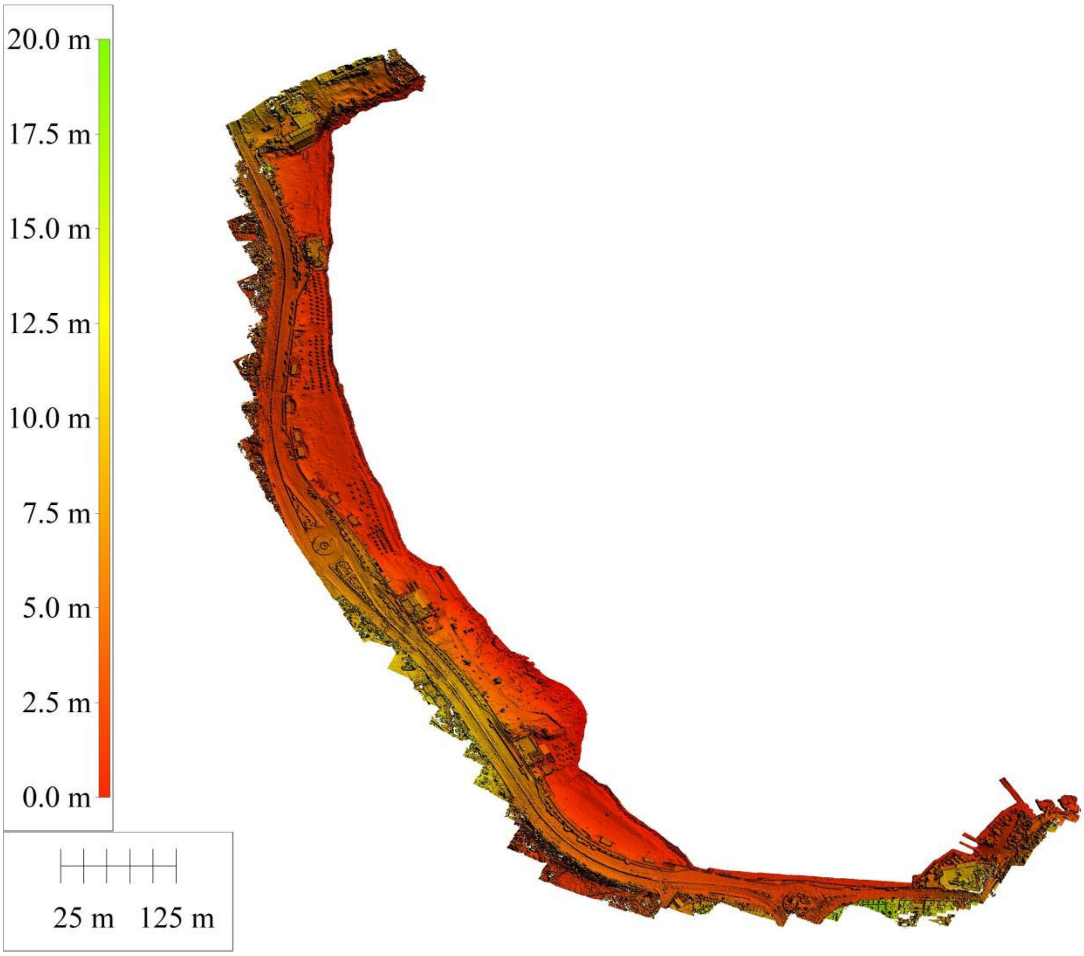


AI.32: Digital Elevation Model of Imgiebha Bay. The colour scale represents the ground elevation above sea level. The survey was carried out in October 2019.

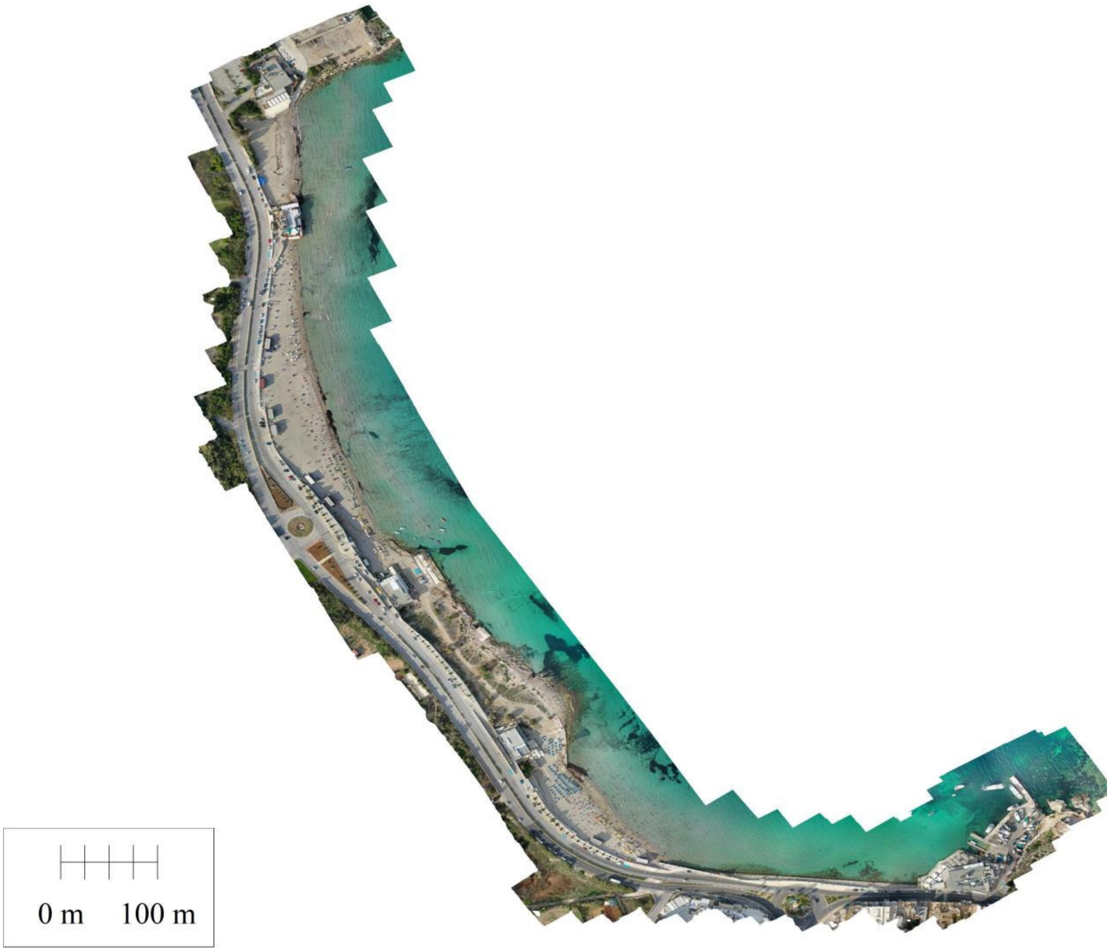
Mellieha Bay



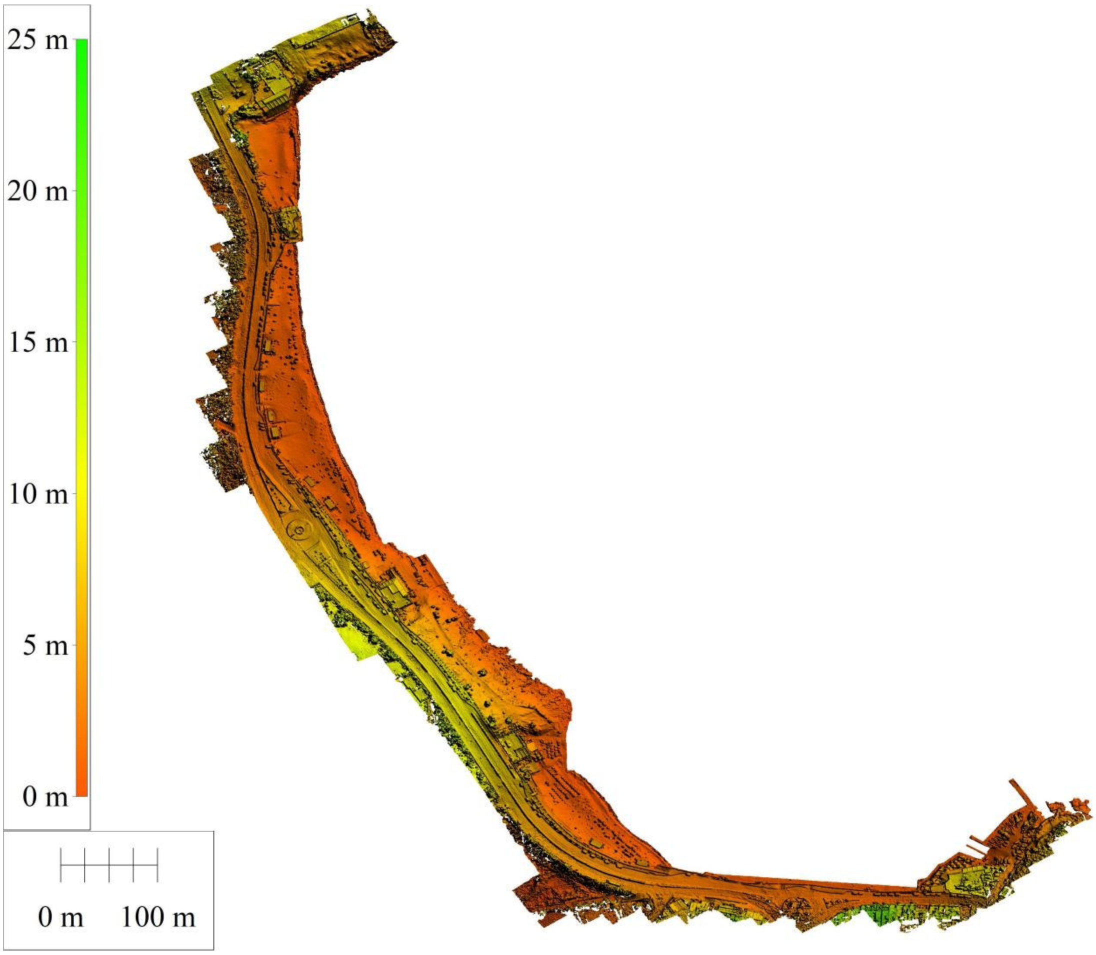
AI.33: Orthomosaic of Mellieha Bay. The survey was carried out in May



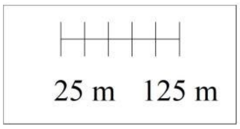
AI.34: Digital Elevation Model of Mellieha Bay. The colour scale represents the ground elevation above sea level. The survey was carried out in May 2019.



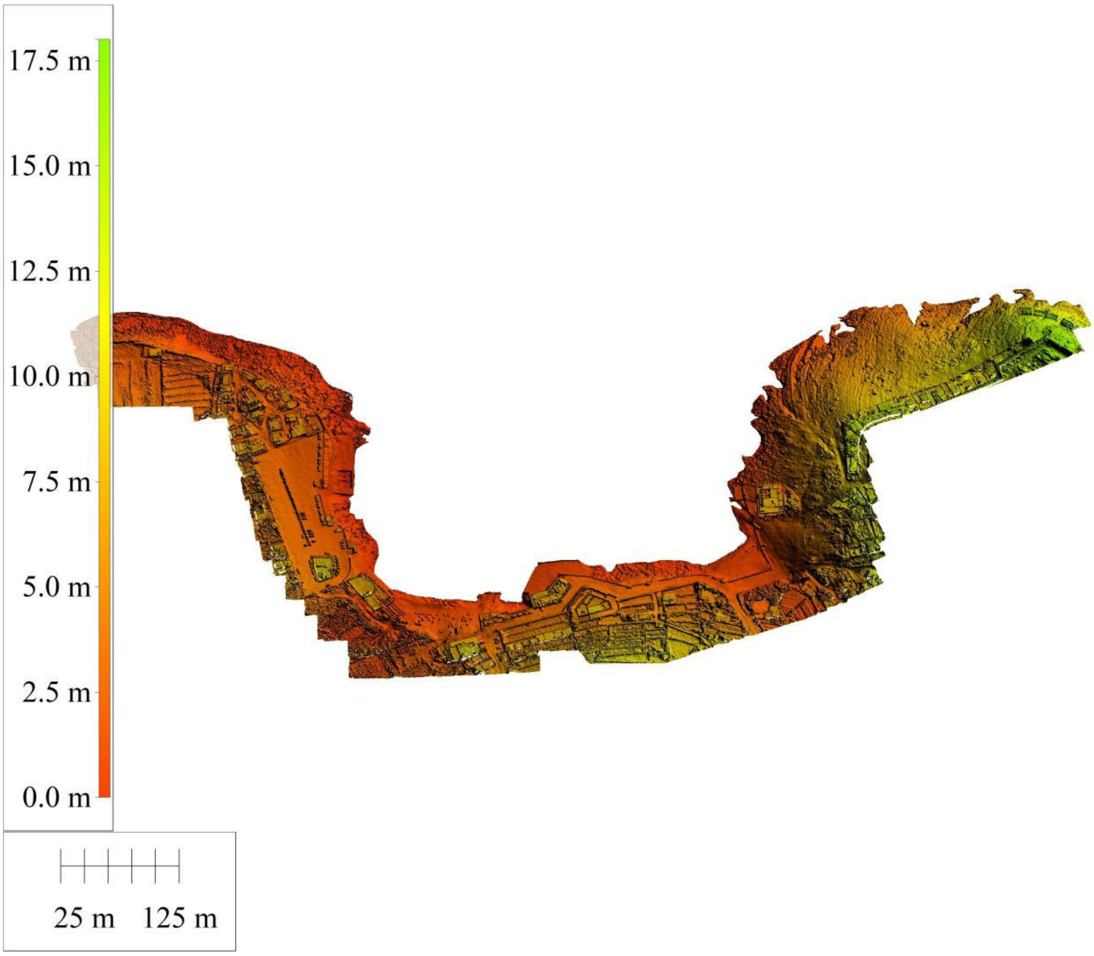
AI.35: Orthomosaic of Mellieha Bay. The survey was carried out in October 2019



AI.36: Digital Elevation Model of Mellieha Bay. The colour scale represents the ground elevation above sea level. The survey was carried out in October 2019.

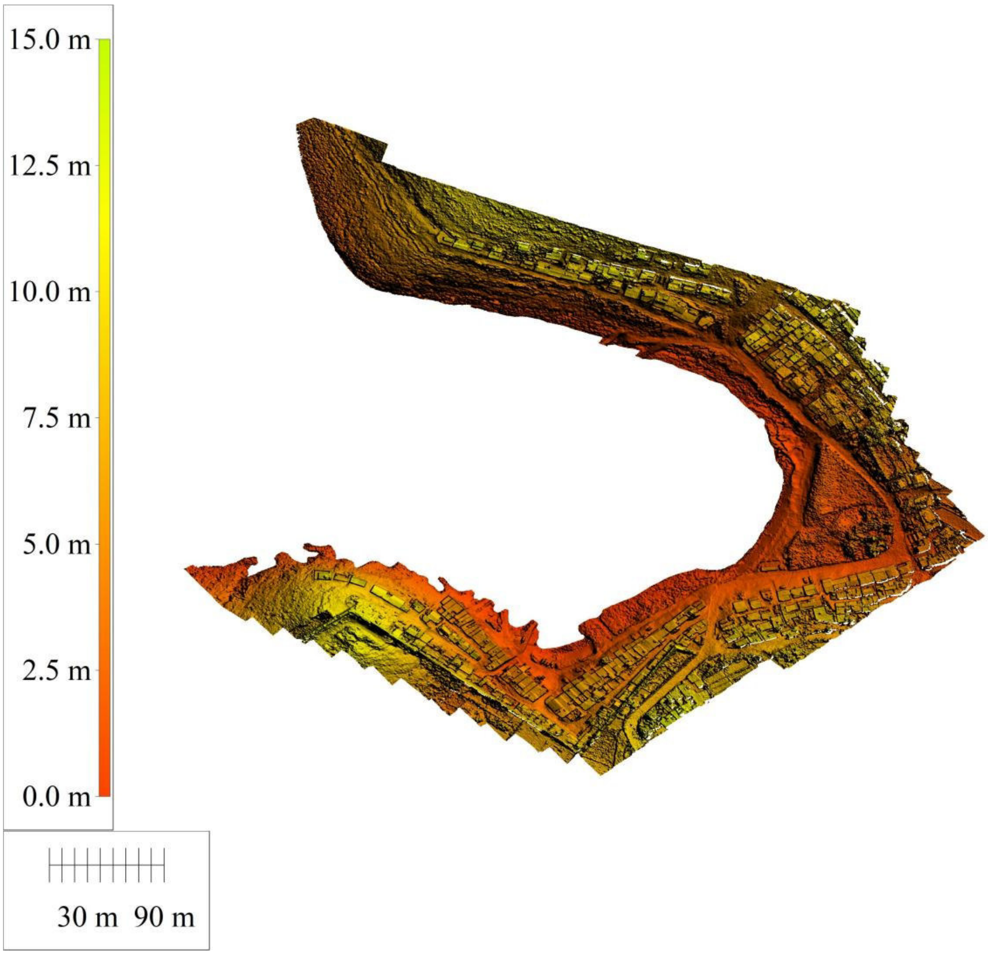


AI.37: Orthomosaic of Armier Bay. The survey was carried out in May 2019.

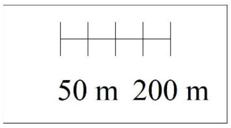


AI.38: Digital Elevation Model of Armier Bay. The colour scale represents the ground elevation above sea level. The survey was carried out in May 2019.

AI.39: Orthomosaic of Armier Bay – White Tower. The survey was carried out in May 2019.



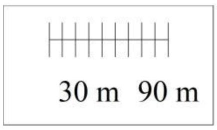
AI.40: Digital Elevation Model of Armier Bay – White Tower. The colour scale represents the ground elevation above sea level. The survey was carried out in May 2019.



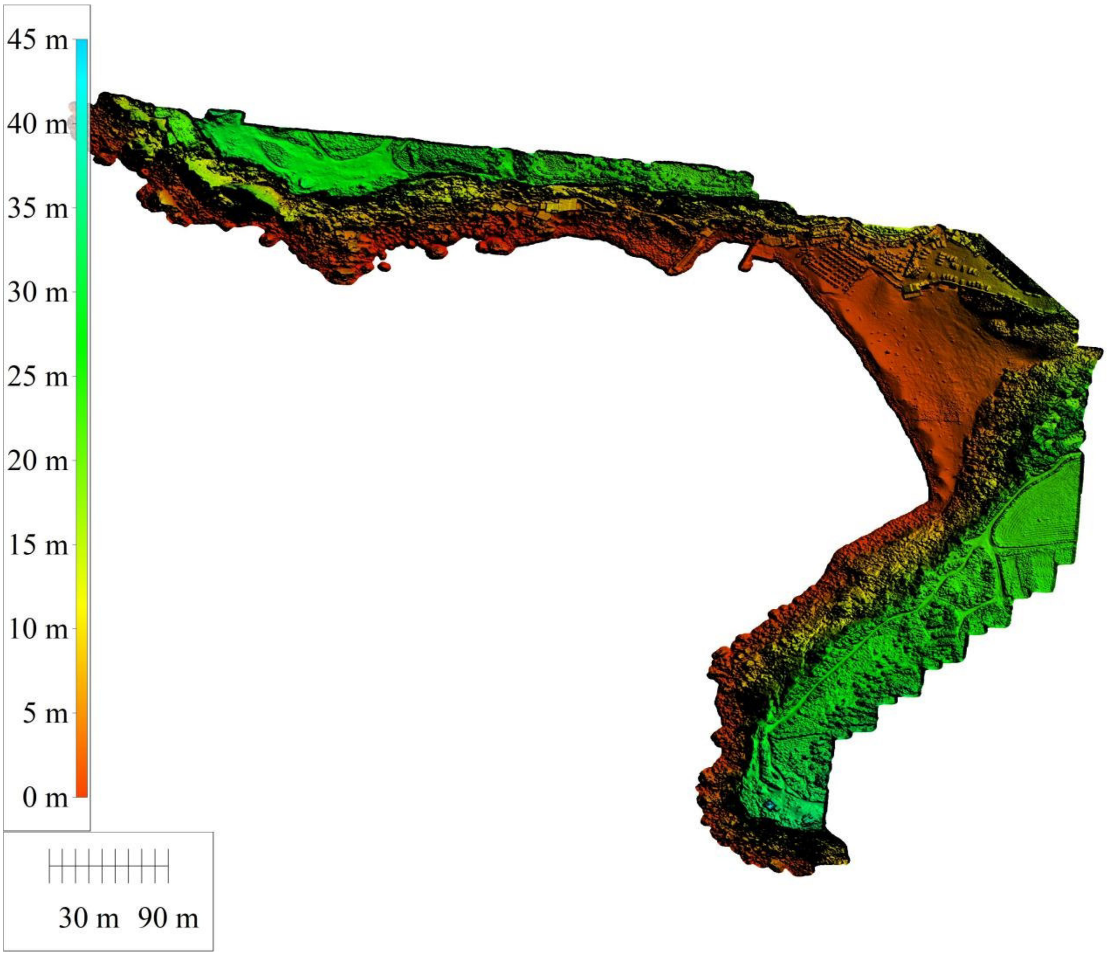
AI.41: Orthomosaic of Armier Bay & White Tower. The survey was carried out in October 2019.

50 m 200 m

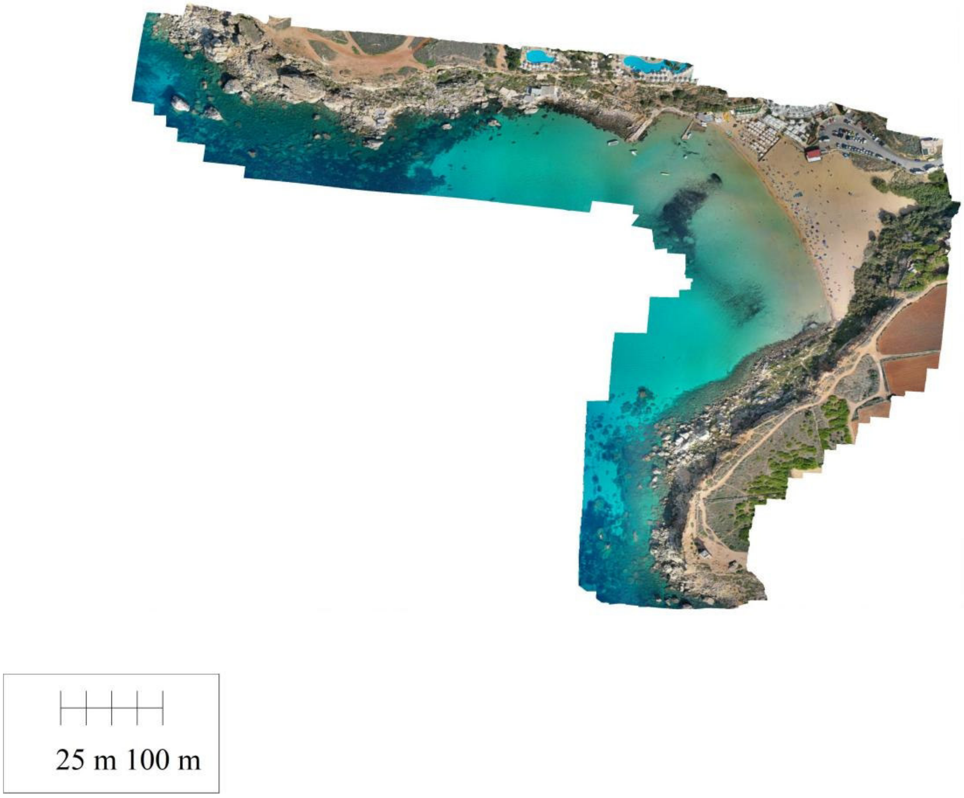
AI.42: Digital Elevation Model of Armier Bay & White Tower. The colour scale represents the ground elevation above sea level. The survey was carried out in October 2019.



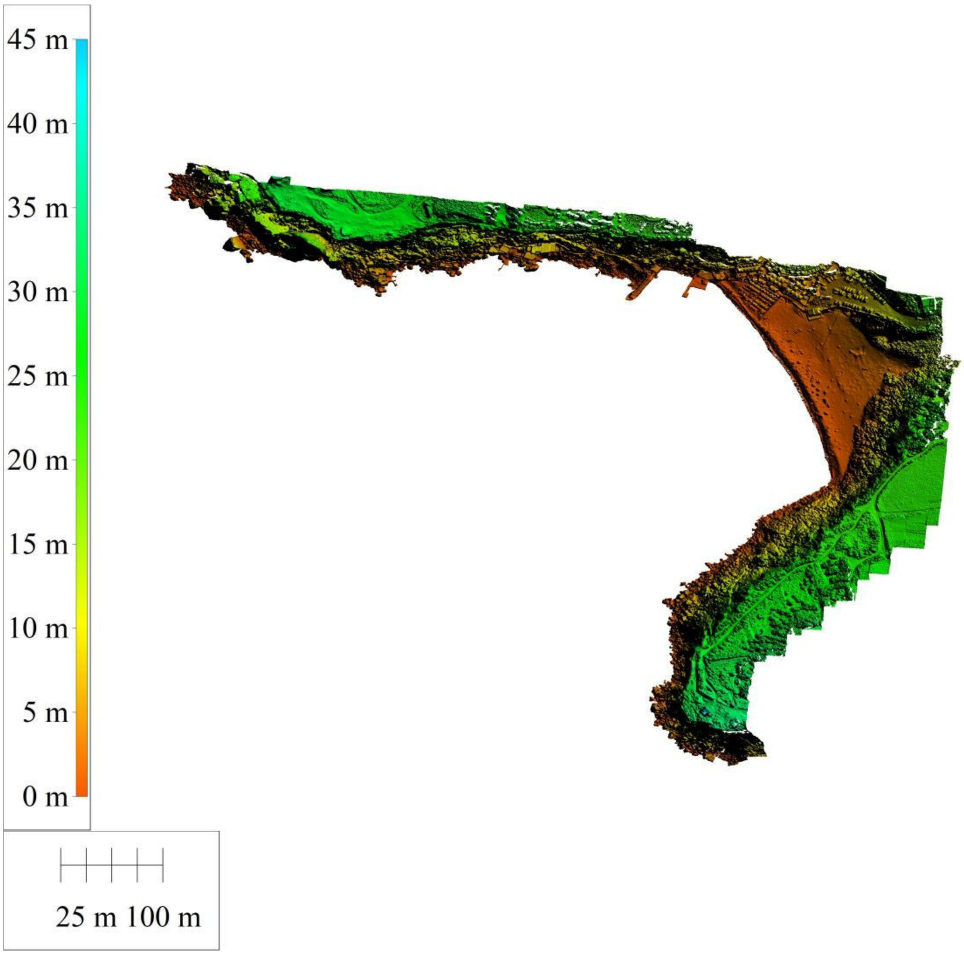
AI.43: Orthomosaic of Golden Bay. The survey was carried out in



AI.44: Digital Elevation Model of Golden Bay. The colour scale represents the round elevation above sea level. The survey was carried out in May 2019.



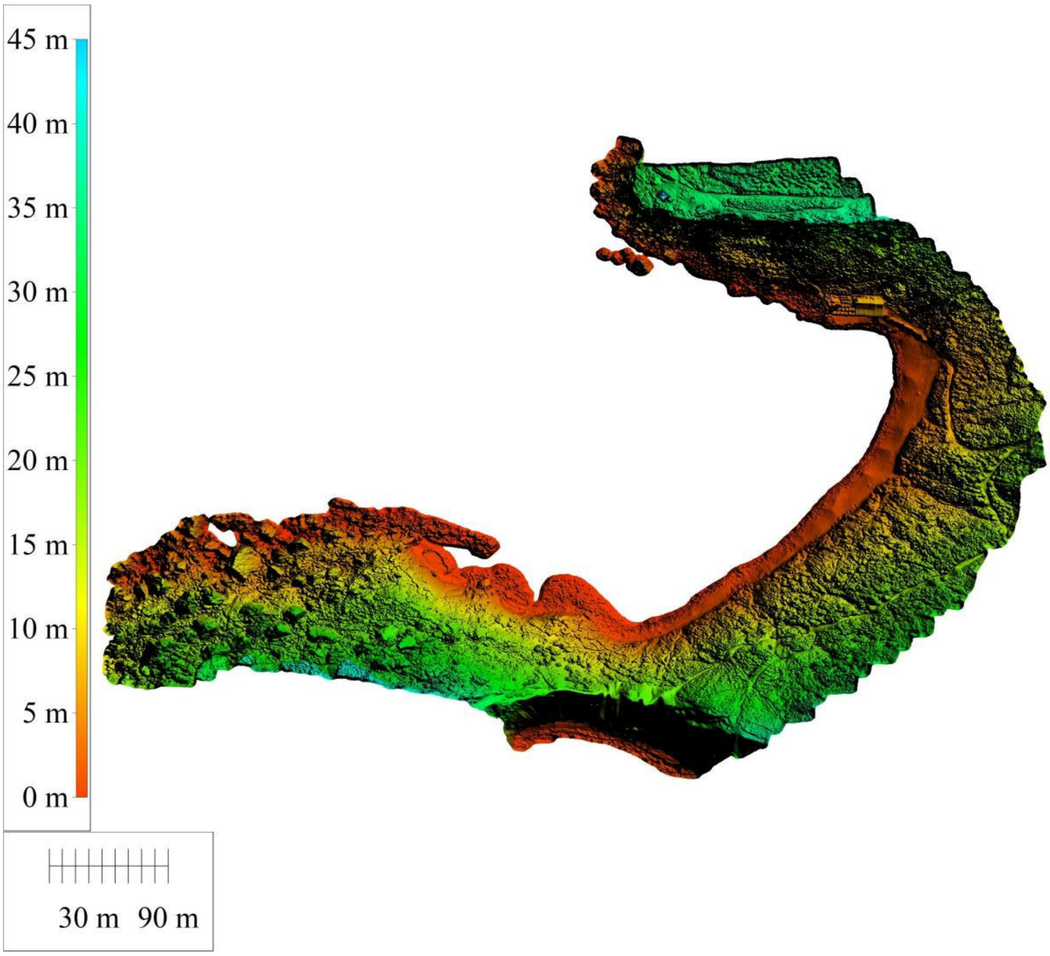
AI.45: Orthomosaic of Golden Bay. The survey was carried out in October 2019.



AI.46: Digital Elevation Model of Golden Bay. The colour scale represents the ground elevation above sea level. The survey was carried out in October 2019.

Riviera Bay

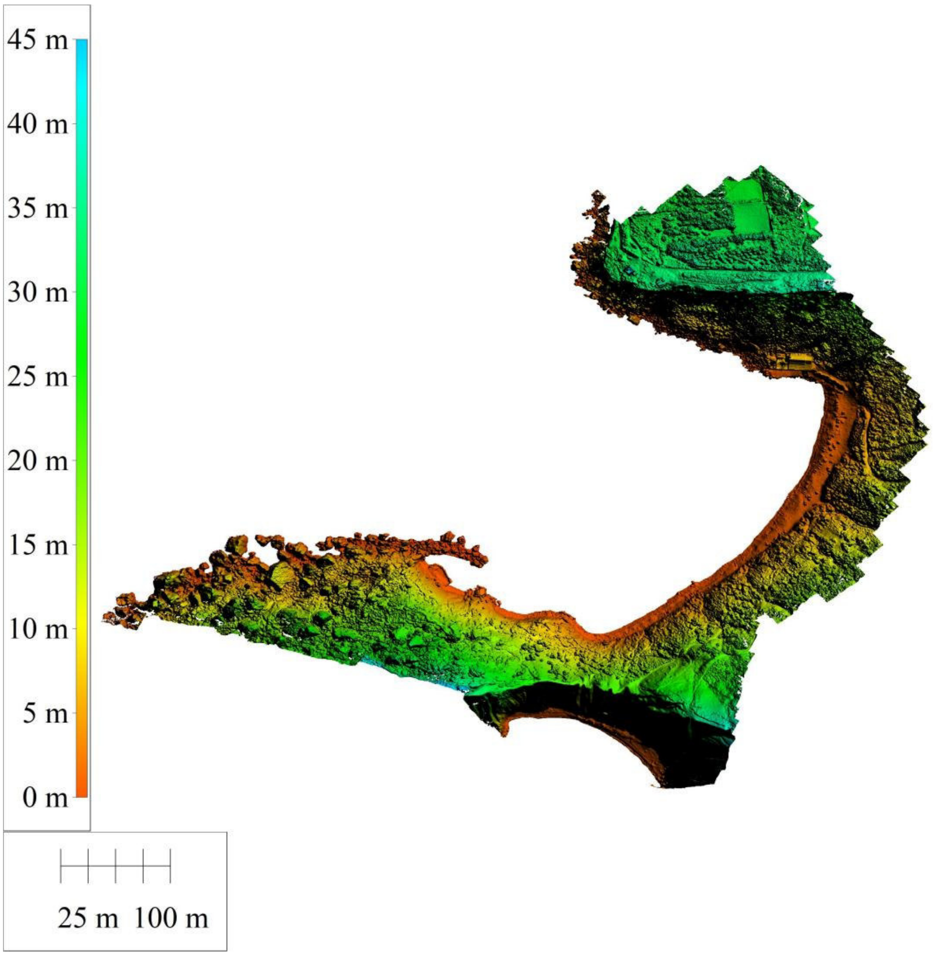
AI.47: Orthomosaic of Riviera Bay. The survey was carried out in May



AI.48: Digital Elevation Model of Riviera Bay. The colour scale represents the round elevation above sea level. The survey was carried out in May 2019.

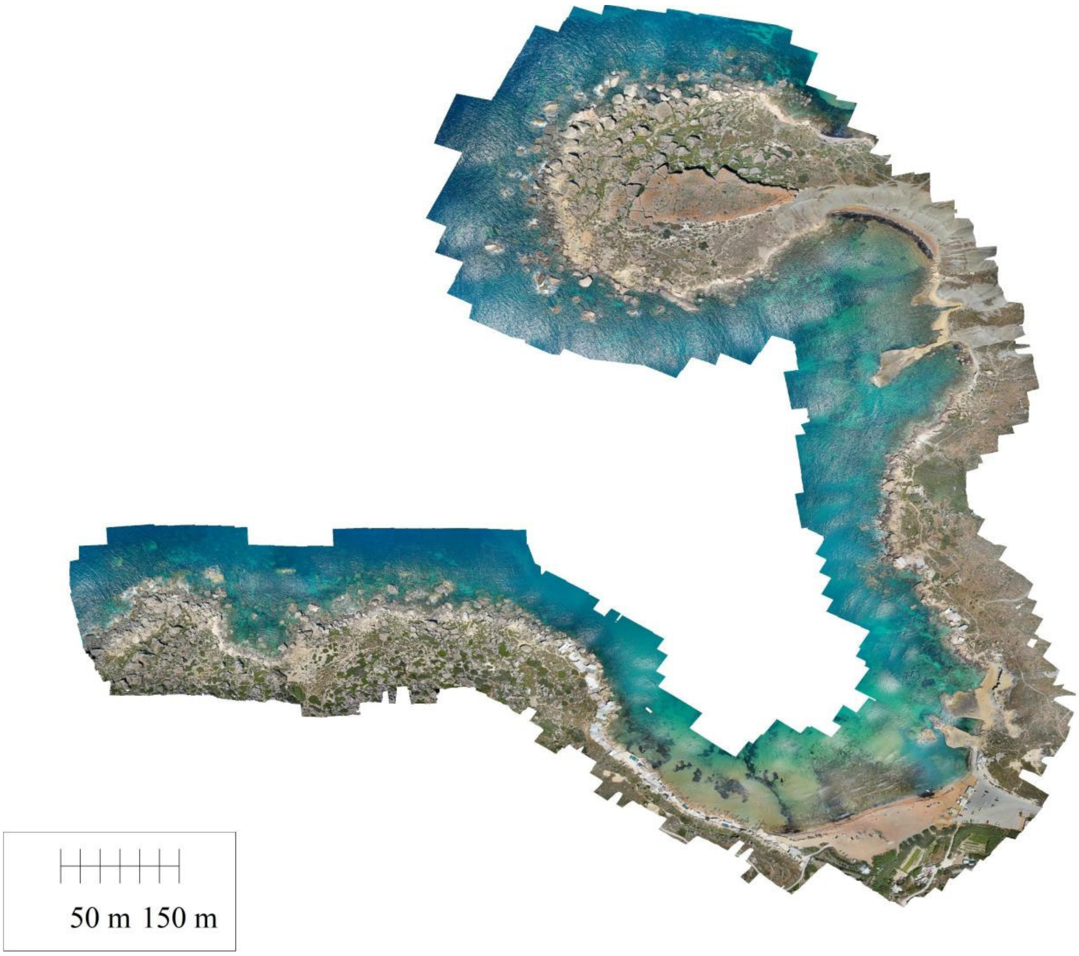
25 m 100 m

AI.49: Orthomosaic of Riviera Bay. The survey was carried out in October

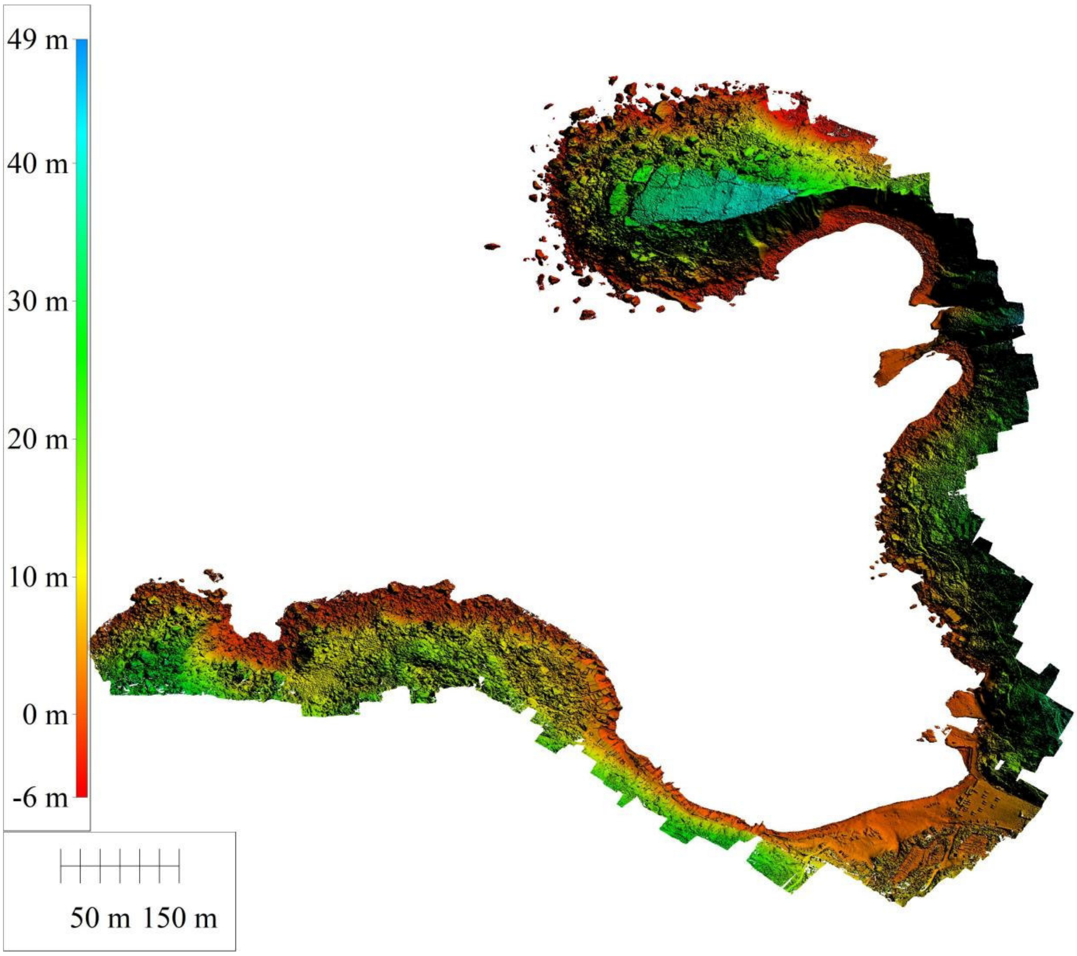


AI.50: Digital Elevation Model of Riviera Bay. The colour scale represents the round elevation above sea level. The survey was carried out in October 2019.

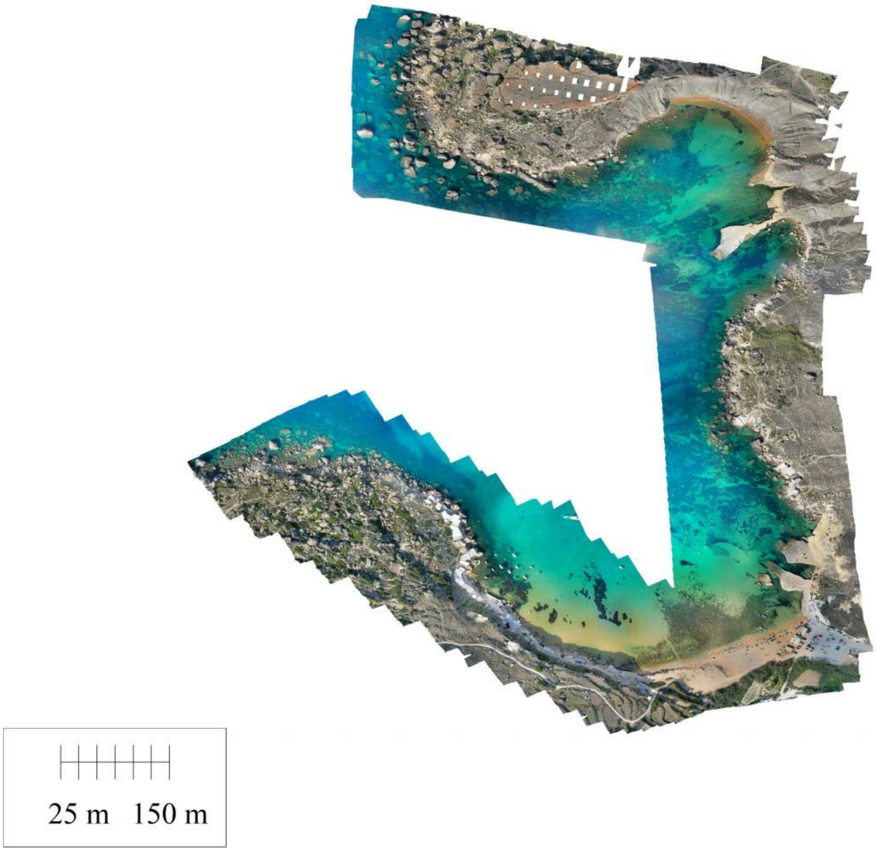
Gnejna Bay



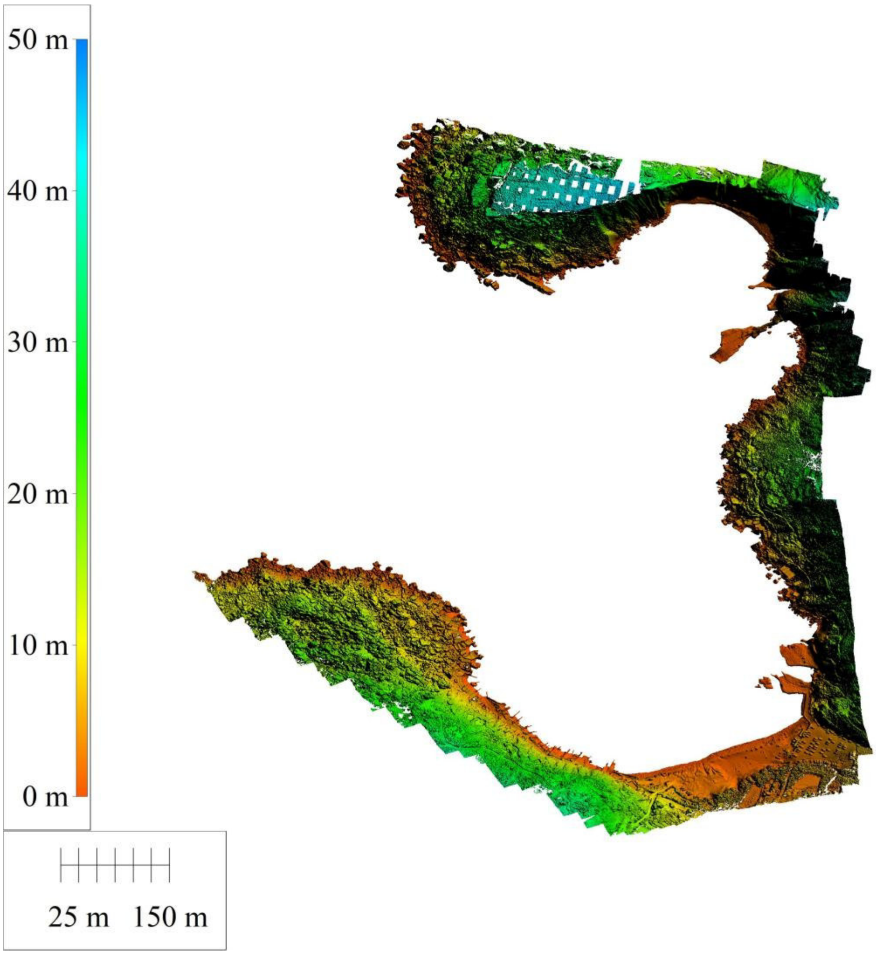
AI.51: Orthomosaic of Gnejna Bay. The survey was carried out in May 2019.



AI.52: Digital Elevation Model of Gnjena Bay. The colour scale represents the ground elevation above sea level. The survey was carried out in May 2019.



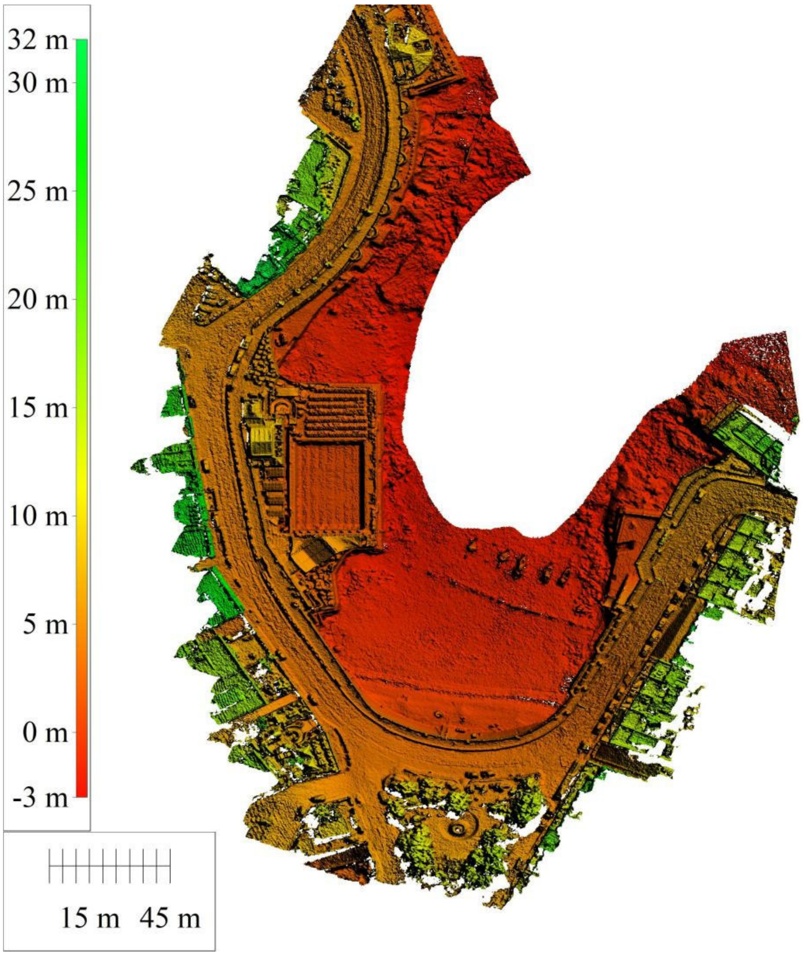
AI.53: Orthomosaic of Gnejna Bay. The survey was carried out in October 2019.



AI.54: Digital Elevation Model of Gnjena Bay. The colour scale represents the ground elevation above sea level. The survey was carried out in October 2019.

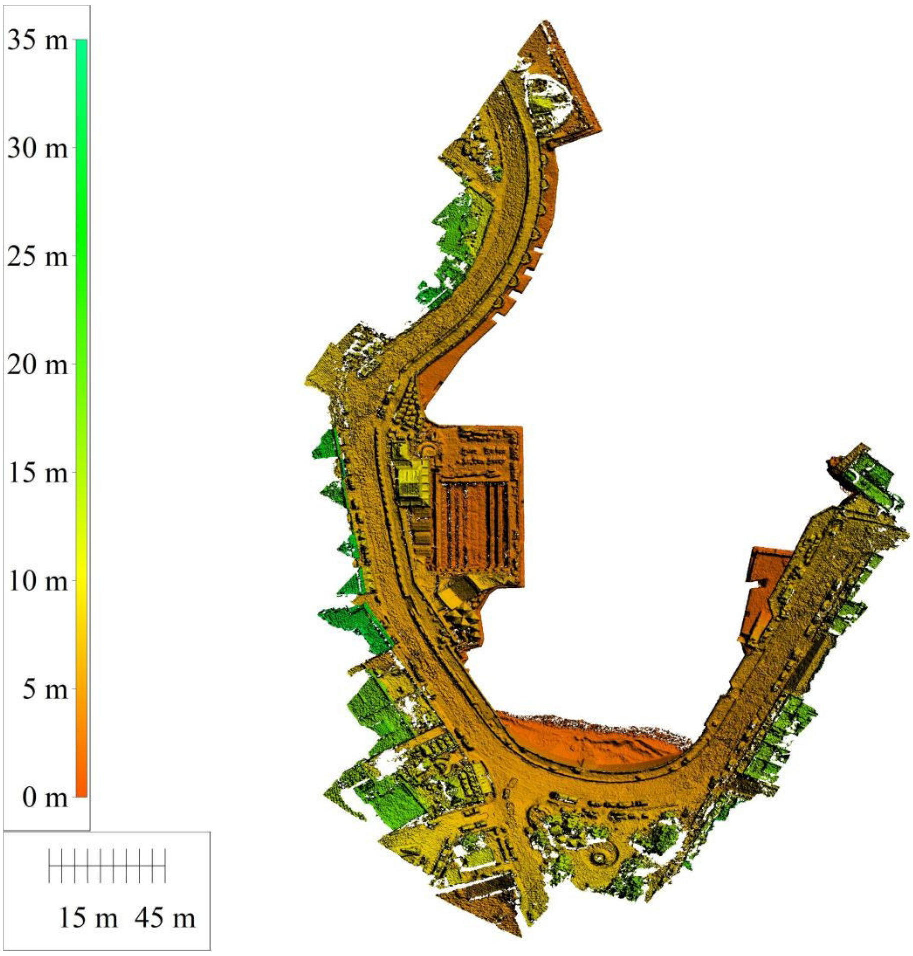
Balluta Bay

AI.55: Orthomosaic of Balluta Bay. The survey was carried out in August 2019.



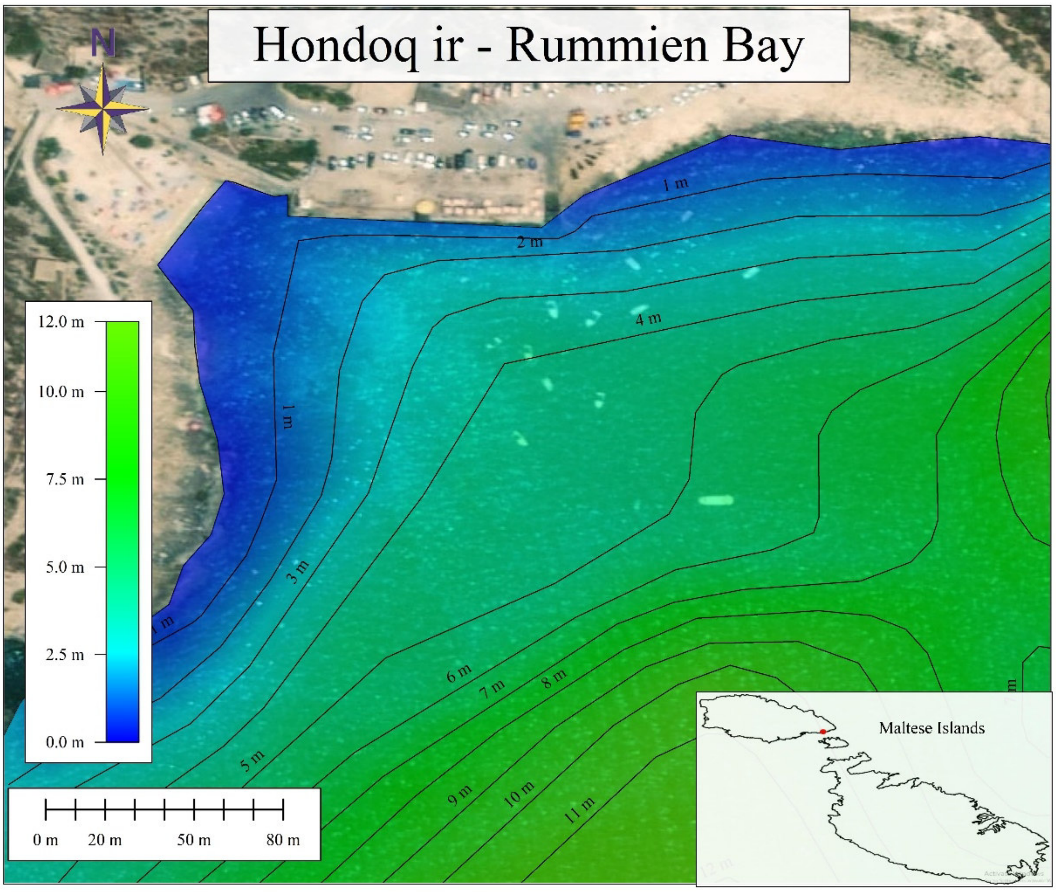
AI.56: Digital Elevation Model of Balluta. The colour scale represents the ground elevation above sea level. The survey was carried out in August 2019.

AI.57: Orthomosaic of Balluta Bay. The survey was carried out in October 2019.

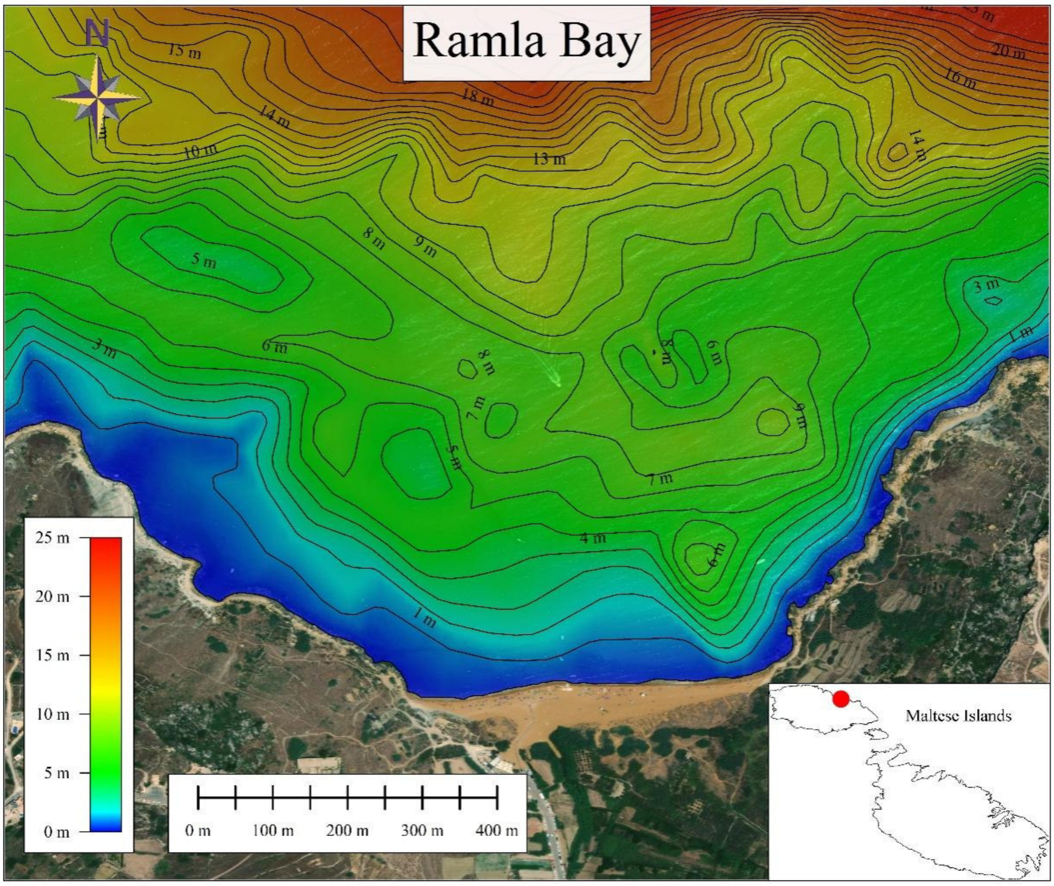


AI.58: Digital Elevation Model of Balluta. The colour scale represents the ground elevation above sea level. The survey was carried out in October 2019.

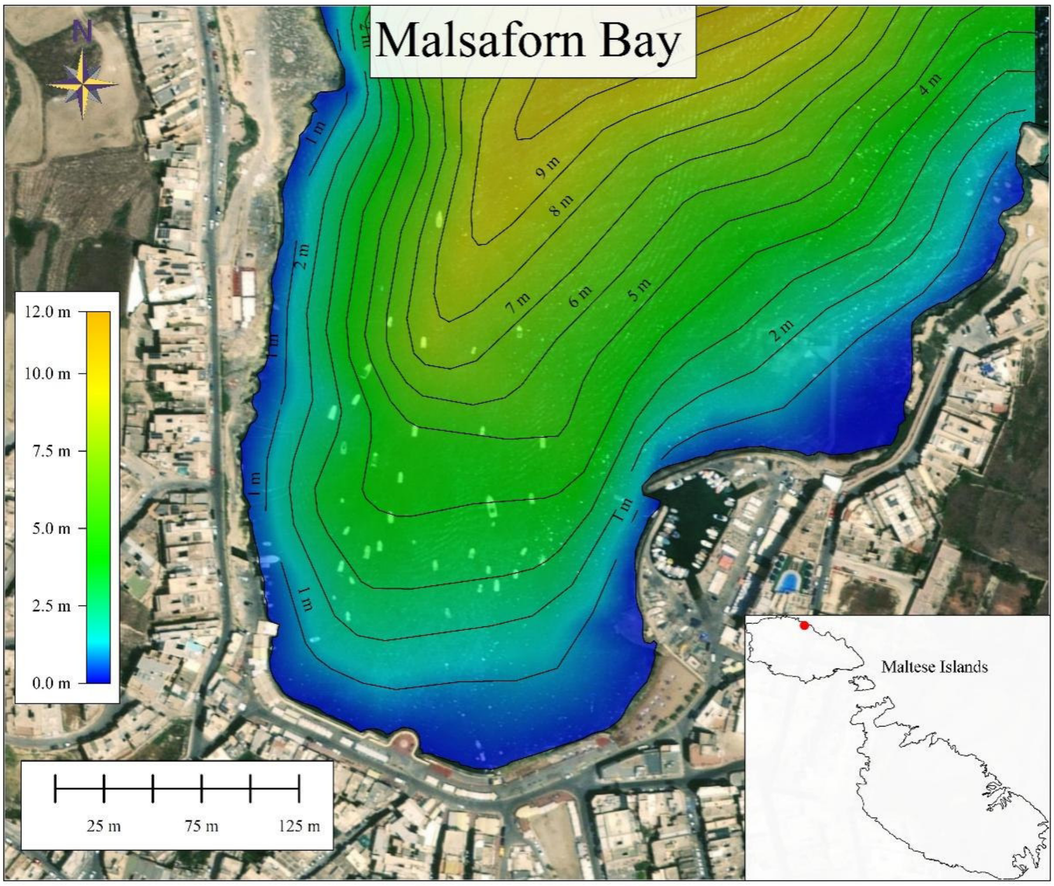
Appendix II: Bathymetry



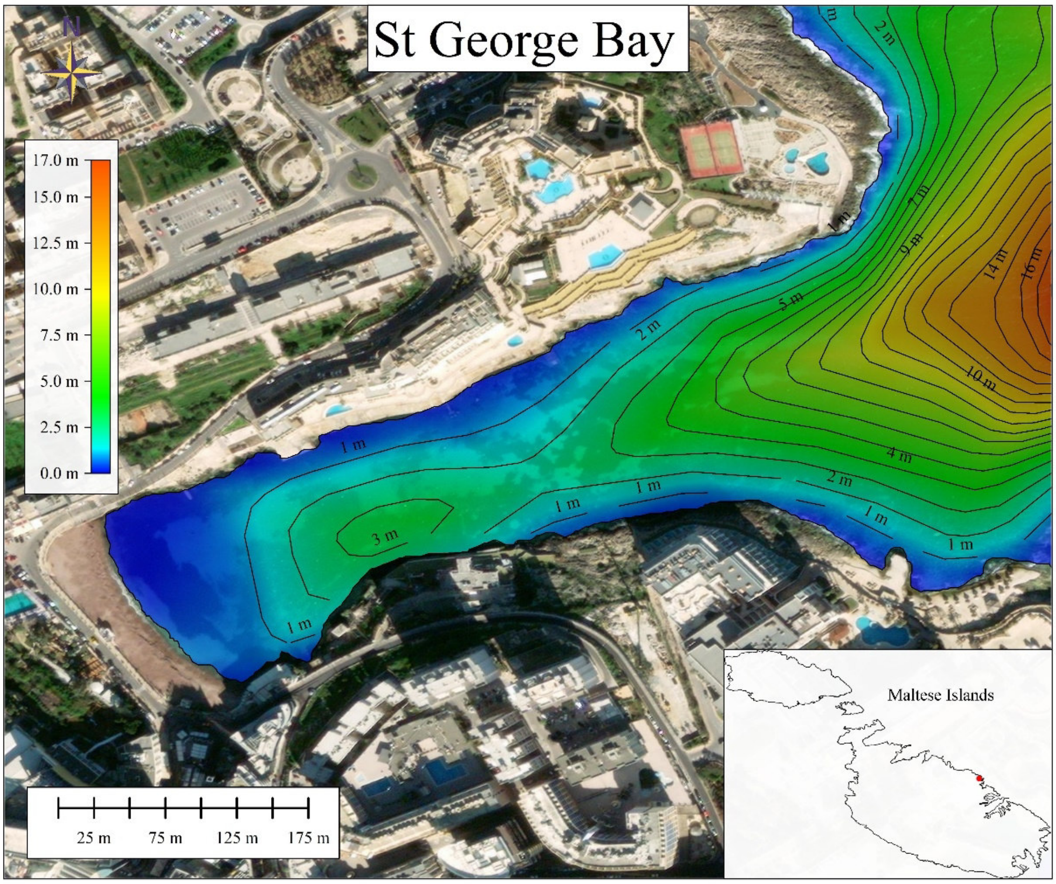
AII.1: Bathymetric map of Hondoq ir - Rummien Bay and figure showing its position in the Maltese Islands. The colour scale and contour lines correspond to the depth of the seabed.



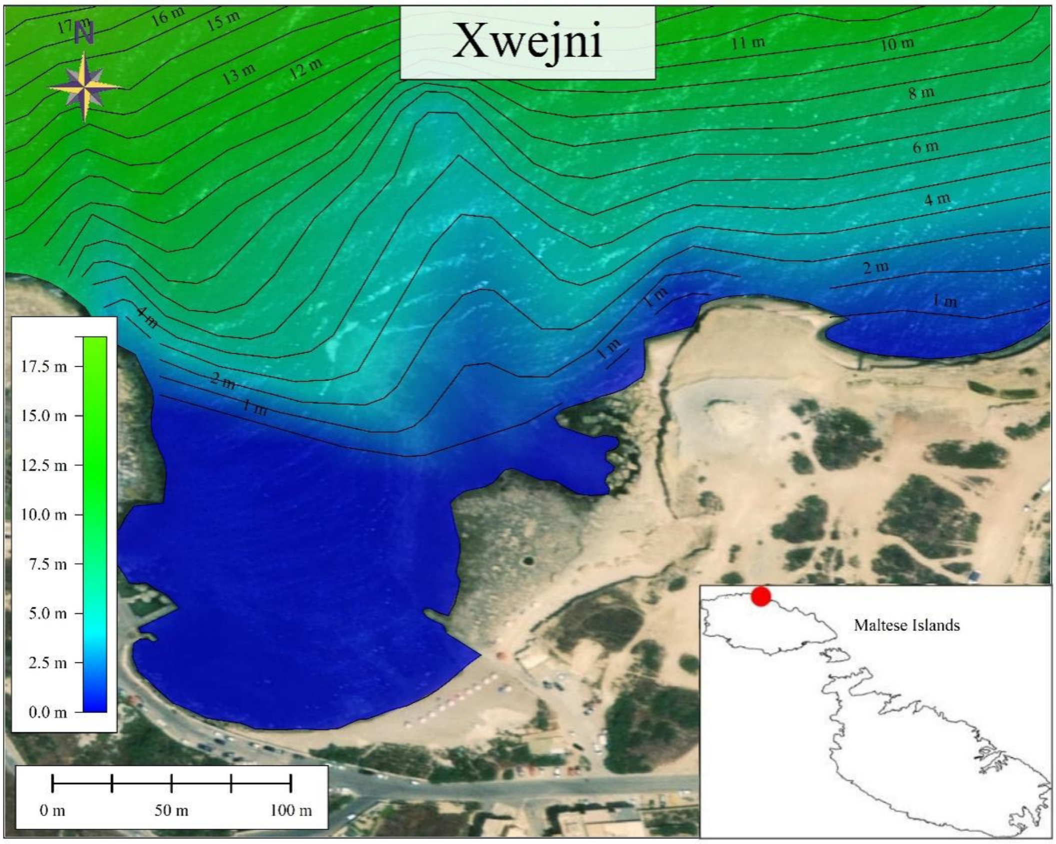
AII.2: Bathymetric map of Ramla Bay and figure showing its position in the Maltese Islands. The colour scale and contour lines correspond to the depth of the seabed.



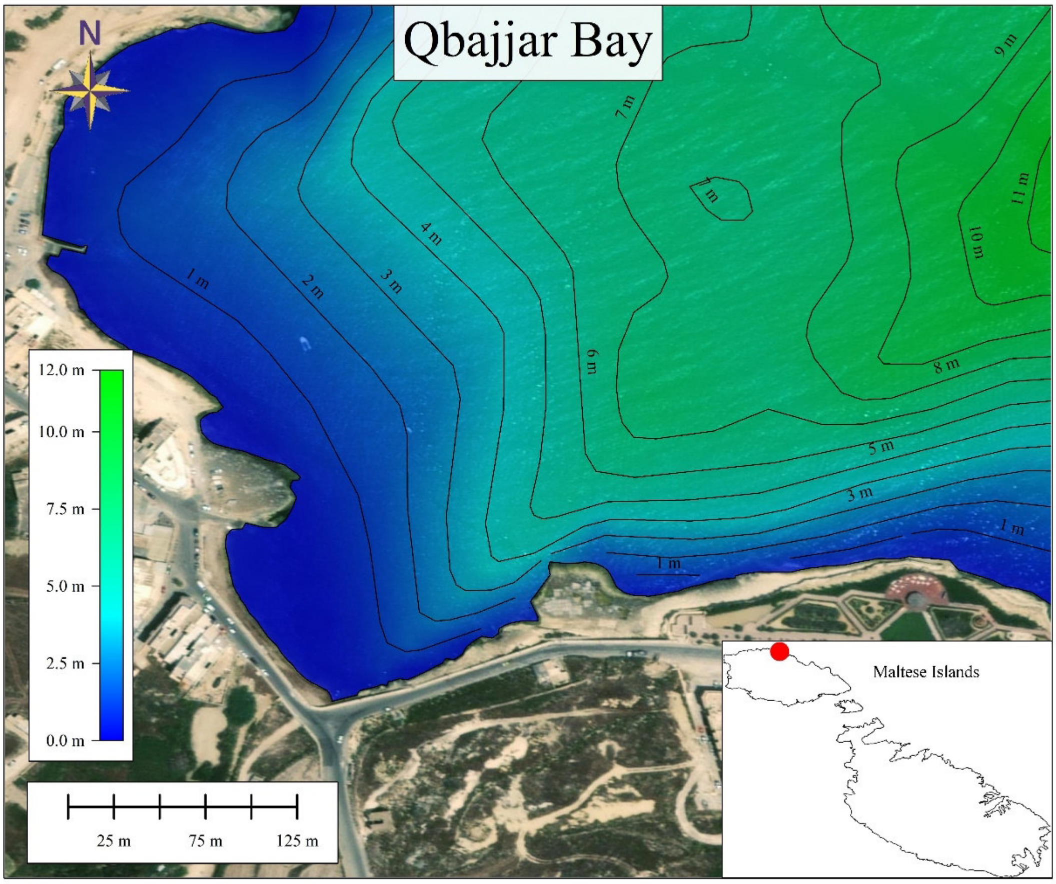
AII.3: Bathymetric map of Malsaforn Bay and figure showing its position in the Maltese Islands. The colour scale and contour lines correspond to the depth of the seabed.



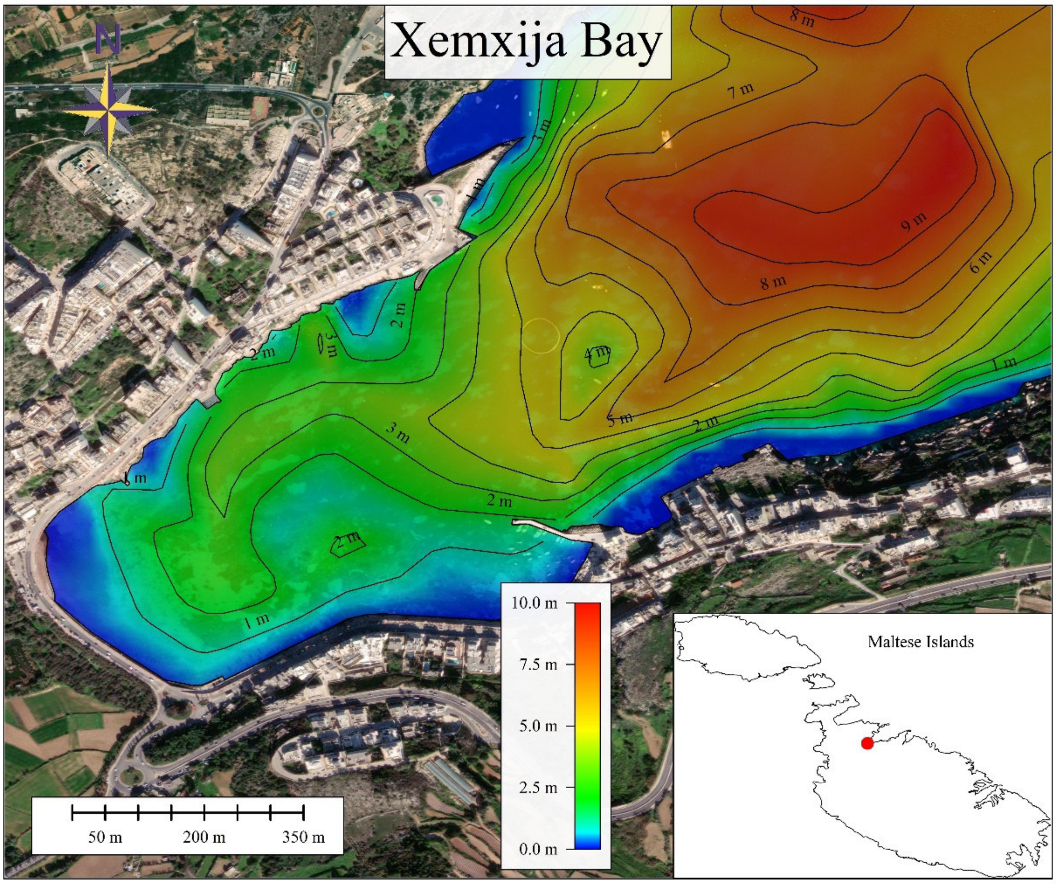
AII.4: Bathymetric map of St George Bay Bay and figure showing its position in the Maltese Islands. The colour scale and contour lines correspond to the depth of the seabed.



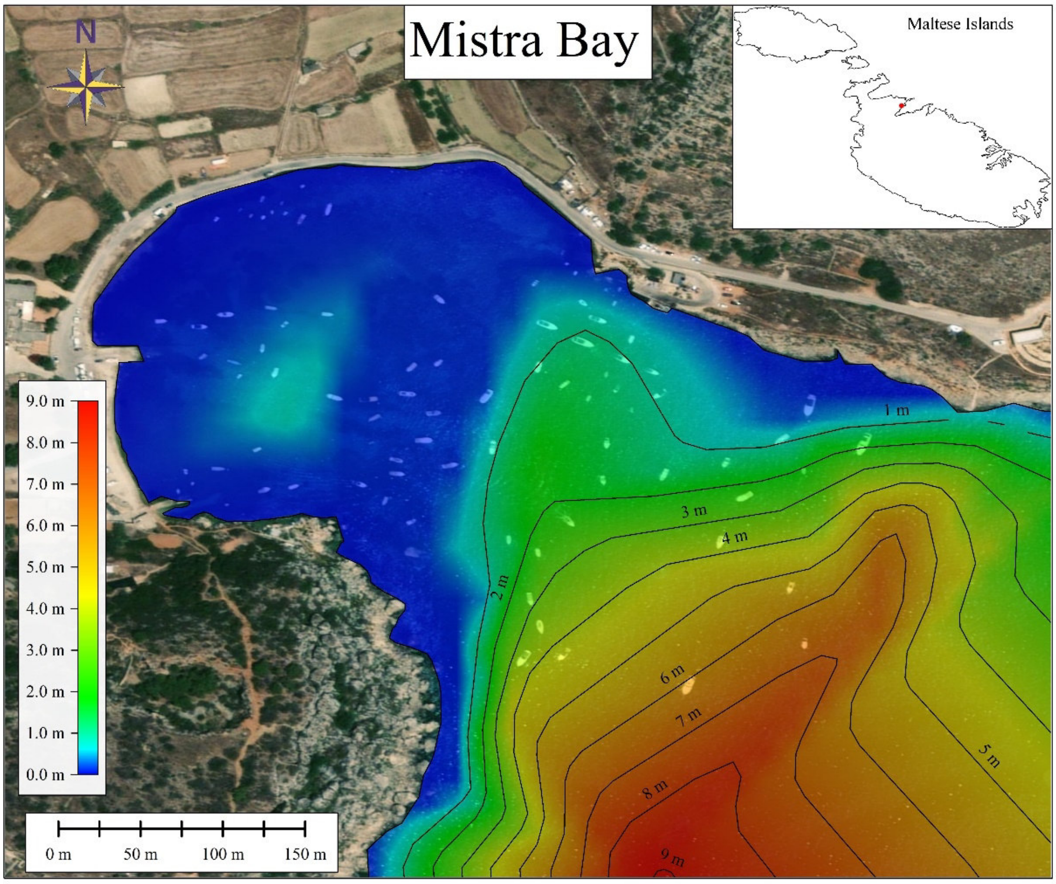
AII.5: Bathymetric map of Xwejni Bay and figure showing its position in the Maltese Islands. The colour scale and contour lines correspond to the depth of the seabed.



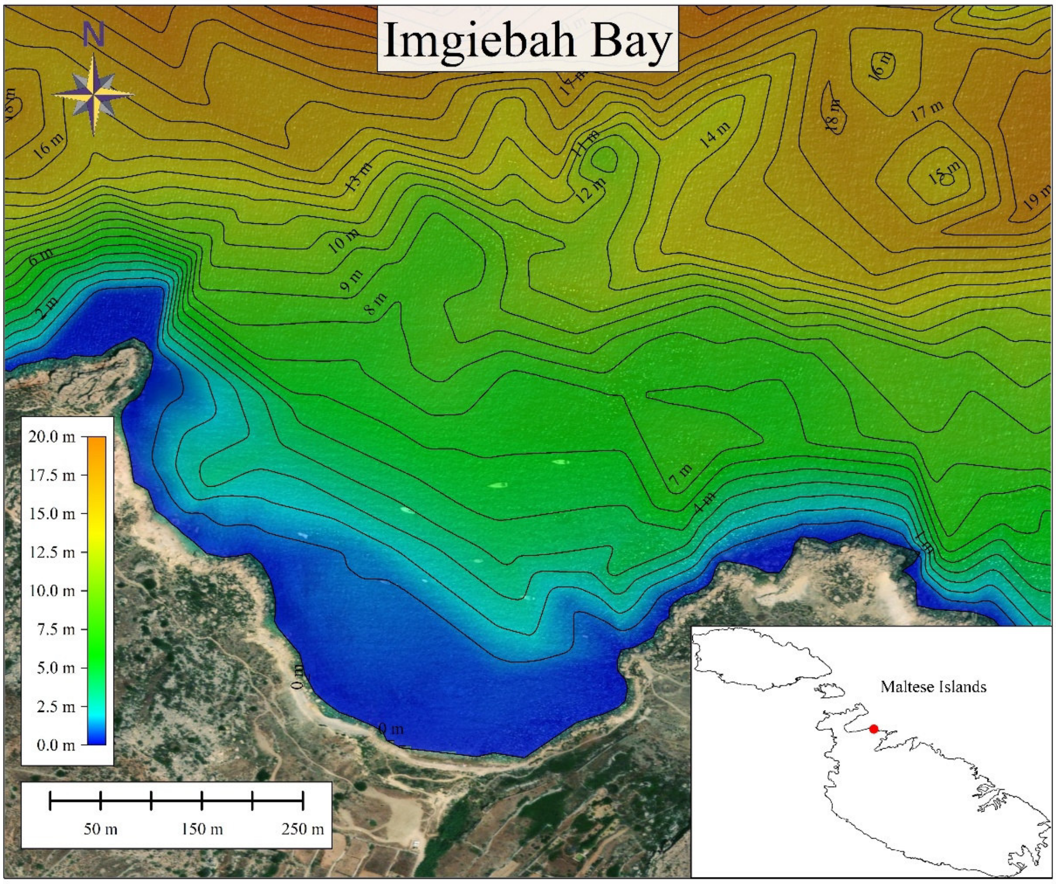
AII.6: Bathymetric map of Qbajjar Bay and figure showing its position in the Maltese Islands. The colour scale and contour lines correspond to the depth of the seabed.



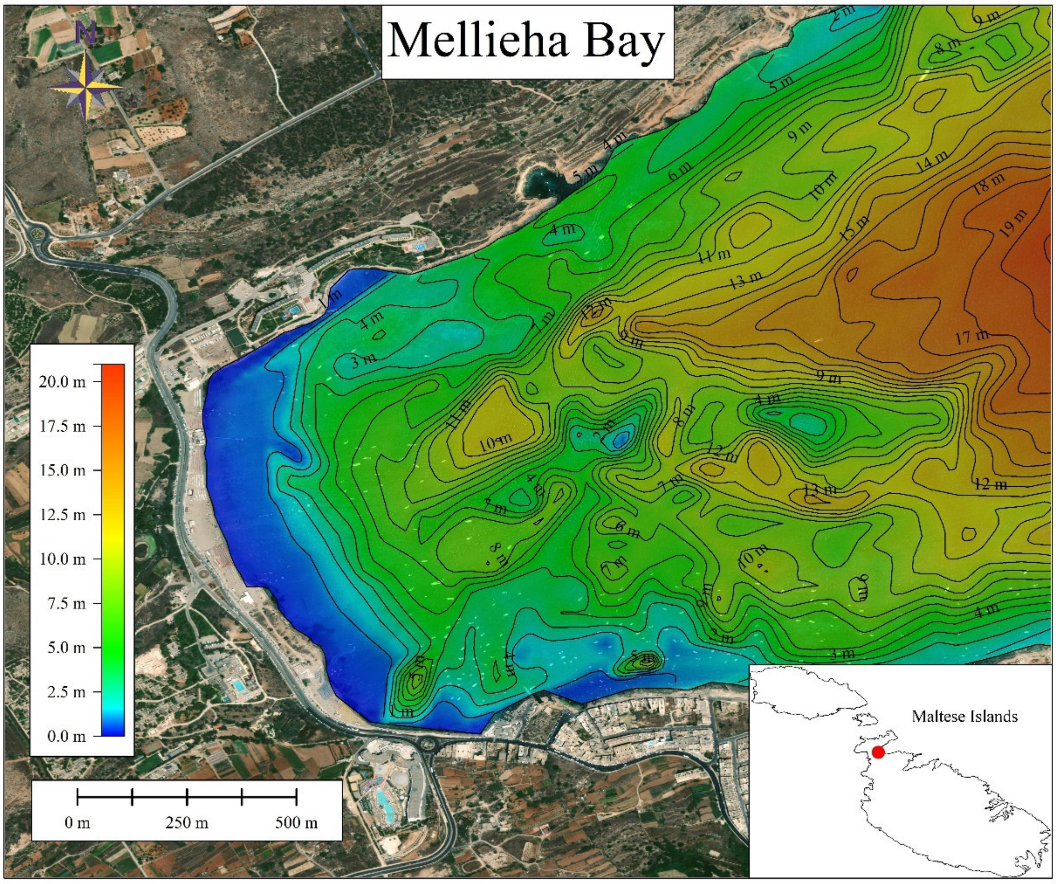
AII.7: Bathymetric map of Xemxija Bay and figure showing its position in the Maltese Islands. The colour scale and contour lines correspond to the depth of the seabed.



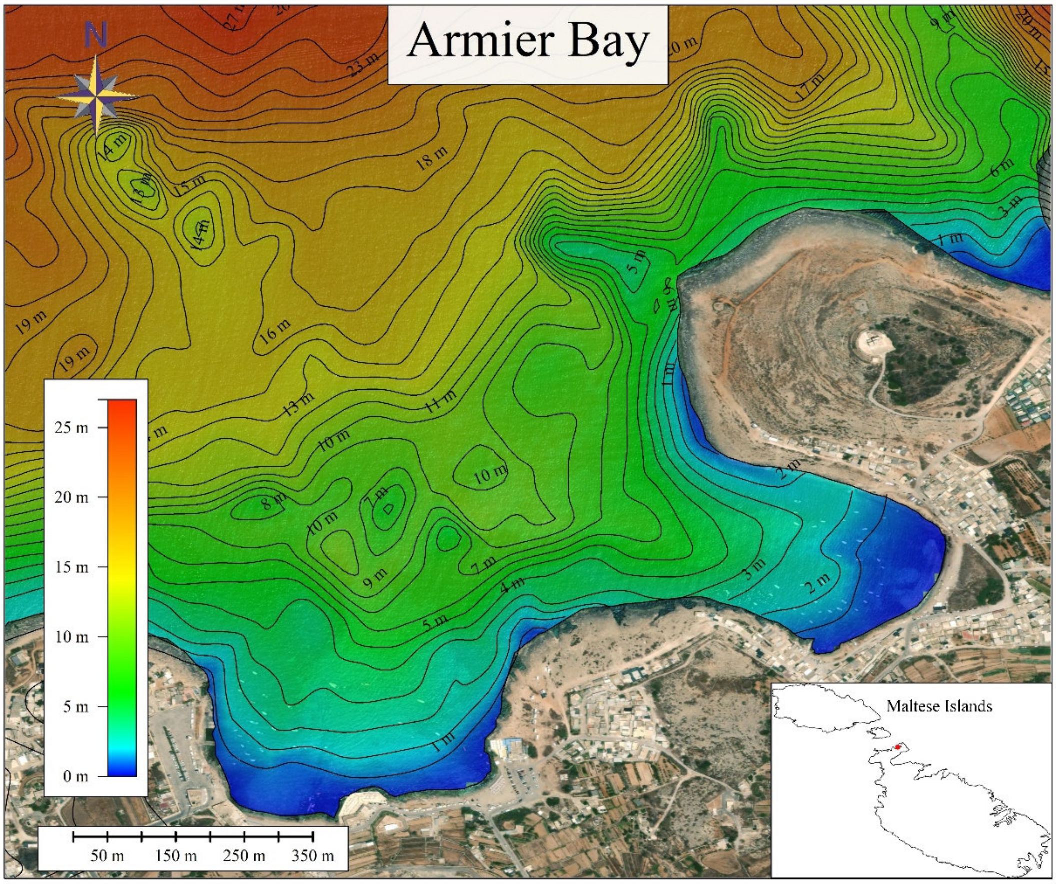
AII.8: Bathymetric map of Mistra Bay and figure showing its position in the Maltese Islands. The colour scale and contour lines correspond to the depth of the seabed.



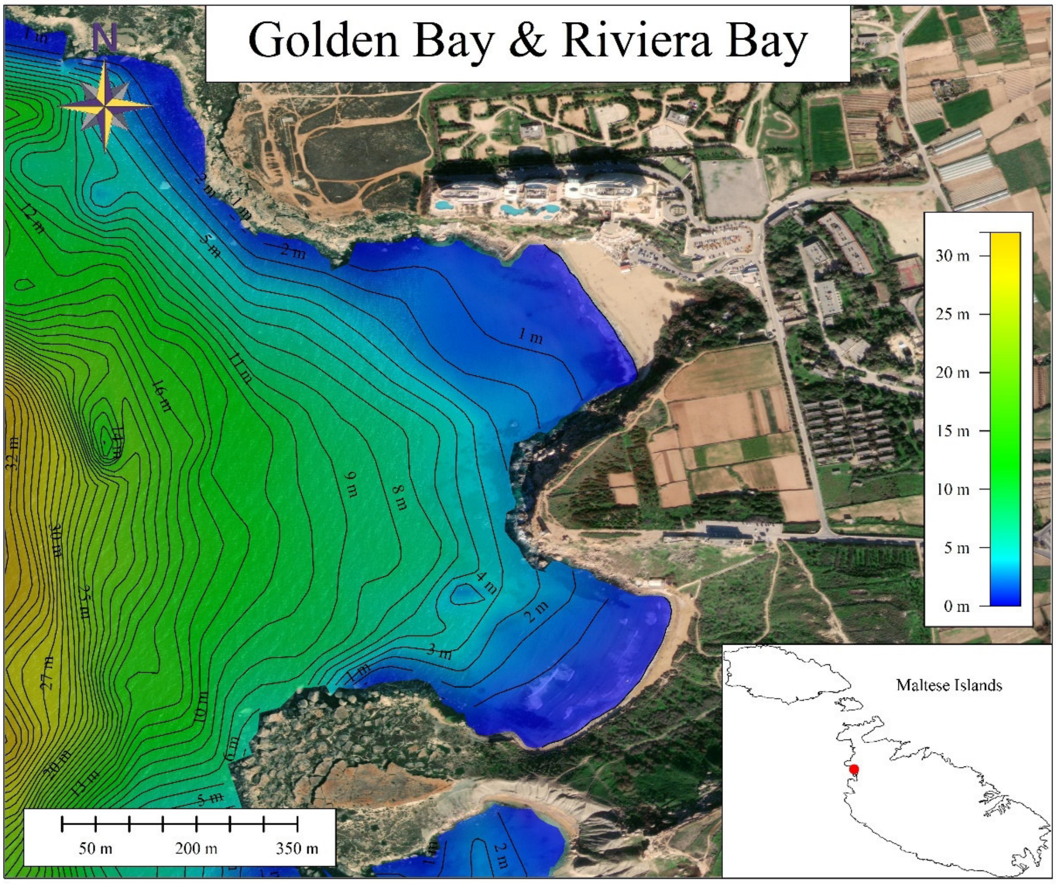
AII.9: Bathymetric map of Imgiebah Bay and figure showing its position in the Maltese Islands. The colour scale and contour lines correspond to the depth of the seabed.



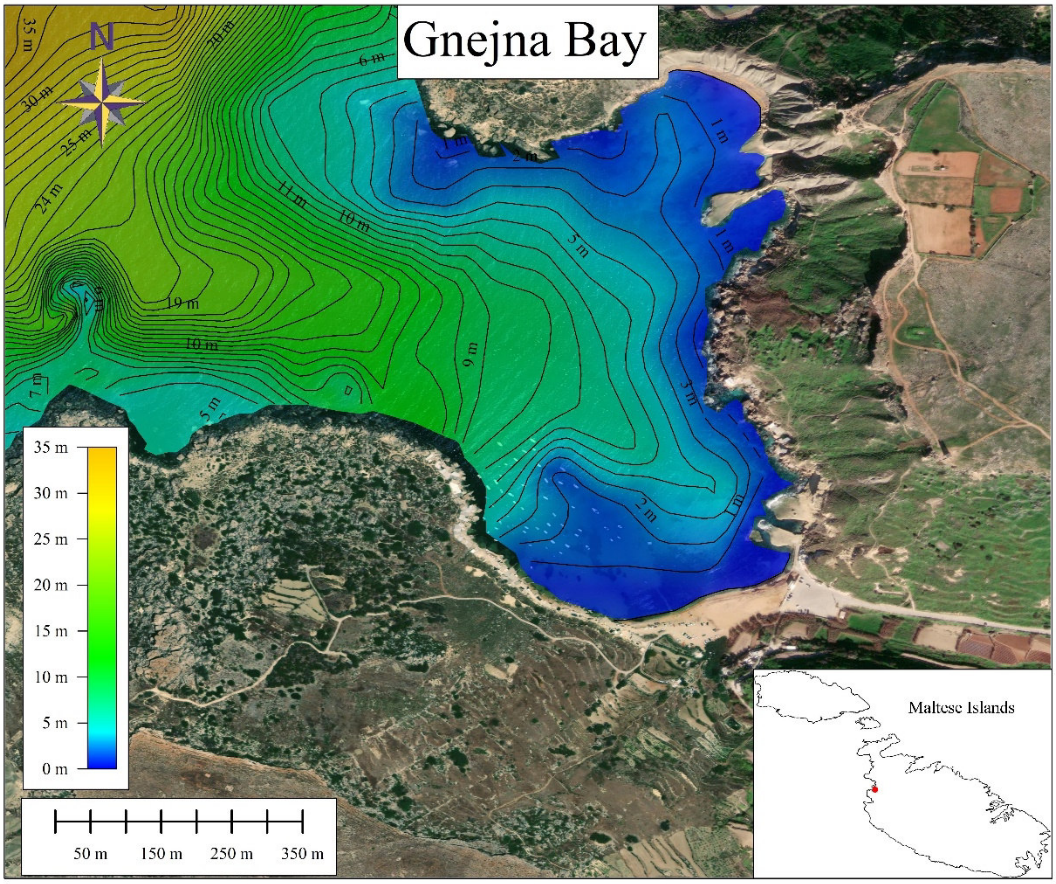
AII.10: Bathymetric map of Mellieha Bay and figure showing its position in the Maltese Islands. The colour scale and contour lines correspond to the depth of the seabed.



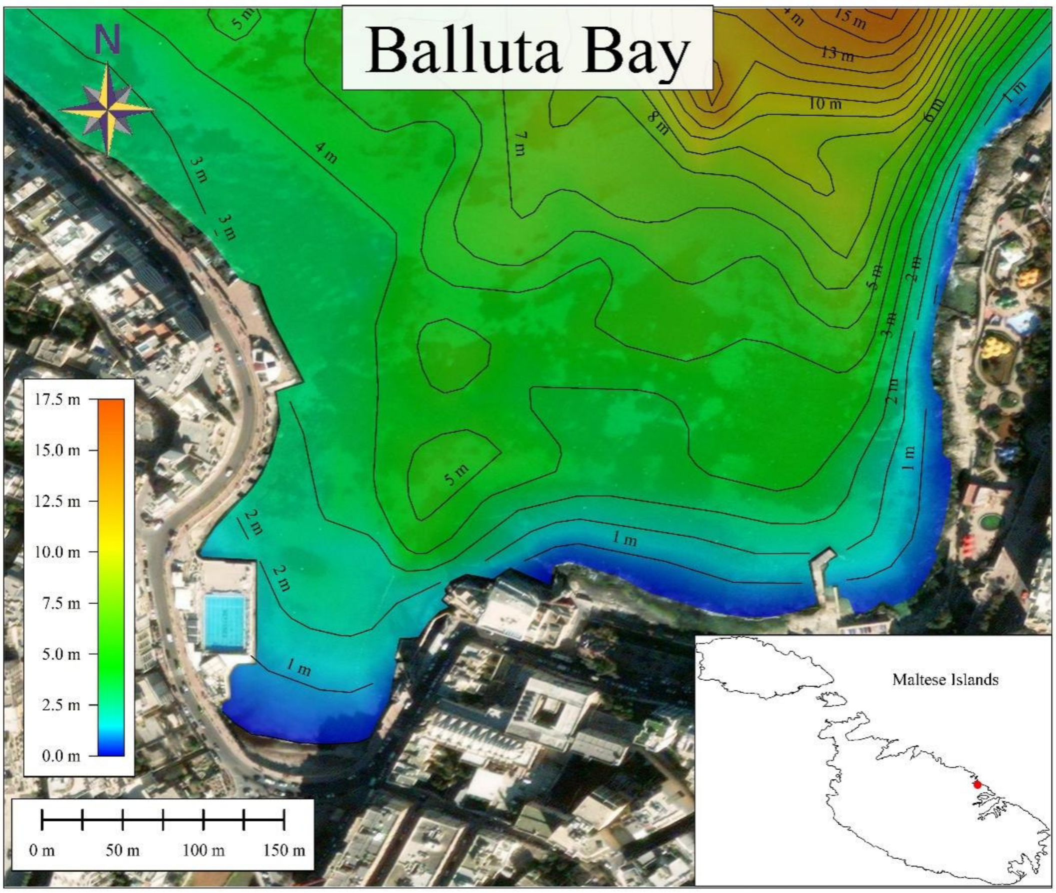
AII.11: Bathymetric map of Armier Bay and figure showing its position in the Maltese Islands. The colour scale and contour lines correspond to the depth of the seabed.



AII.12: Bathymetric map of Golden Bay & Riviera Bay and figure showing its position in the Maltese Islands. The colour scale and contour lines correspond to the depth of the seabed.



AII.13: Bathymetric map of Gnejna Bay and figure showing its position in the Maltese Islands. The colour scale and contour lines correspond to the depth of the seabed.



AII.14: Bathymetric map of Balluta Bay and figure showing its position in the Maltese Islands. The colour scale and contour lines correspond to the depth of the seabed.

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