WP4: Pilot Cases on ICZM

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Project co-funded by European Union, European Regional Development Funds (E.R.D.F.) and by National Funds of Greece and Italy

WP4 OUTLINE

- Decription of WP4
- Deliverables of WP4
- Pilot cases of WP4
- Conclusions

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WP4 DESCRIPTION

WP4 (PILOT CASES on ICZM) involves the establishment of an integrated coastal management programme in the Apulia region and the Region of Western Greece with the use of pilot study areas in both countries.

In the **Region of Western Greece** the pilot study areas include the gulf of Patras "constructed" as a model coastal erosion observatory and the Kotychi Lagoon. In the **Apulia Region** the pilot study areas include the Municipality of Bari as well as the Municipality of Ugento.

Pilot areas in both countries have been thoroughly investigated with several - state of the art techniques - in order to develop a joint tool for efficient detection and analysis of shoreline evolution. The joint tools developed under this procedure are the use of: **a) high-resolution satellite images and b) analytical methods for detecting and analysing shoreline evolution**. The analytical methods for the detection and analysis of shoreline evolution include numerical modelling and Bayesian network applications.

Numerical modelling performed in the Gulf of Patras, with the use of several data bases and data obtained from the installed equipment (wave buoy system, marigraphs and weather station), and provide details on shoreline evolution due to erosion. **Bayesian Network** performed in the Municipality of Ugento with the use of data collected and processed for the training of the BN model, and provide details on shoreline evolution with the presentation of 'what-if' scenario analysis, accounting for potential changes in the climate and management conditions.

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WP4 DELIVERABLES

D4.1 Call for expression of interest by stakeholders

D4.2 Call for tender for interventions selected

D4.3 Pilot test and joint tool development with local operators and players involvement

D4.4 Benchmark analysis and results after integration with data systems

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PILOT CASES –
THE GULF OF PATRAS IN WESTERN GREECE

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THE COASTAL EROSION OBSERVATORY OF THE GULF OF PATRAS

The Gulf of Patras has been selected as a coastal erosion observatory because of its biodiversity and the increased urban and touristic development along its coastline

AIM AND OBJECTIVES OF A PILOT EROSION OBSERVATORY

The establishment of a pilot erosion observatory in areas that suffer significant erosion problems aims to collect real-time data, with the monitoring of several parameters that negatively affect shorelines. The collected data can be used with the appropriate interpretation in the design of long-term protection measures of the suffered shorelines.

In order to achieve this goal, it is necessary to create from the early beginning a detailed geomorphological and coastal plan of the study area and install the necessary equipment for real-time monitoring.

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EQUIPMENT INSTALLATION and DATA PROCESSING

Equipment installation and data processing involved two stages:

A) installation and use of equipment for a continuous monitoring of the following parameters: i) shoreline development and alteration of sea-bed topography, ii) changes in the marine ecology and the quality of sea-bed sediments, iii) meteorological changes, iv) sea wave creation and rise of sea level with real-time measurements

B) Data processing for the elaboration of an integrated coastal zone management plan and protection against erosion

ENGAGED ACTIVITIES

Equipment installation performed by the Region of Western Greece

- one wave data buoy system for wave intensity measurements
- two tide gauges (marigraphs) for sea rise level and tidal measurements
- two weather stations for real time meteorological measurements

Surveys and studies performed by the University of Patras

- Geotechnical surveys and engineering geological studies
- Satellite, aerial photo imaging and UAV surveys
- Marine surveys and digital bathymetric plans
- Environmental monitoring in the protected areas
- Numerical study of waves, currents and sediment transport

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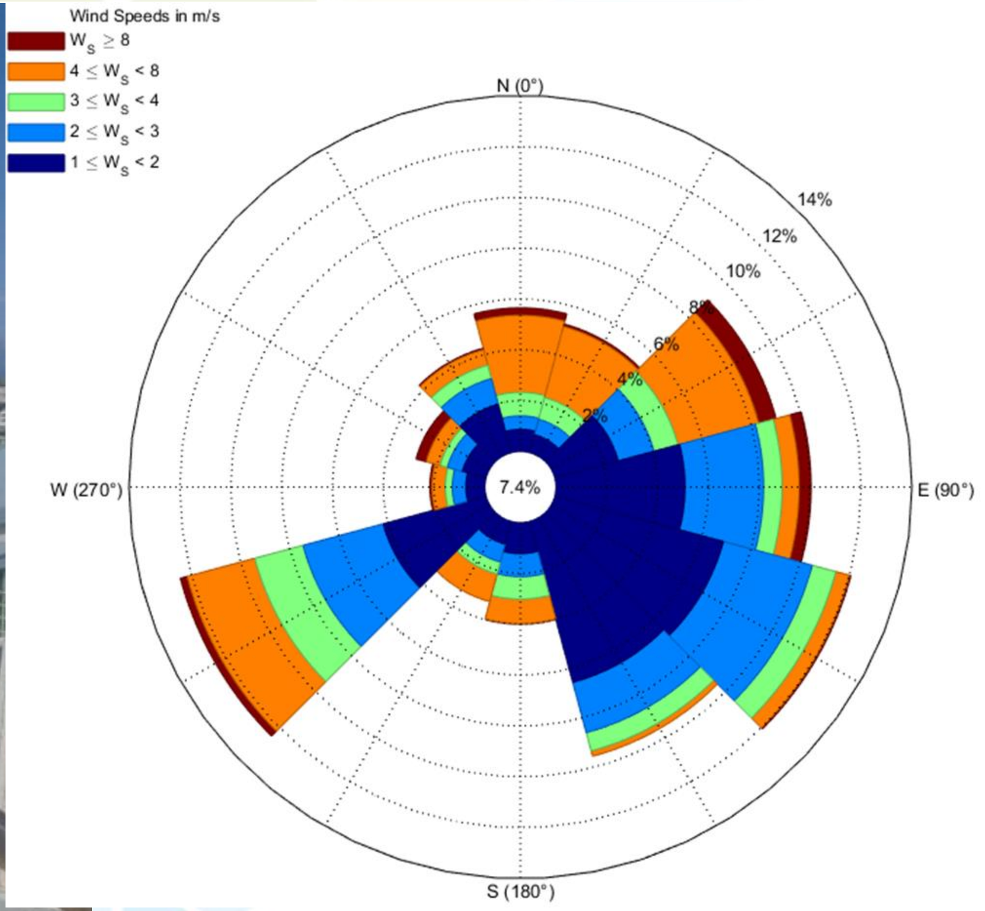
EQUIPMENT INSTALLATION

The installation of the equipment aims to facilitate the collection of useful data and enable the development and adoption of the necessary measures in order to address the erosion phenomenon and involved.

- A weather station, a tide gauge (marigraph) and a wave buoy system installed in the wider area of the new port of Patras.
- A weather station and a tide gauge (marigraph) installed in the port of Killini

WEATHER STATION IN THE NEW PORT OF PATRAS

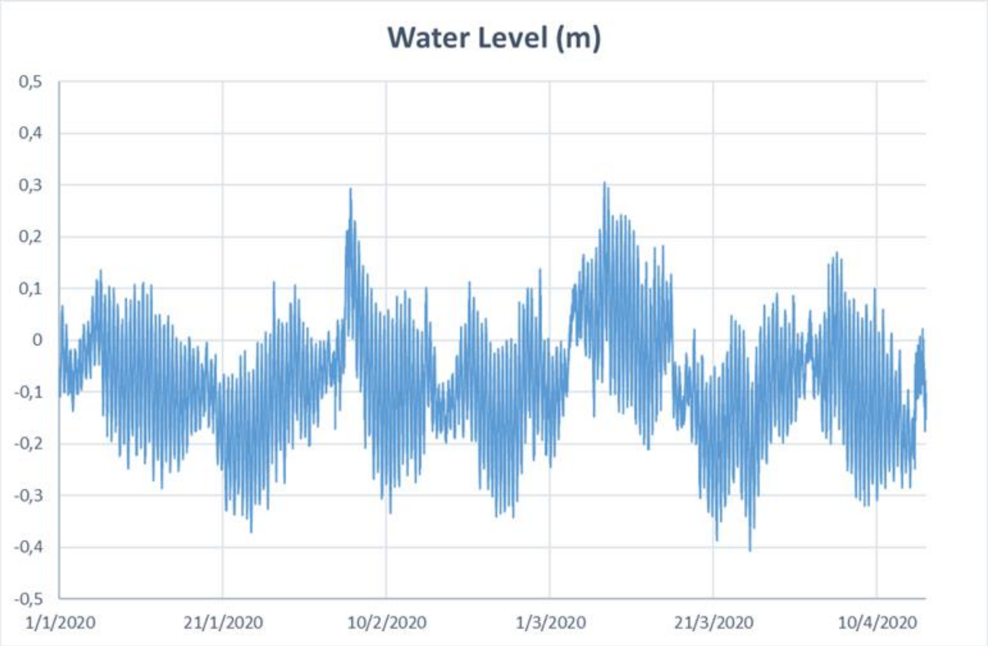
The weather station installed on 16/10/2019 and provides real time atmospheric measurements (temperature, humidity, wind speed/direction and rain height)



Wind rose diagram for the period 01/01/2020-15/04/2020

TIDE GAUGE IN THE NEW PORT OF PATRAS

The Patras tide gauge (marigraph) installed on 16/10/2019 and provides real-time sea-level and tidal measurements every 10 minutes



Sea level measurements for the period 01/01/2020-15/04/2020

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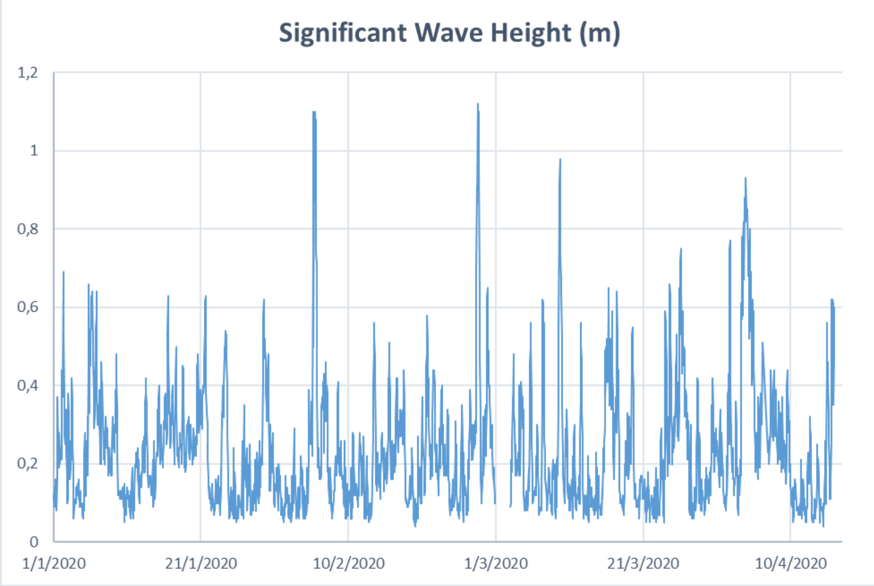
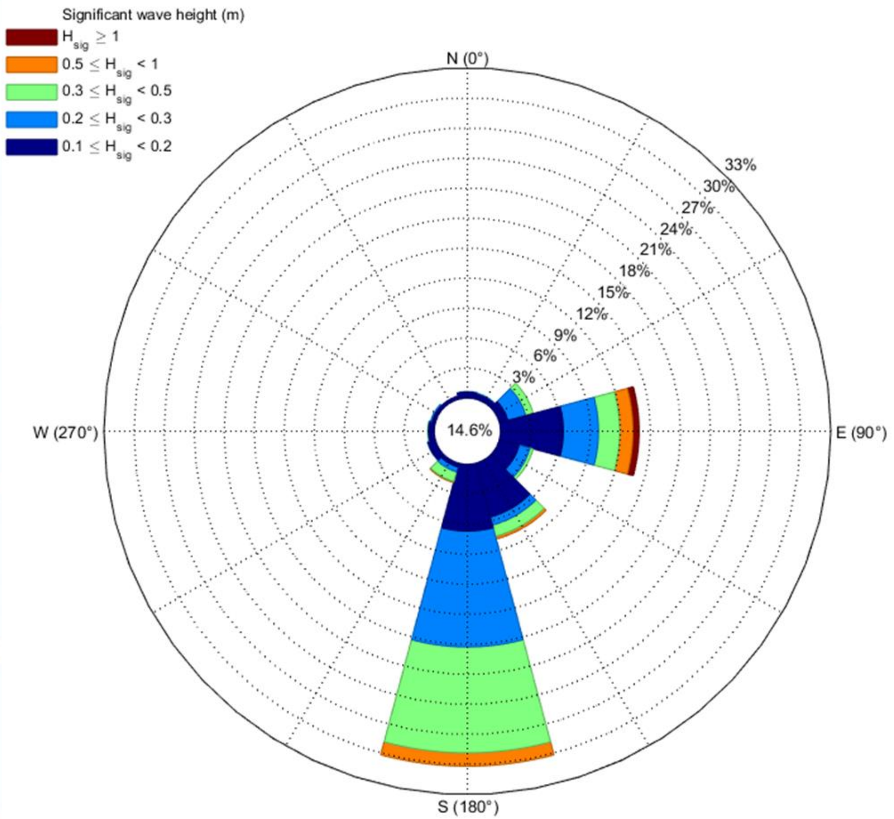
WAVE DATA BUOY SYSTEM IN THE GULF OF PATRAS

The Wave data buoy system installed on 16/10/2019 south of the new port of Patras and provides real time wave measurements every 30 minutes



Significant wave height for the period 01/01/2020-15/04/2020



Wave rose diagram for the period 01/01/2020-15/04/2020

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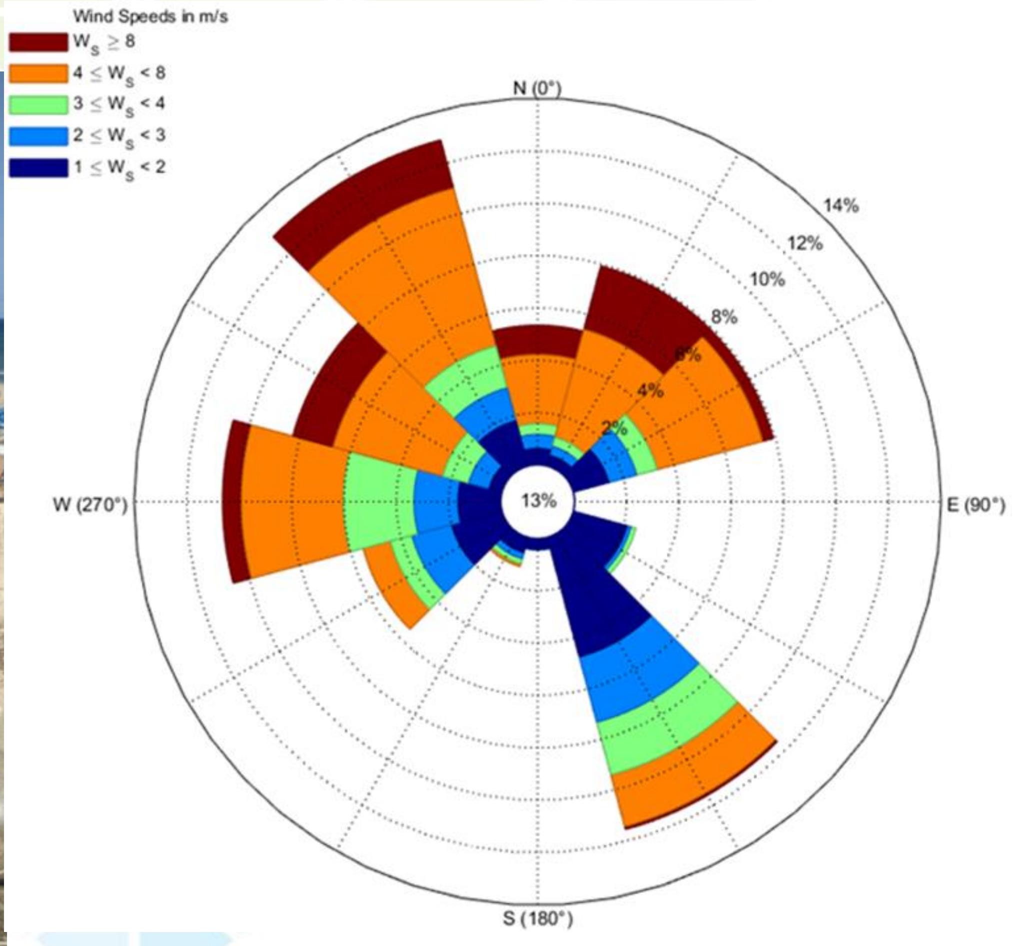
WEATHER STATION IN THE PORT OF KILLINI

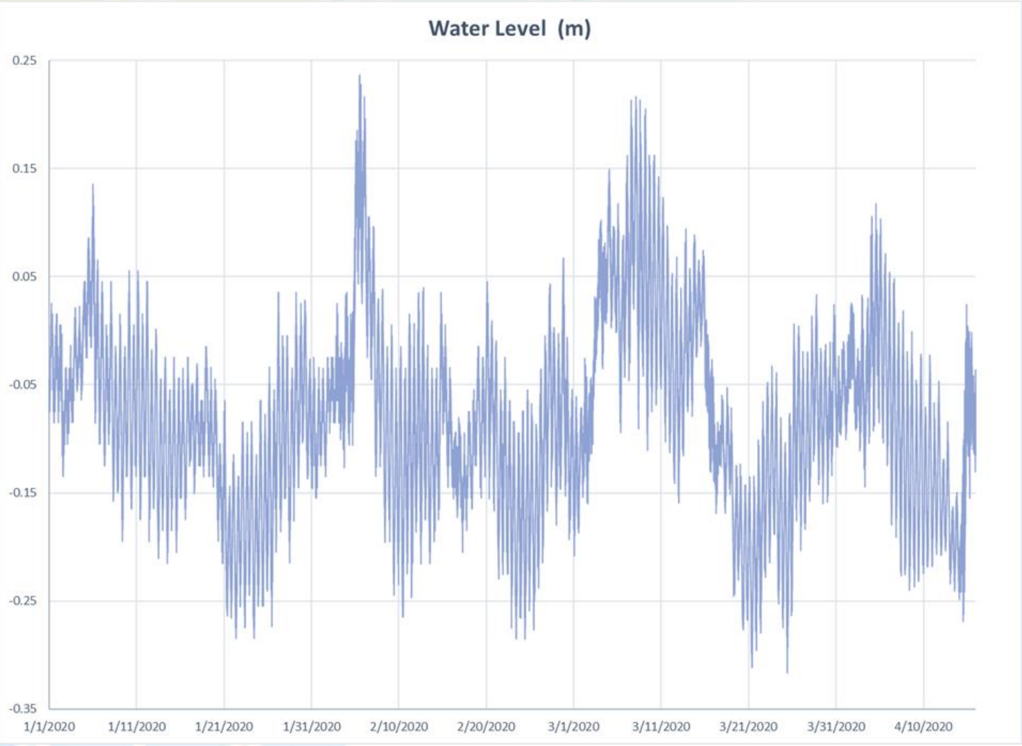
The weather station installed on 22/09/2019 and provides real time atmospheric measurements (temperature, humidity, wind speed/direction and rain height)



Wind rose diagram for the period 01/01/2020-15/04/2020

TIDE GAUGE IN THE PORT OF KILLINI

The Killini tide gauge (marigraph) installed on 13/09/2019 and provides real-time sea-level and tidal measurements every 10 minutes



Sea level measurements for the period 01/01/2020-15/04/2020

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SURVEYS AND STUDIES IN THE GULF OF PATRAS

- Geotechnical surveys and engineering geological studies
- Satellite, aerial photo imaging, UAV and USV surveys
- Marine surveys and digital bathymetric plans
- Environmental monitoring in the protected areas
- Numerical study of waves, currents and sediment transport

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GEOTECHNICAL SURVEYS

In the frame of the TRITON project an extensive geotechnical investigation program was performed along the shoreline of the gulf of Patras, comprising of:
(a) Borehole drilling and core sampling
(b) in-situ and lab tests
(c) sediment analysis

The purpose of this program was to identify the soil's stratigraphy and its geotechnical properties for specific coastal applications

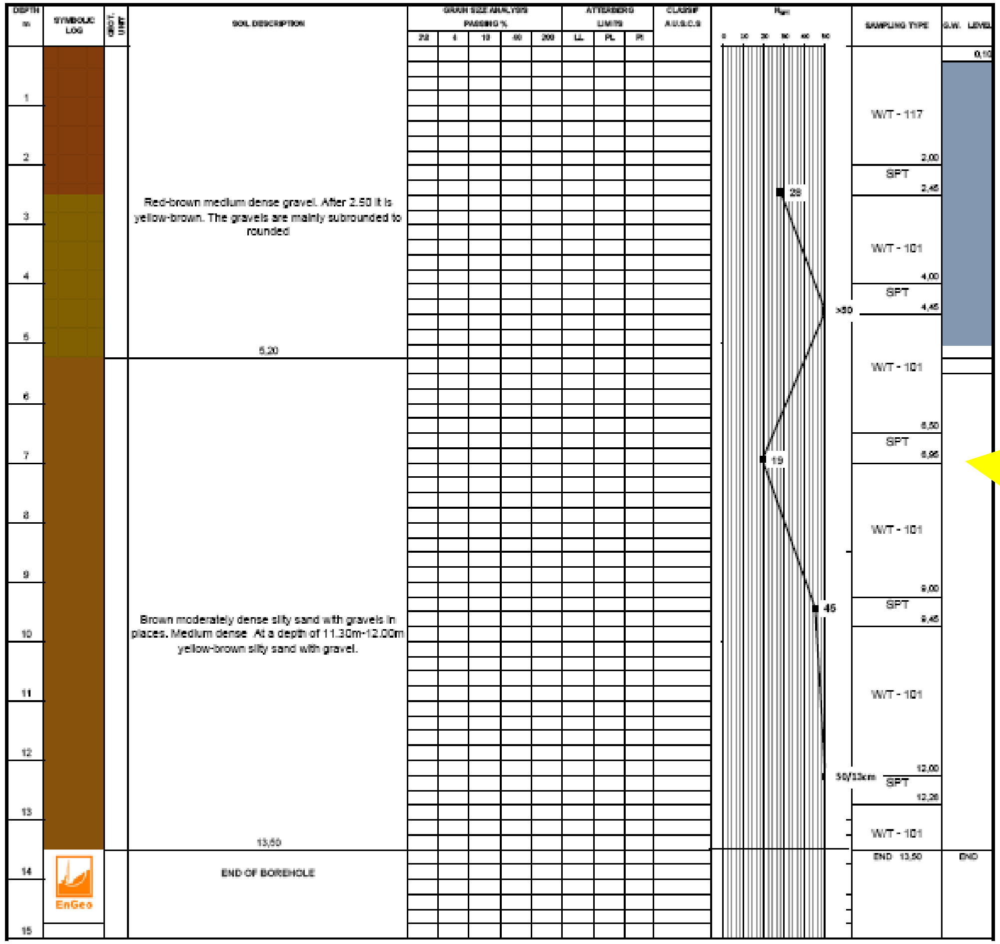
Google-Earth map representing the geotechnical operations performed along the shoreline of the gulf of Patras (borehole drilling: ΓΝ, CPT tests and sampling points for sediment analysis: S)

Borehole drilling and core sampling

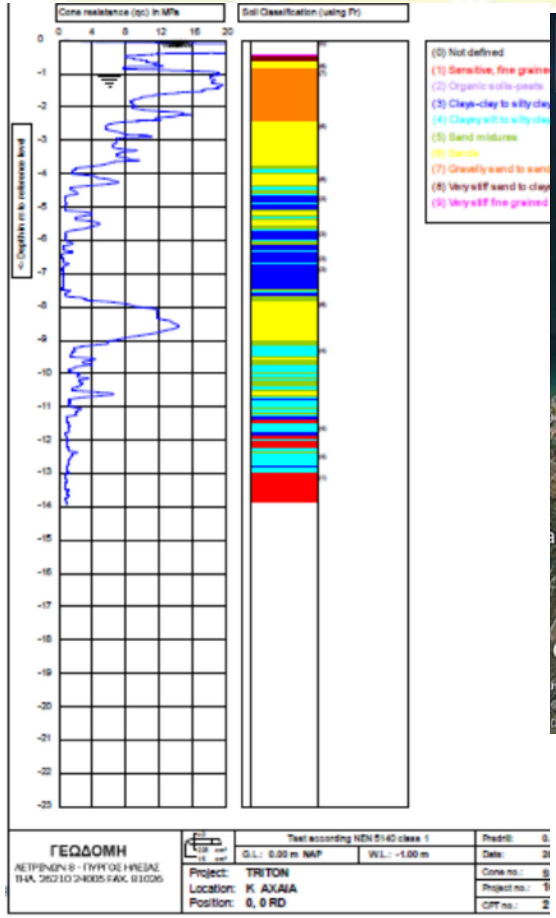
- Six (6) boreholes were drilled along the shoreline of the gulf of Patras with a total length of 86,50m and the relevant soil core sampling, in-situ (SPT, CPT) and laboratory tests were performed.
- All soil core samples, after on-site macroscopic examination and recording, were placed in special log boxes, photographed, and transported in the lab for testing.

Borehole logs

BOREHOLE ΓN-01



CPT (Cone Penetrometer Tests)



Google-Earth map representing the penetration tests performed along the shoreline of the gulf of Patras, in the areas of Kato Achaia and Alykes fishery port

Sediment sampling and grain size analysis

A) Sediment sampling in 102 different positions along the shoreline of the gulf of Patras and
B) Execution of laboratory identification and classification tests on the received soil samples with an emphasis given in grain size analysis and other physical properties.

This procedure identifies the origin of the deposited sediments in the coastal zone, which is very important in the subsequent analyses of sediment transport and the relevant numerical modelling

Geotechnical Implementation in the area of intervention

- Determination of the erosion sensitivity of the coastal sediments
- Assessment of the Liquefaction Potential Index along the coastal zones
- Use of results, information and data for the production of several maps and diagrams in order to detect any potential geological hazards and erosion trend across the shoreline that may affect future construction activities and residential development
- Improvement of the coastal vulnerability index (CVI) with the initiation of geotechnical data

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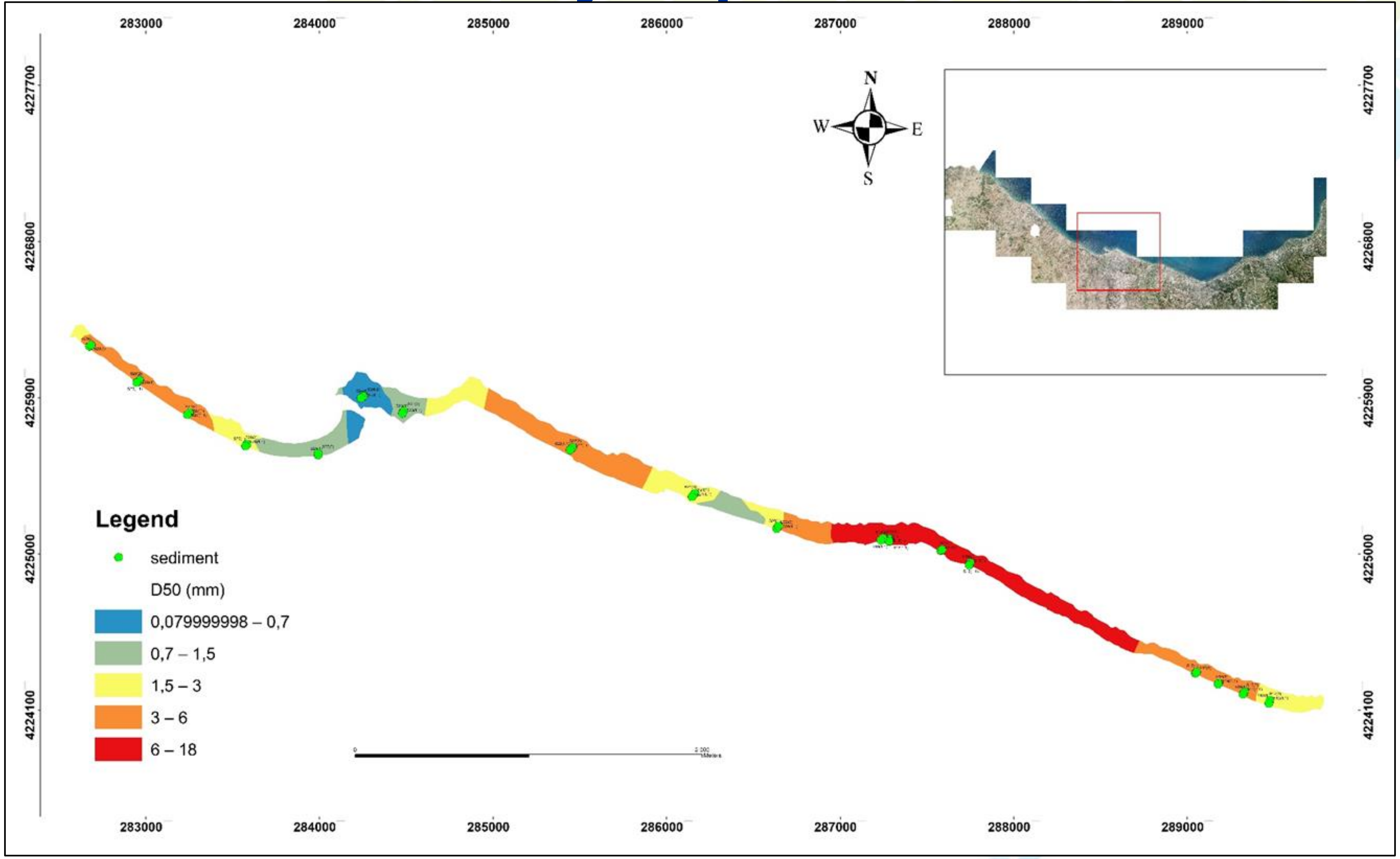
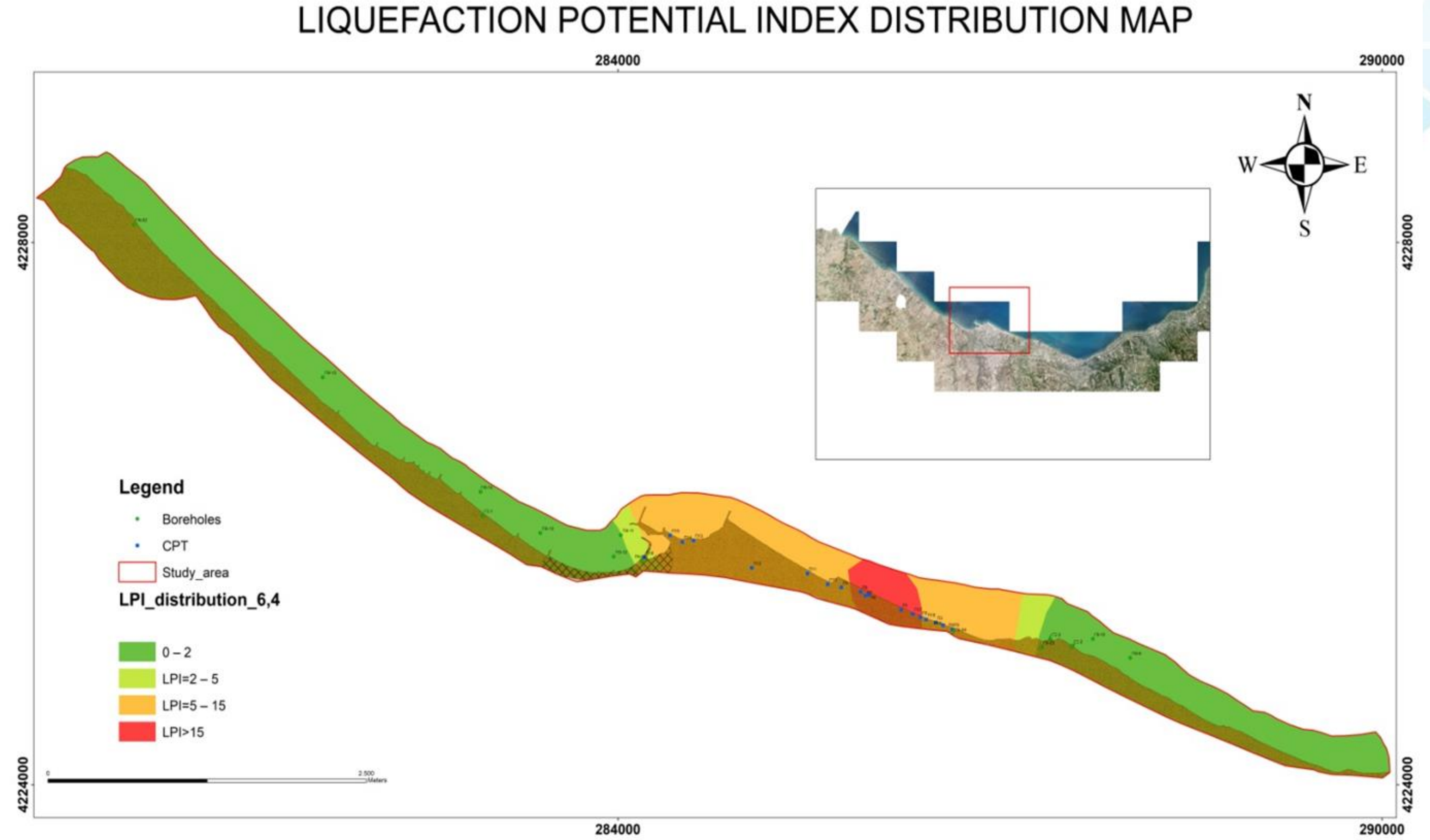
Sediment sensitivity maps in the Gulf of Patras



Liquefaction Potential Index (LPI) maps in the Gulf of Patras



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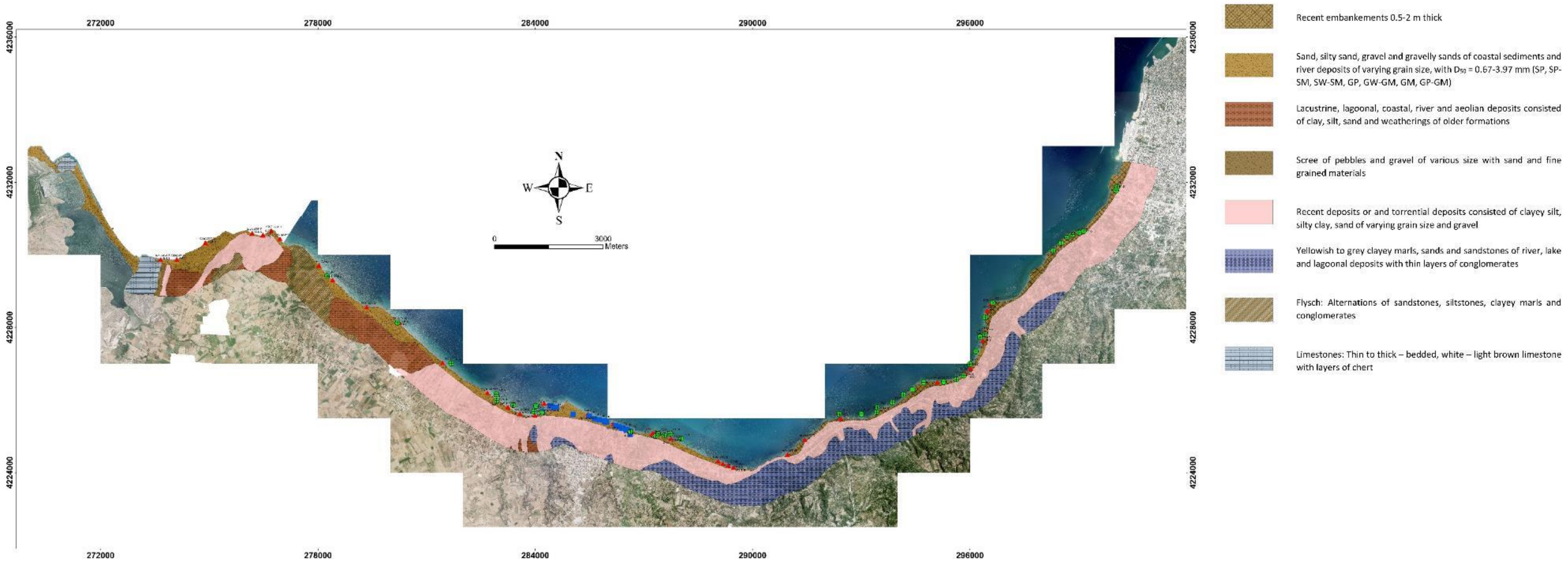
Engineering geological maps in the Gulf of Patras



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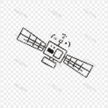
Satellite, aerial photo imaging and UAV data collection



- Medium to very high-resolution satellite data
- Airphotos

- USV data
- UAV data

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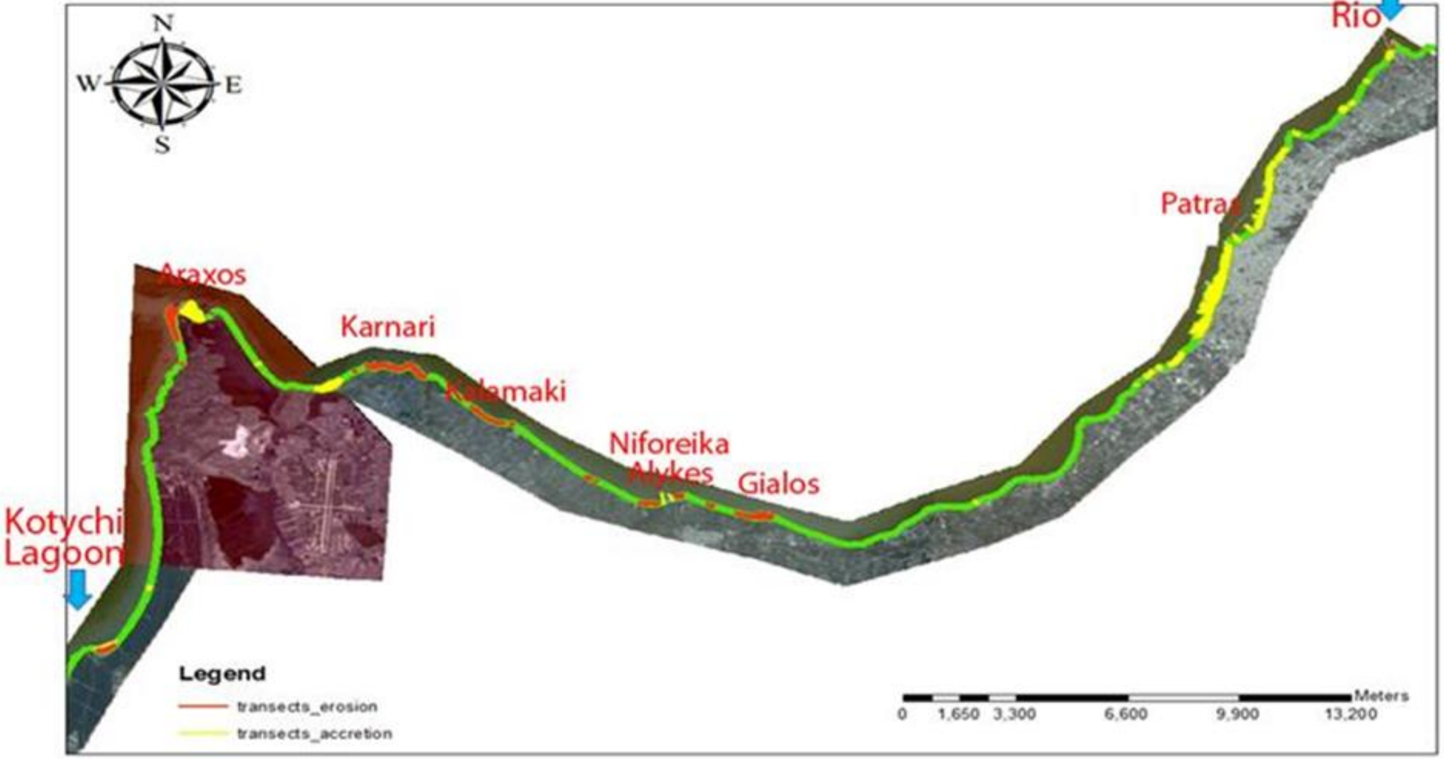
Satellite, aerial photo imaging and UAV Surveys

Digital processing of diverse remote sensing data has been performed along the shoreline of the Gulf of Patras.

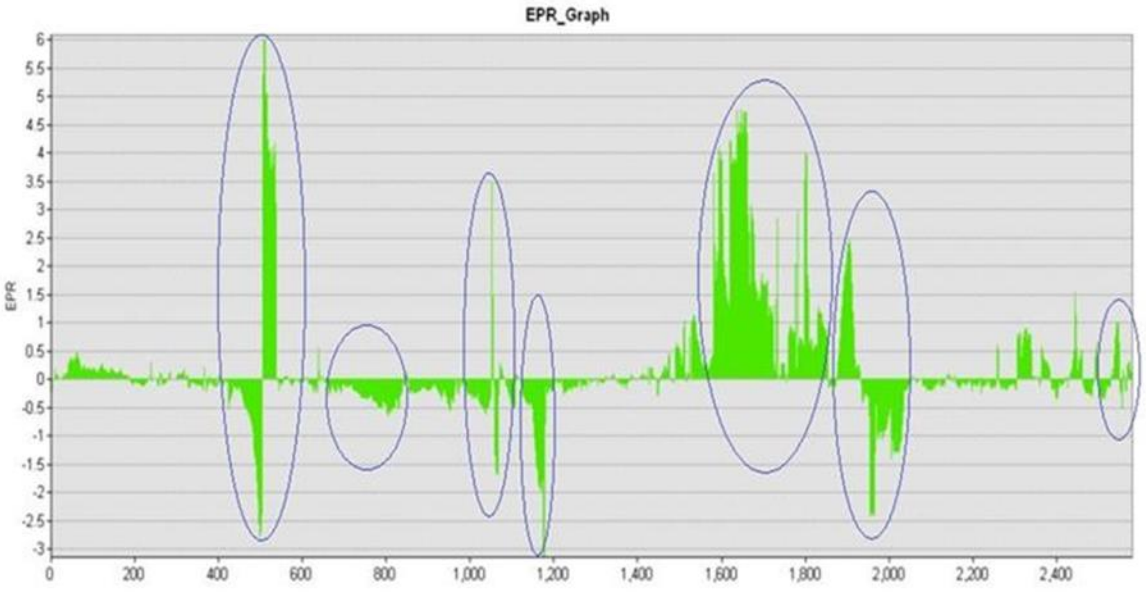
Medium to Very High Resolution (VHR) satellite data have been processed to map the recent coastline and classical analogue air photos (1945-2008) are used to detect the shoreline changes.

Unmanned Aerial Vehicles and Unmanned Surface vehicles are used for up-to-day data collection in specific areas.



Map of the shoreline displacement from 1945 to 2018 along the coastline of the gulf of Patras. Red color represents areas where the erosion is higher than 30m, yellow color represents areas where the accretion is higher that 30m and green color represents areas where the shoreline displacement is lower than 30m.

Satellite, aerial photo imaging and UAV Surveys



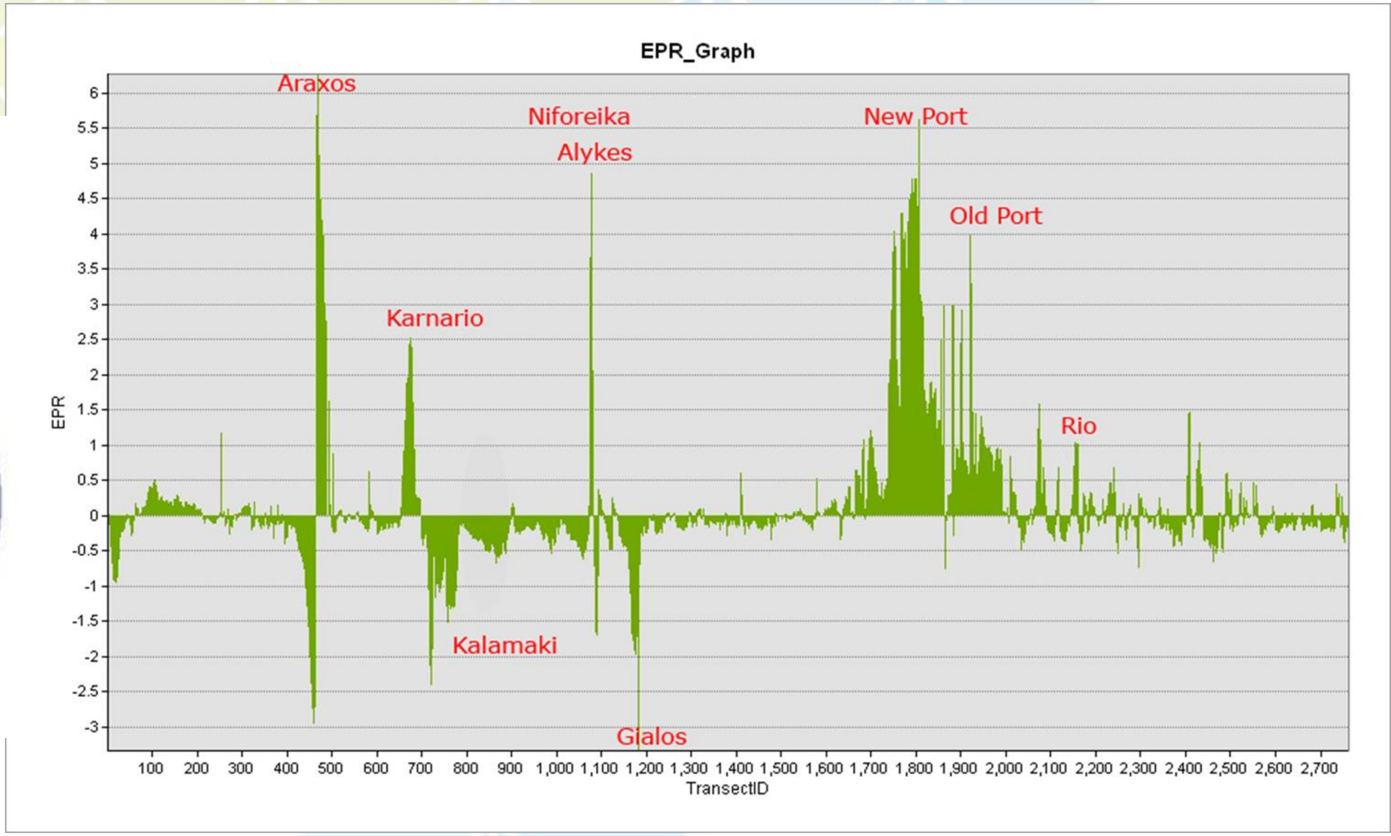


Diagram of the mean annual rate of erosion or deposition along the the coastline of the gulf of Patras. The circled areas correspond to the areas with an erosion or accretion more than 30m. Transects numbering starts from Kotychi Lagoon (no1) and reaches Rio at Transect (no2150)

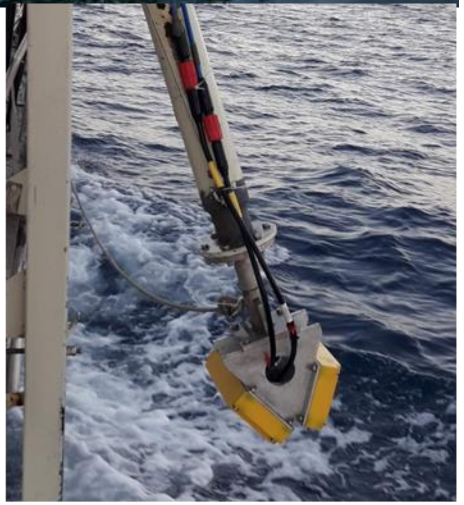
MARINE SURVEYS AND DIGITAL BATHYMETRIC PLANS

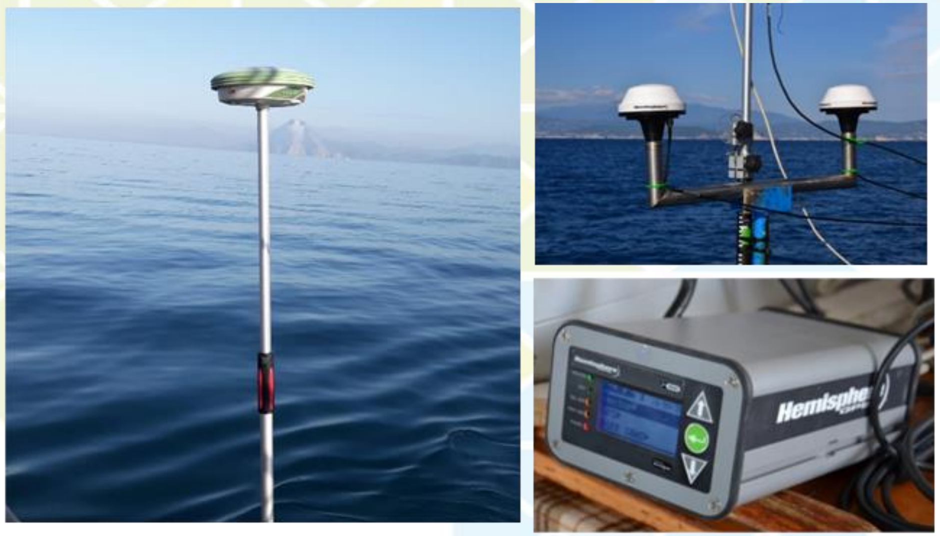
An extensive marine survey was conducted comprising of:
(a) marine research and data acquisition methods for mapping the bathymetry of the southern part of the gulf of Patras,
(b) processing and analysis of the collected data
(c) development of bathymetric plans

Instrumentation used	No. of survey-lines	Total length (km)	Line Order/ Orientation	Line spacing (m)	Research area
MBES, SBES	52	276	Parallel to the coastline	100	Southern part of the gulf of Patras

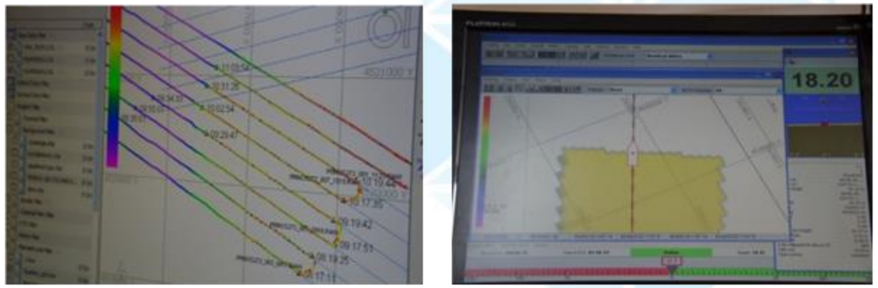
Map of the gulf of Patras presenting the vessel's bathymetric survey track lines

Marine Survey Equipment



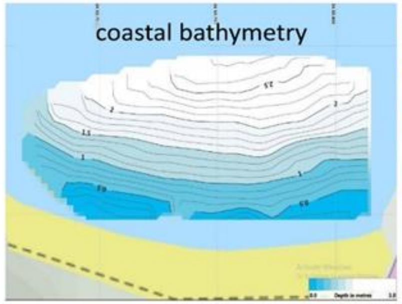


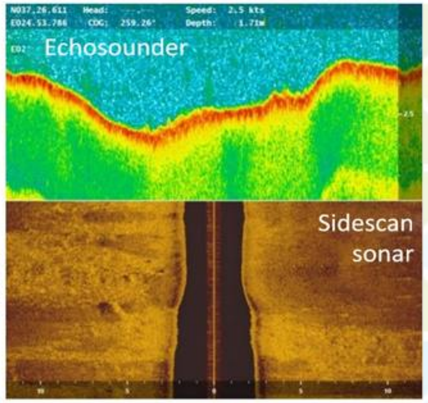
Leica GS08 RTK GNSS System (left image) and Hemisphere VS101 GPS (right image)

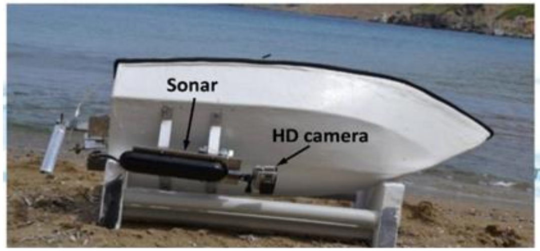


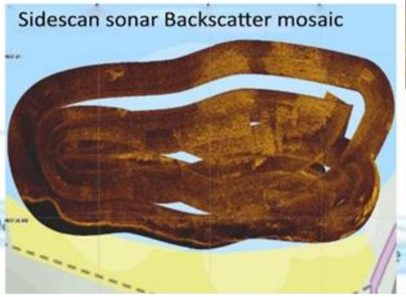
Hypack 2014 navigation software display

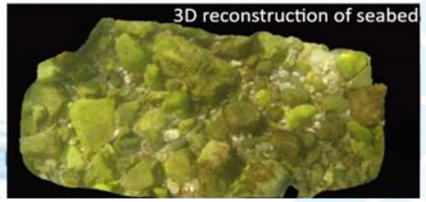
Unmanned Surface Vehicle Equipment (USV)











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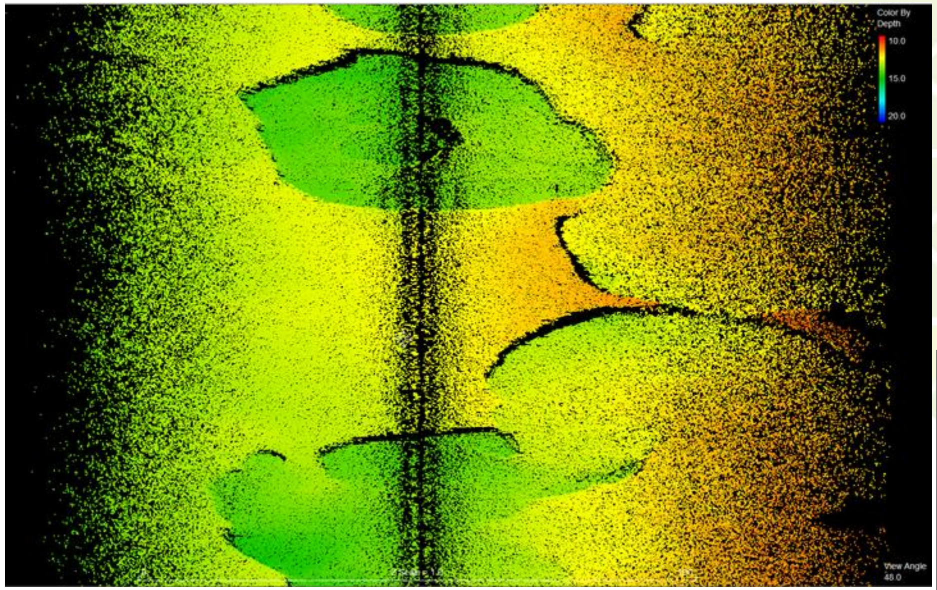
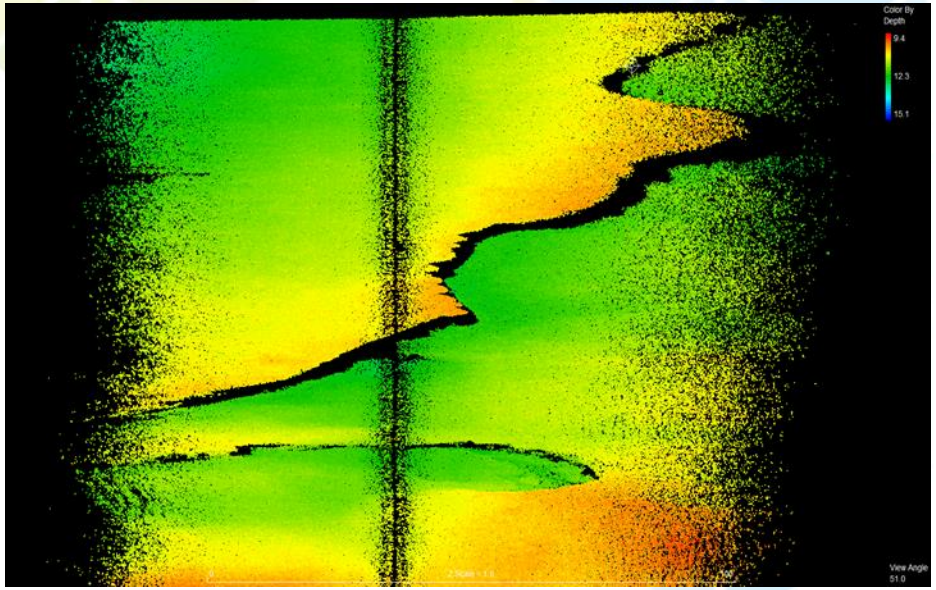
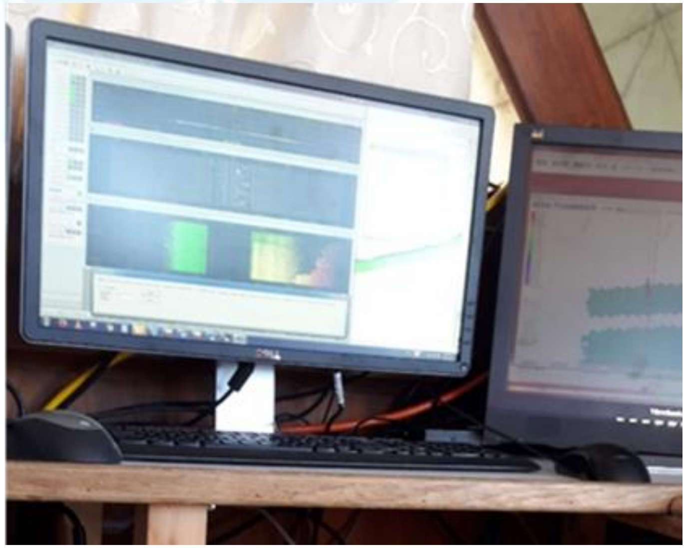
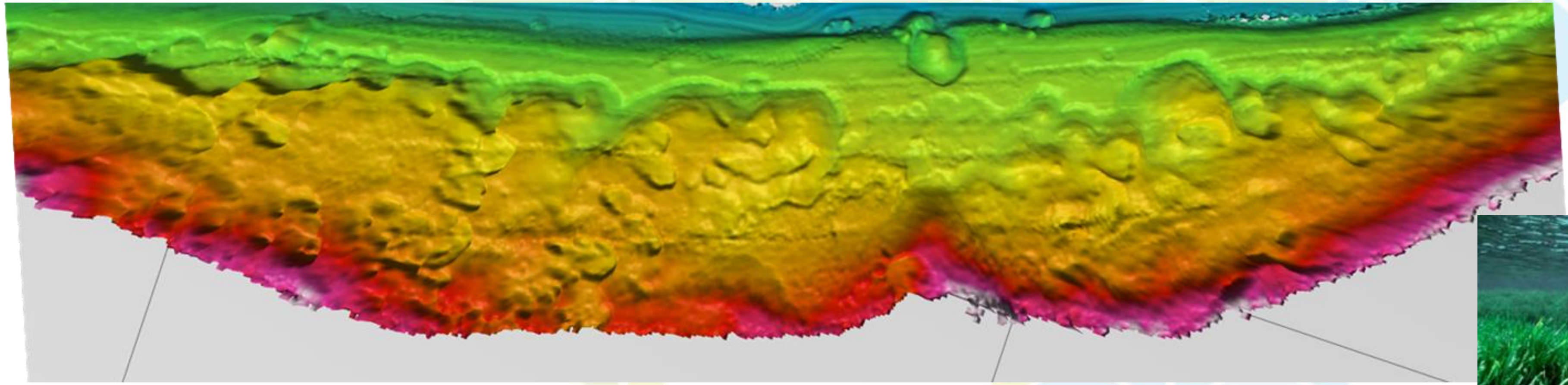
Data Acquisition

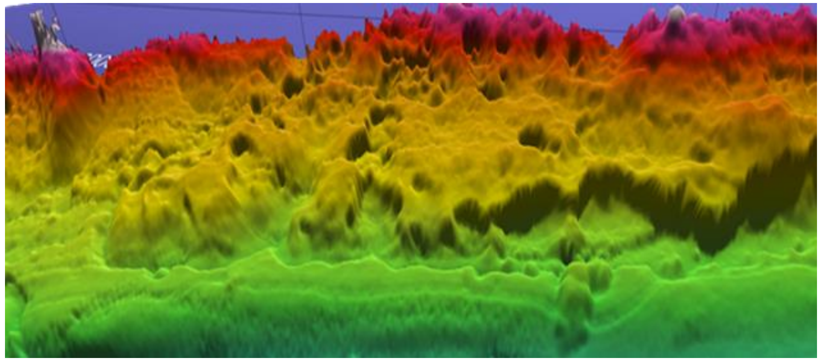




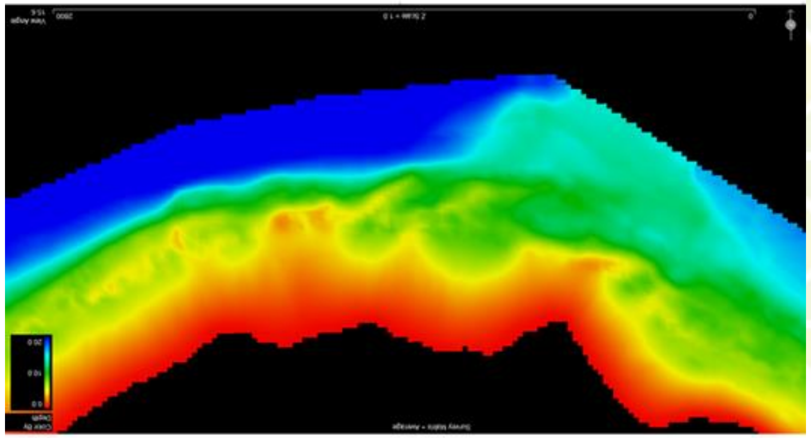


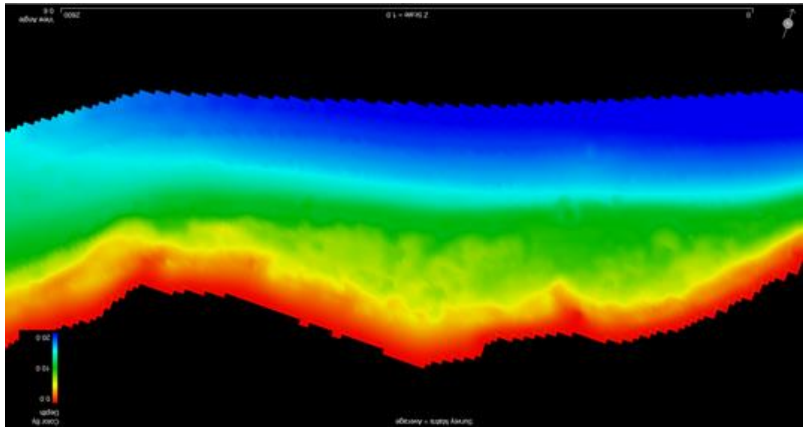
General Bathymetry of the Gulf of Patras

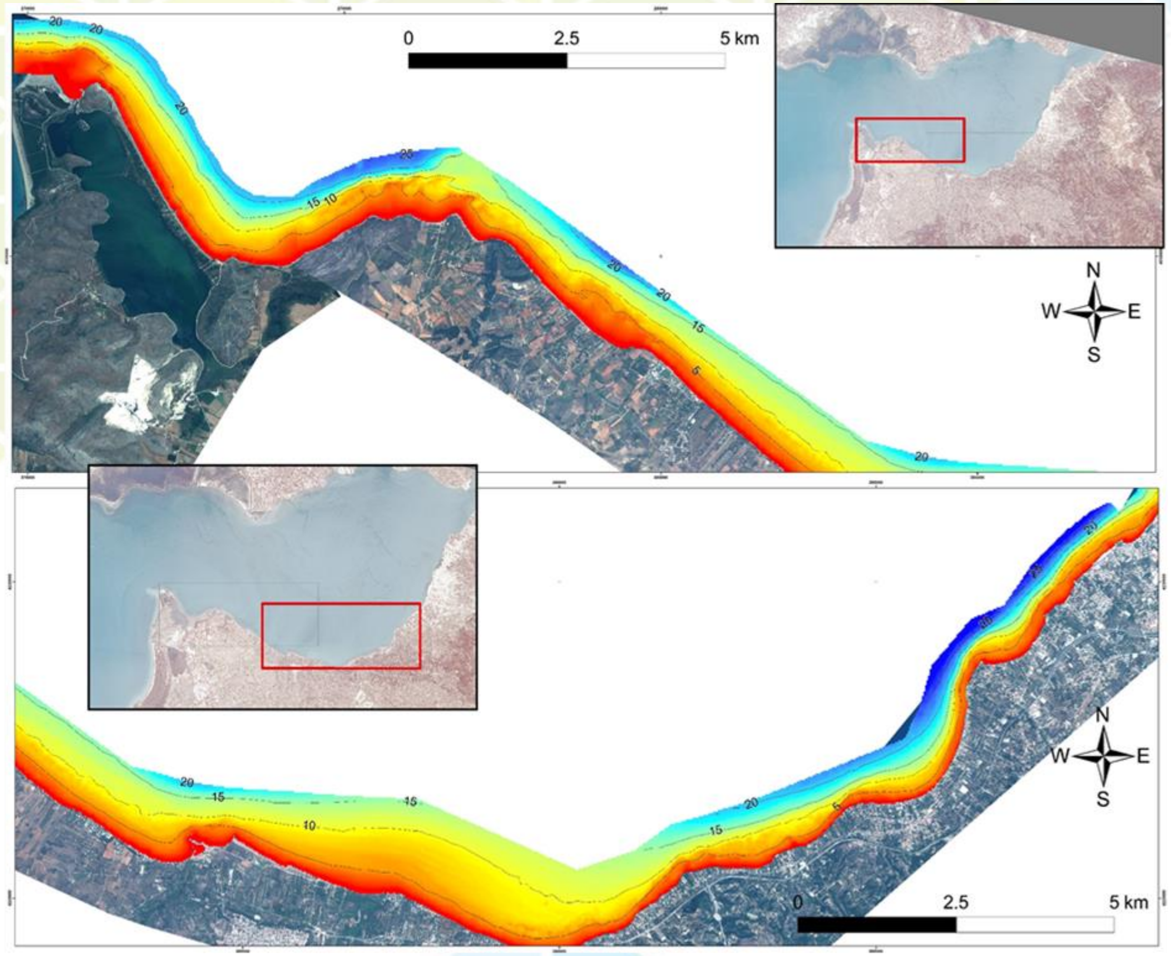




Digital Bathymetric Plans of the Gulf of Patras





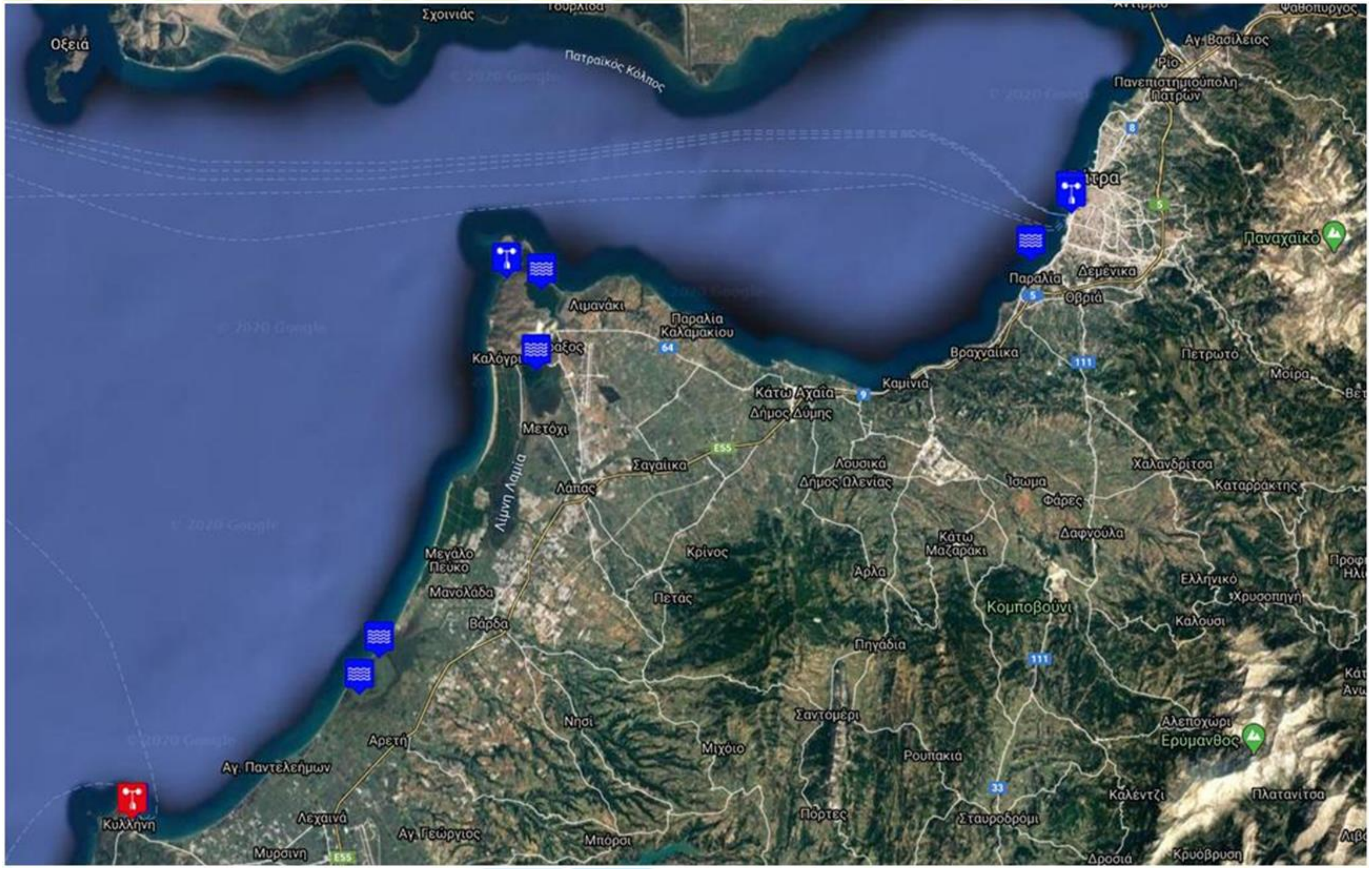


Bathymetric map of the coastal area of the Southern part of the gulf of Patras

ENVIRONMENTAL MONITORING IN THE PROTECTED AREAS

Processing of the data collected from the installed equipment and the environmental stations in

- The gulf of Patras and the Killini port
- The Management Body of Kotyhi Strofylia Wetlands & Kyparissia Gulf (Papas, Prokopos, Kotychi lagoons)



[1-2: weather station and marigraph in the new port of Patras; 3: wave buoy system in the gulf of Patras; 4-5: weather and water quality stations in the Papas lagoon; 6: water quality station in the Prokopos lagoon; 7-8: water quality stations in the Kotychi lagoon; 9-10: weather station and marigraph in the Killini port]

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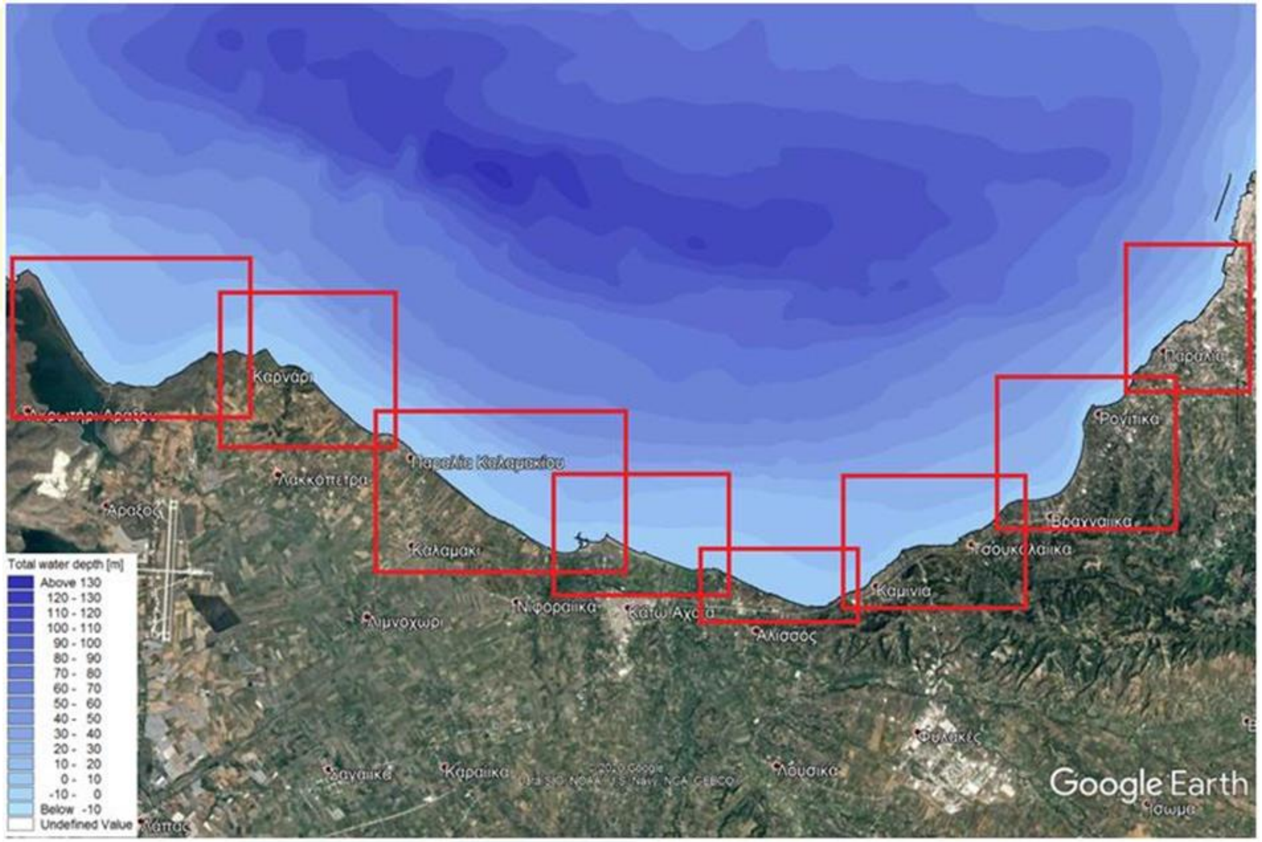
NUMERICAL STUDY OF WAVES, CURRENTS AND SEDIMENT TRANSPORT

<u>The pilot area of the gulf of Patras was divided into 8 coastal independent sub regions and numerical simulations included 4 stages:</u>

1. Determination of the wave climate in the deep waters due to NE, NW, W and SW winds
2. Numerical simulation of wave propagation for wind speed of 1-year return period for each wind direction
3. Numerical simulation of the magnitude and the direction of the wave-generated currents in the coastal zone of the gulf for each one of the wind cases of Stage 2
4. Numerical simulation of the magnitude and the direction of sediment transport in the coastal zone of the gulf for each one of the wind cases of Stage 2

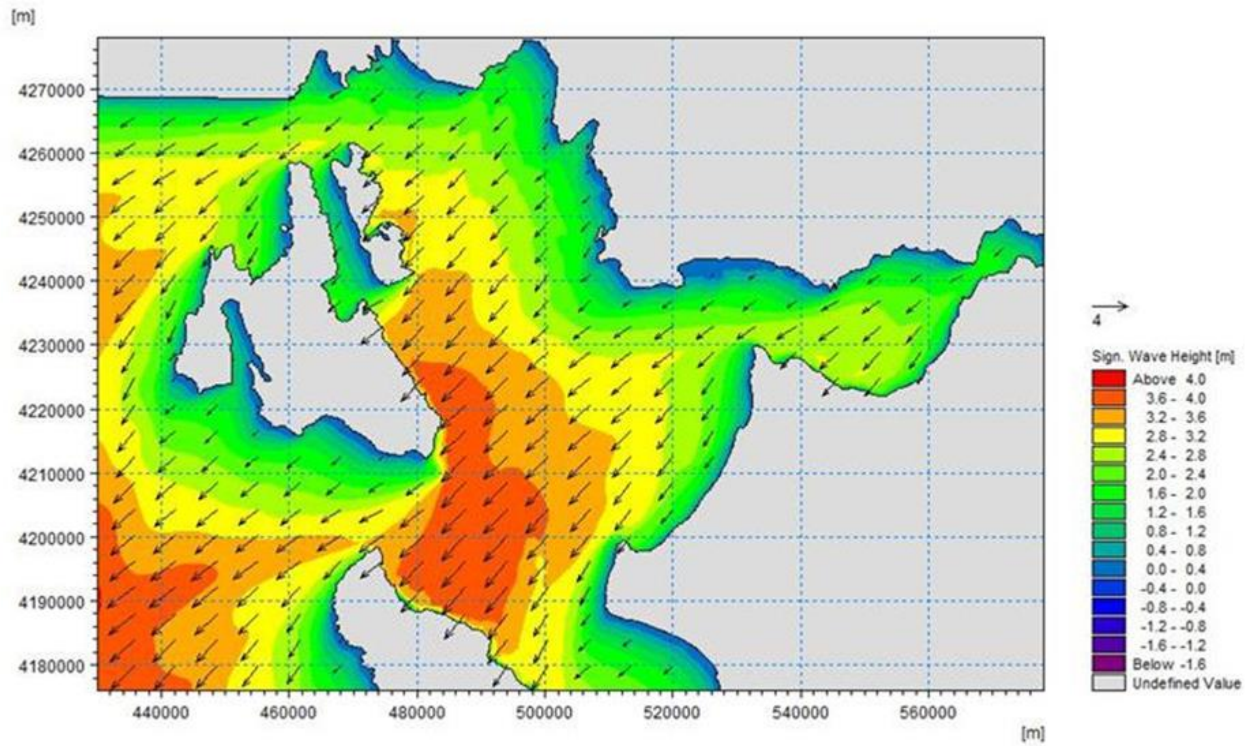


Satellite image (Google Earth) of the pilot area of the Gulf of Patras showing the 8 coastal independent subregions

Wave Development in the Gulf of Patras

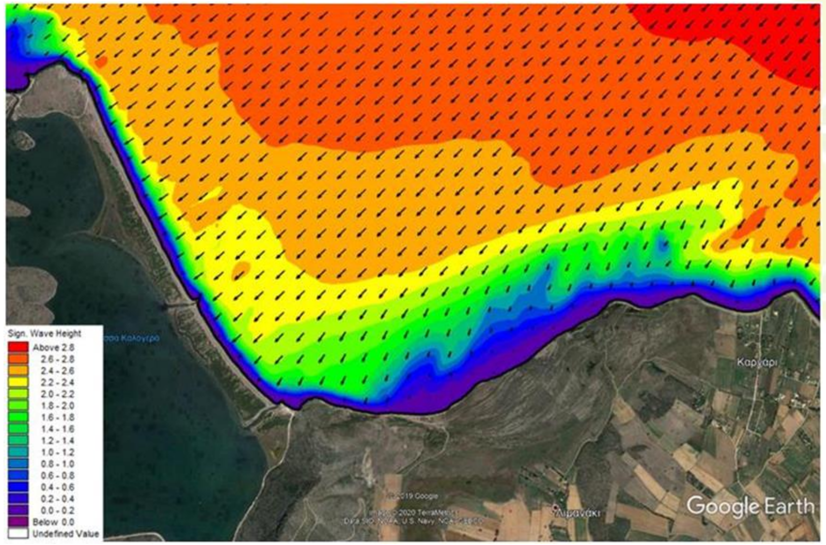
Wind and wave data with a return period of 1 year, per wind direction, in deep waters offshore of the coastal zone of the pilot area of the Gulf of Patras

HNMS Station		Nafpaktos		Araxos		
Wind Direction		**NE**	**E**	**NW**	**W**	**SW**
Wind Speed, U_{10}	**m/s**	18.9	10.3	9.3	13.0	11.6
Wind Intensity	**Beaufort**	8	5	5	6	6
Significant Wave Height, $H_{S\text{-}1yr}$	**m**	2.7	0.6	0.6	1.8	1.5
Wave Spectrum Peak Period, $T_{P\text{-}1yr}$	**s**	8	4.4	5	8	6.8
Wave Direction with respect to the North	**º**	45	60	315	270	235

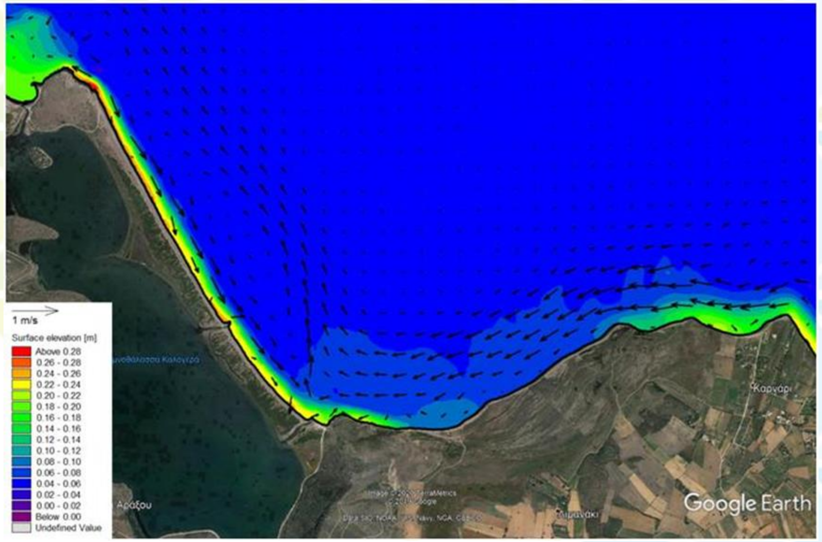


Wave height, velocity and direction distribution in the area of the Ionian Sea west of the Gulf of Patras due to the action of northeastern winds

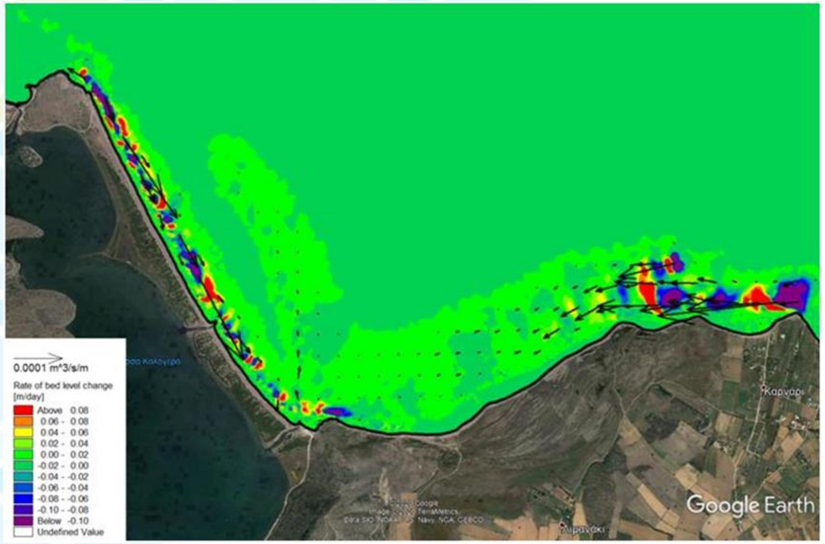
Coastal Erosion Vulnerability Assessment in the Gulf of Patras



Significant wave height and velocity (vectors) distribution due to northeastern waves in the coastal zone of subregion 1



Wave-generated currents (vectors) and wave setup due to northeastern waves in the coastal zone of subregion 1

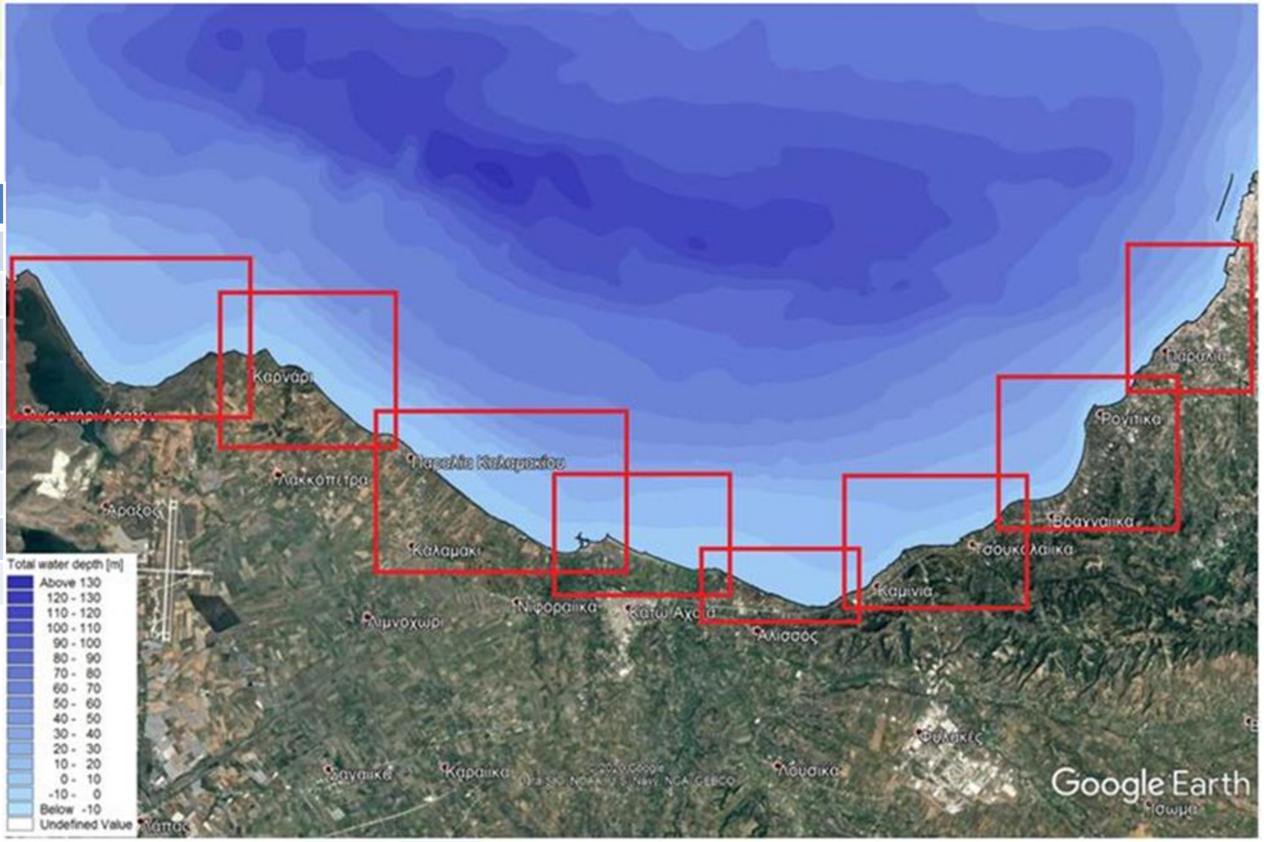


Bed level change due to northeastern waves in the coastal zone of subregion 1

Coastal Erosion Intensity in the Gulf of Patras

Characterization of the erosion intensity in the 8 subregions of the pilot area of the Gulf of Patras, for each wind direction, according to the numerical results of the present work

#	Subregion	NE	NW	W	SW
1	Papas Lagoon – Karnari	High	Low	Zero	Zero
2	Karnari – Ioniki Akti	High	Low	Zero	Zero
3	Ioniki Akti – Alykes	Moderate	Low	Zero	Zero
4	Alykes – Gialos	High	Low	Zero	Zero
5	Gialos – W. Kaminia	Moderate	Moderate	Low	Zero
6	W. Kaminia – W. Vrachneika	Moderate	High	Moderate	Zero
7	W. Vrachneika – Roitika	Low	High	High	Low
8	Roitika – Glafkos	Zero	High	High	Low



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PILOT CASES –
THE MUNICIPALITY OF UGENTO IN APULIA REGION

The TRITON pilot case of the Municipality of Ugento

(Apulia Region, Italy)

Apulia region

- 970 km of coastline (mostly flat, sandy beaches)
- 13.8% characterized by marine protected areas, national and regional parks

Regional Coastal Plan

- Shoreline analysis (2005-2017 timeframe)
- Identification of 7 Physiographic Units
- Analysis performed within a 10 m buffer zone

Municipality of Ugento

- ✓ Selected as best practice for coastal erosion management within the **TRITON** project
- ✓ Integration of nature-based solutions (NBS) to address coastal erosion risk

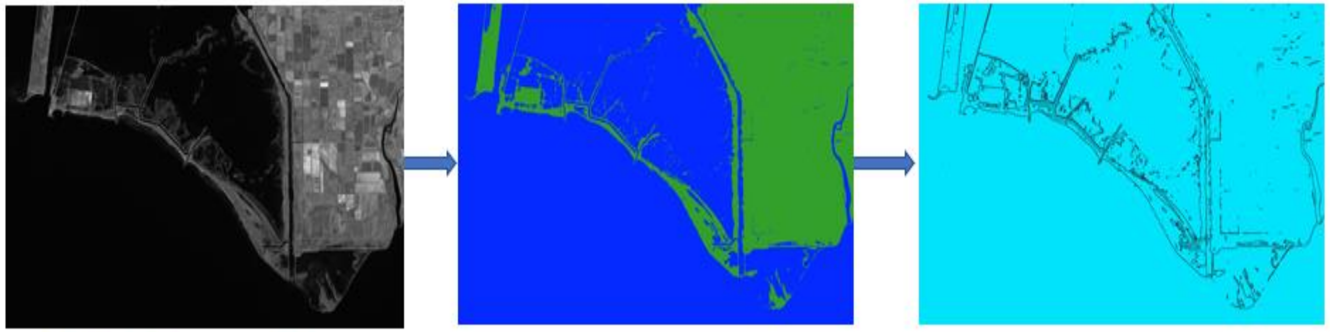
Project co-funded by European Union, European Regional Development Funds (E.R.D.F.) and by National Funds of Greece and Italy

Data collection

Variable	BN name	Unit	Original data		Type
			Time range	Temporal resolution	
Sea surface height above geoid	SLR	[m]	1987-12/16/2018	dd	Oceanic drivers
Eastward sea water velocity	ESV	[m s^{-1}]	1987-12/16/2018	dd	
Northward sea water velocity	NSV	[m s^{-1}]	1987-12/16/2018	dd	
Wave direction from	WAD	[degree]	2006-01/01/2019	hh	
Wind wave direction from	WID	[degree]	2006-01/01/2019	hh	
Significant wave height	WAH	[m]	2006-01/01/2019	hh	
Significant wind wave height	WIH	[m]	2006-01/01/2019	hh	
Sea surface wave mean period	WAP	[s]	2006-01/01/2019	hh	
Sea surface wind wave mean period	WIP	[s]	2006-01/01/2019	hh	
Incident wave energy at the breaker zone	IWE	[J m-1 s-1]	2009-2018	yy	
Infrastructures	IFS	[0 or 1]	2009-2018	yy	Management measures
Nature-based solutions	NBS	[0 or 1]	2009-2018	yy	
Shoreline evolution	SEV	[m]	2009-2018	yy	Assessment endpoints
Suspended Matter	SPM	[gm^{-3}]	1997-01/06/2019	mm	
Diffuse Attenuation	KD	[m^{-1}]	1997-01/06/2019	mm	

Project co-funded by European Union, European Regional Development Funds (E.R.D.F.) and by National Funds of Greece and Italy

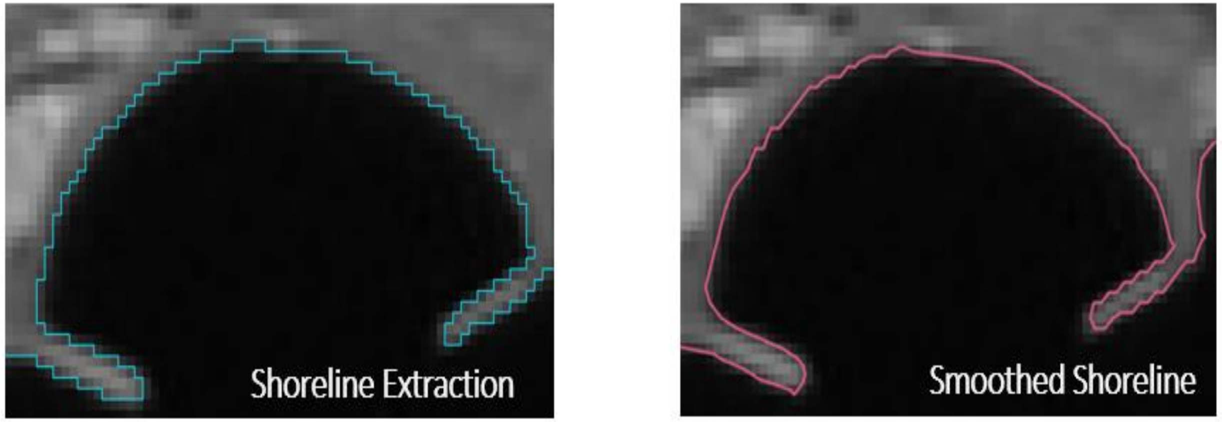
Data pre-processing: *Shoreline Evolution Analysis*



Satellite Image – Near Infrared Band

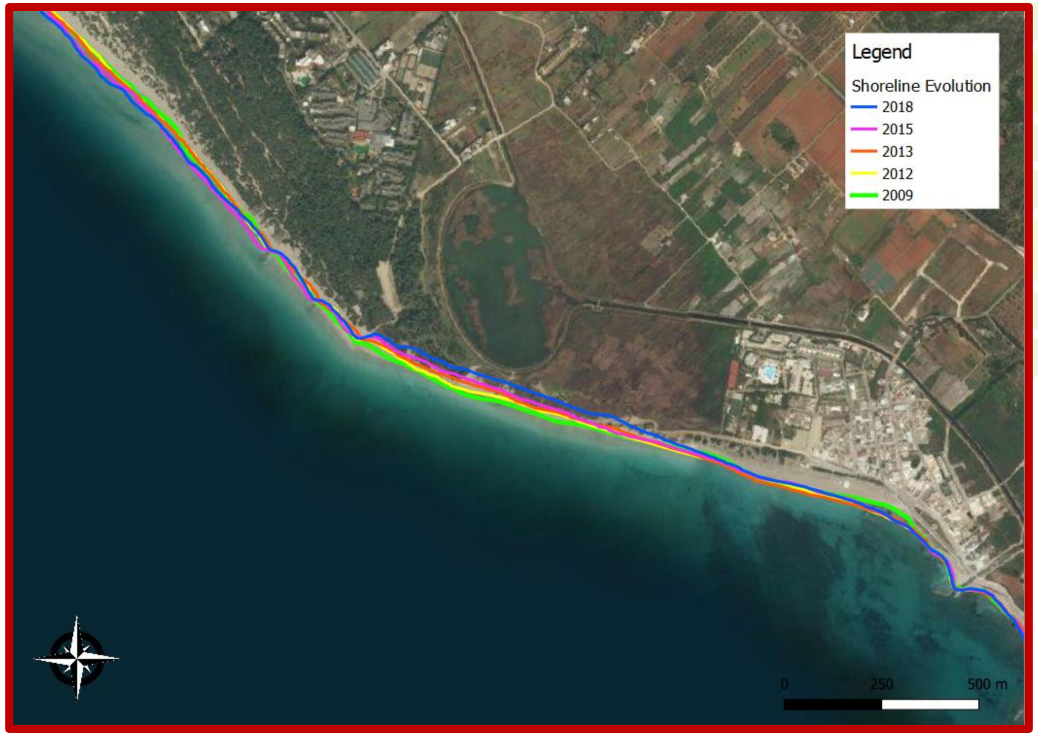
Classified Image (Land - Sea)

Raster to Vector



Data pre-processing

Shoreline Evolution Analysis



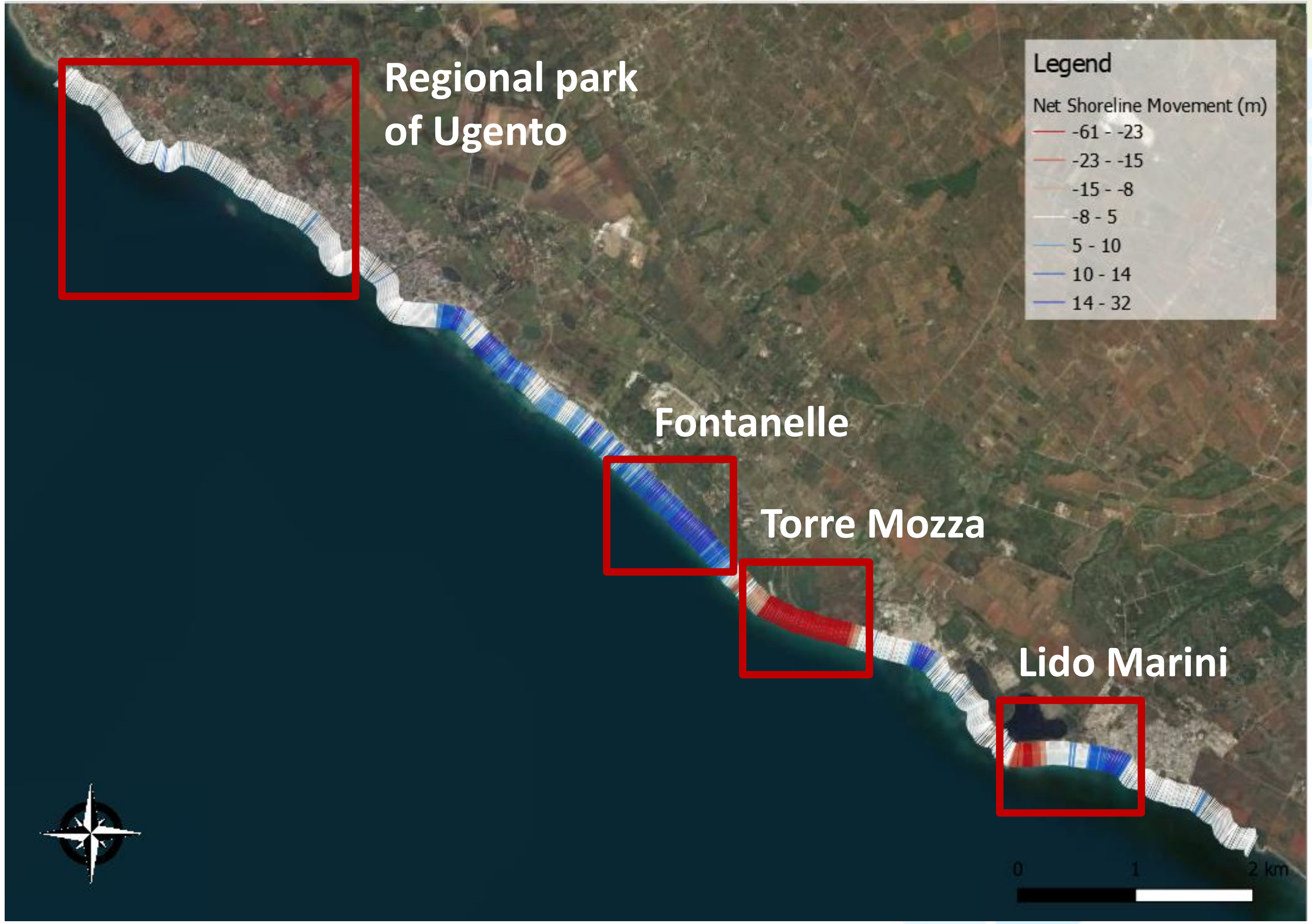
Data Products	Resolution	Year of Image Acquisition	Source
RapidEye	5 m	07/05/2009 24/08/2012 28/10/2013 06/08/2015 20/07/2018	Planet Explorer Beta www.planet.com/explorer

Data pre-processing: *Shoreline Evolution Analysis*

Application of the DSAS (Digital Shoreline Analysis System) tool provided by the USGS

- 10 m distance among transects

DSAS tool



OUTPUT

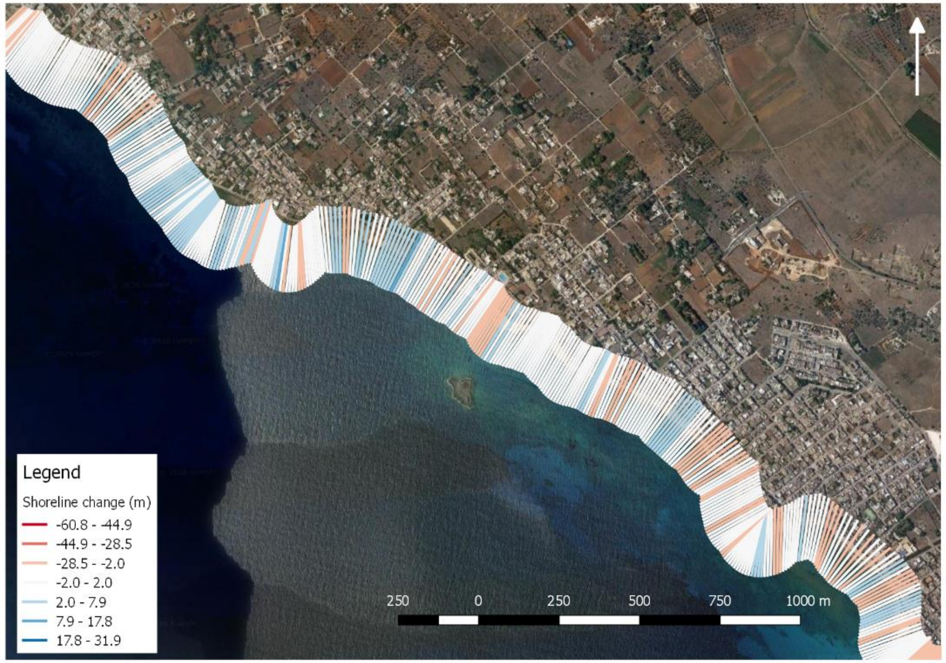
Net Shoreline Movement (**NSM**)

Distance between the oldest and the earliest shorelines for each transect

➢ **Ugento case study**

Data pre-processing: *Net Shoreline Movement*

Regional park
Of Ugento



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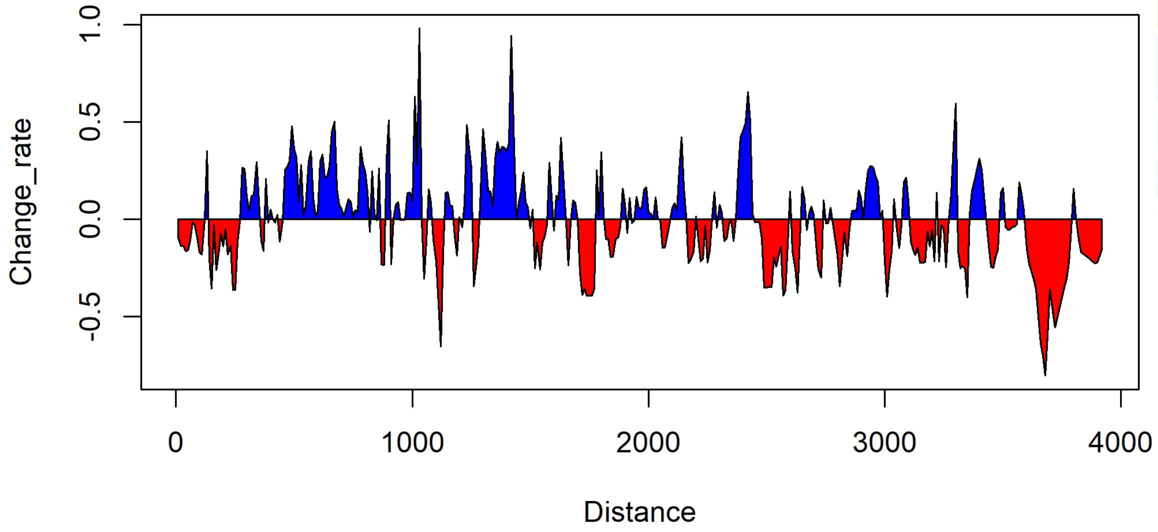
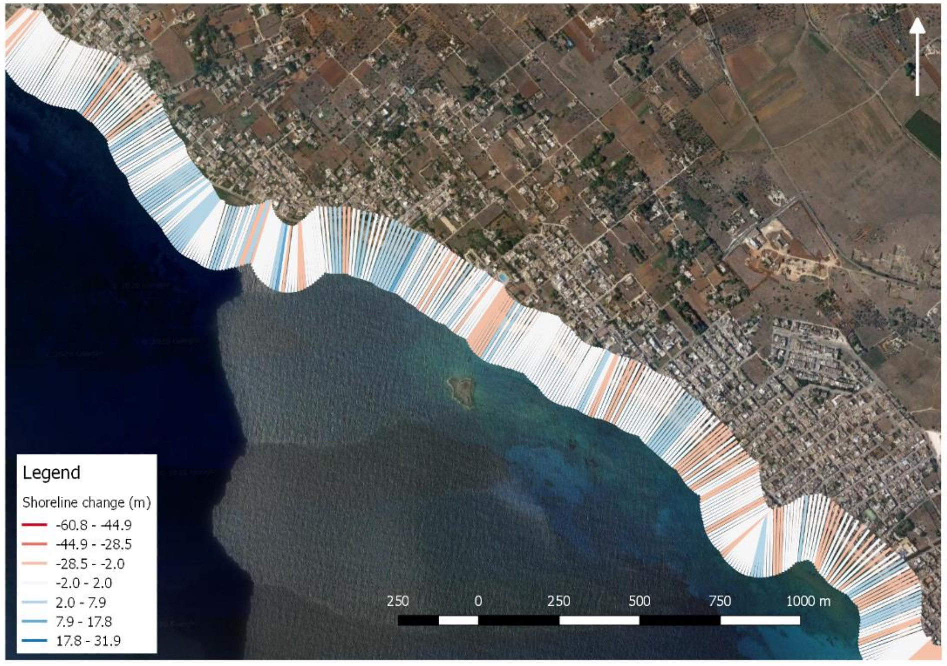
Data pre-processing: *Net Shoreline Movement*

Regional park
Of Ugento





The geomorphology of the Regional park of Ugento is mostly rocky.

The shoreline evolution trend is mostly **STABLE**.

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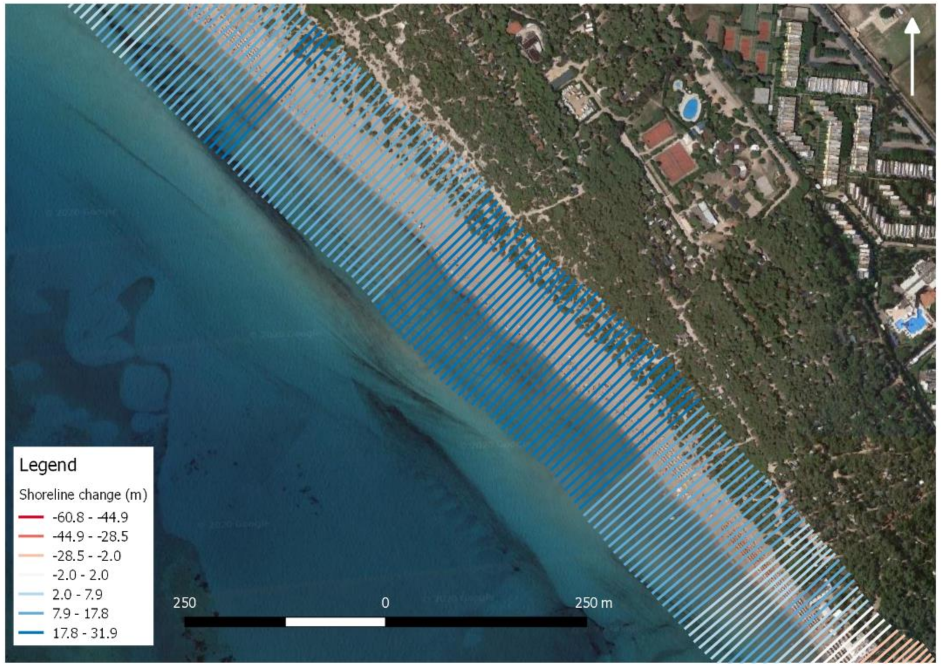
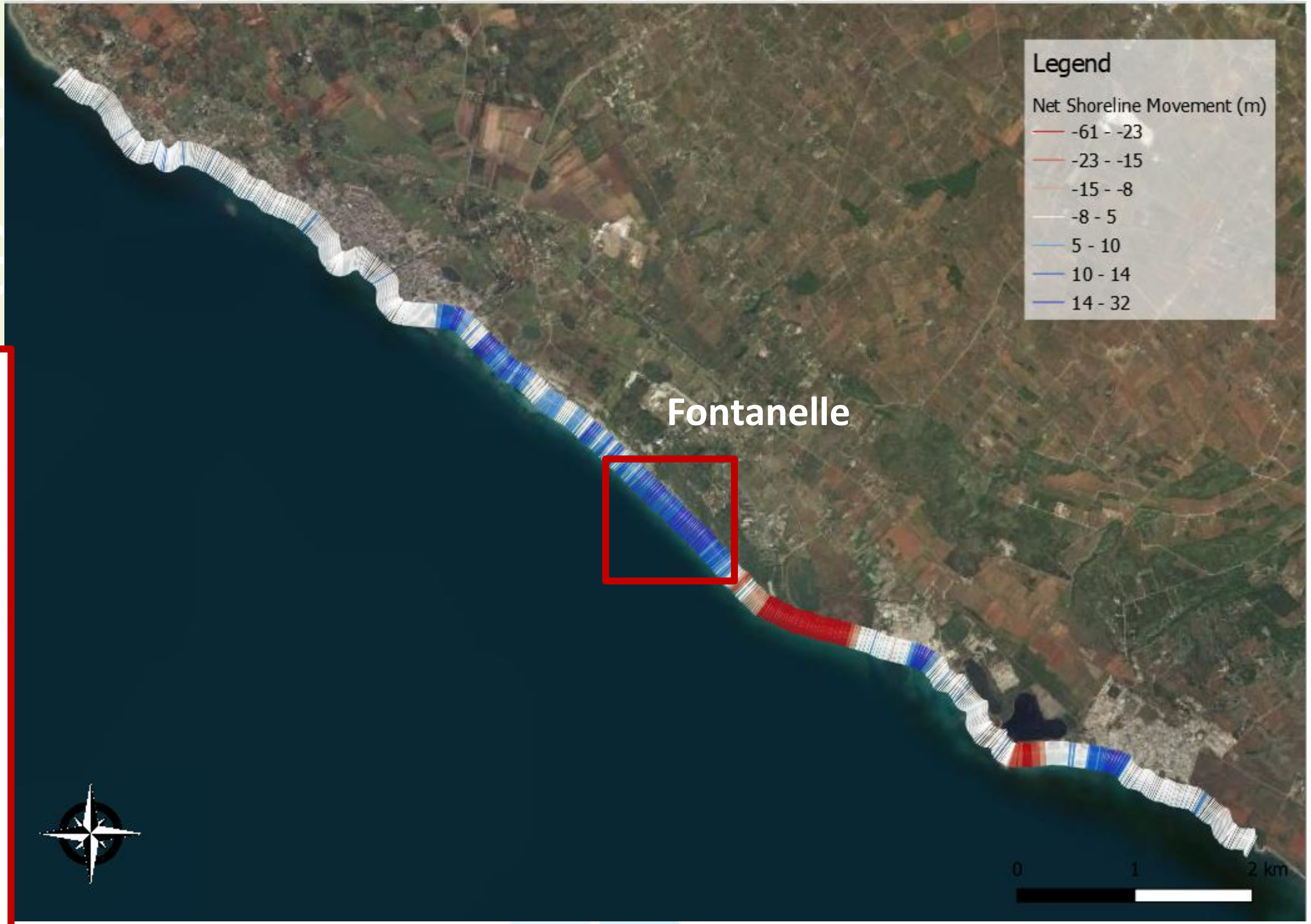
Data pre-processing: *Net Shoreline Movement*

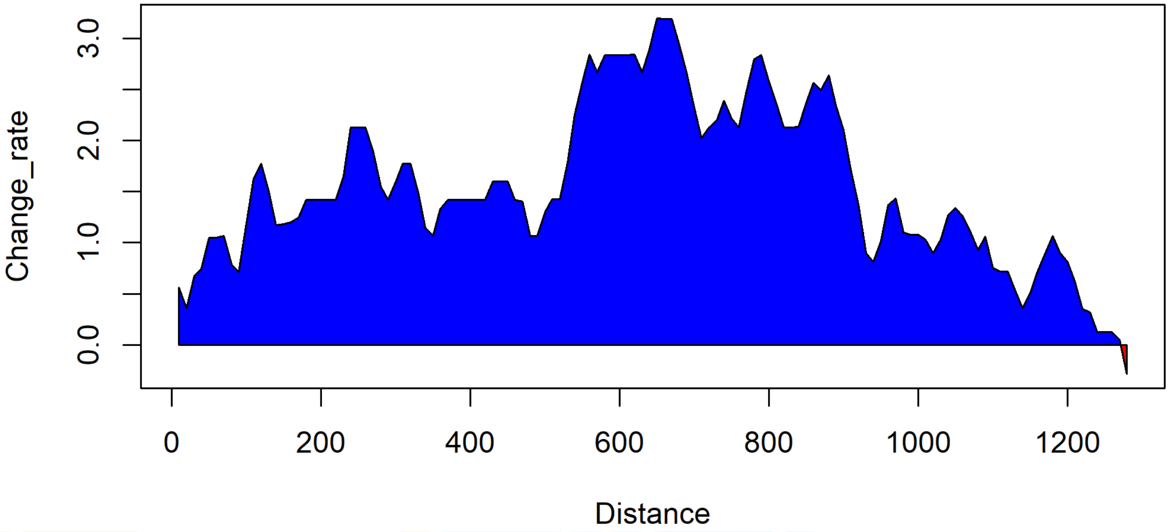
Fontanelle

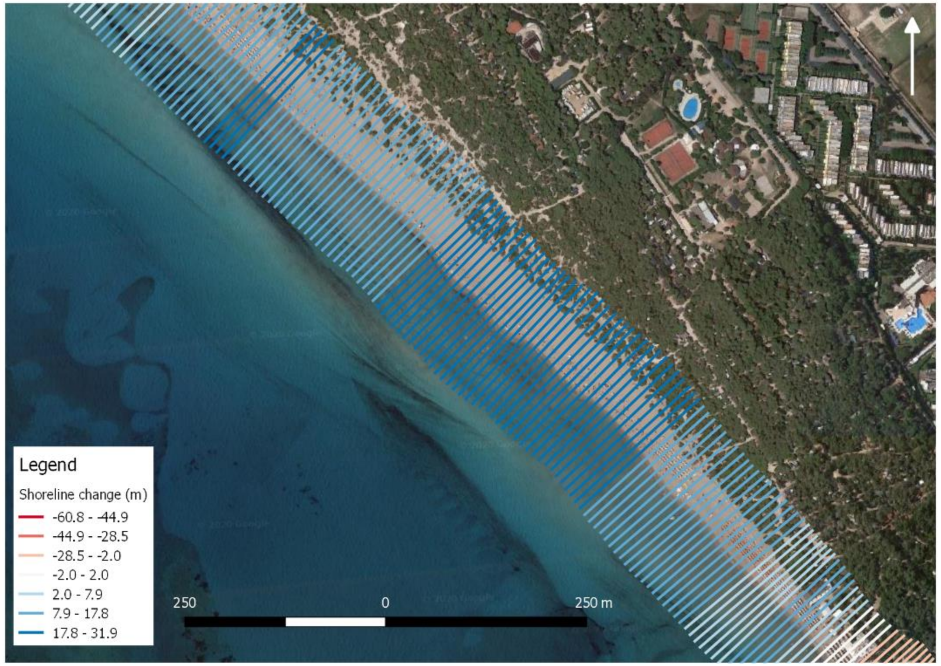




Data pre-processing: *Net Shoreline Movement*

Fontanelle

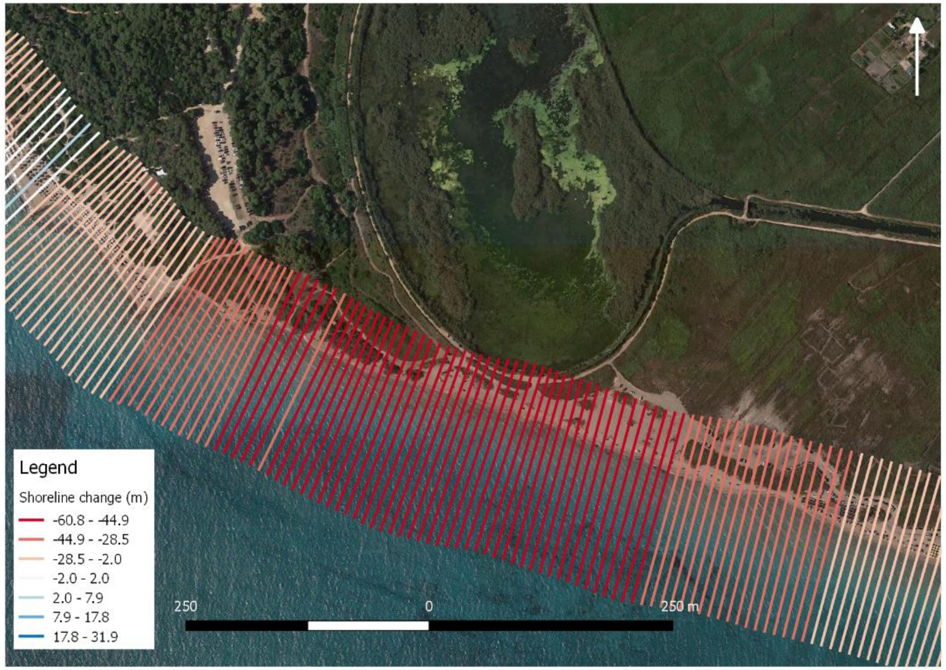




The sandy shoreline of Fontanelle is **ADVANCING**.

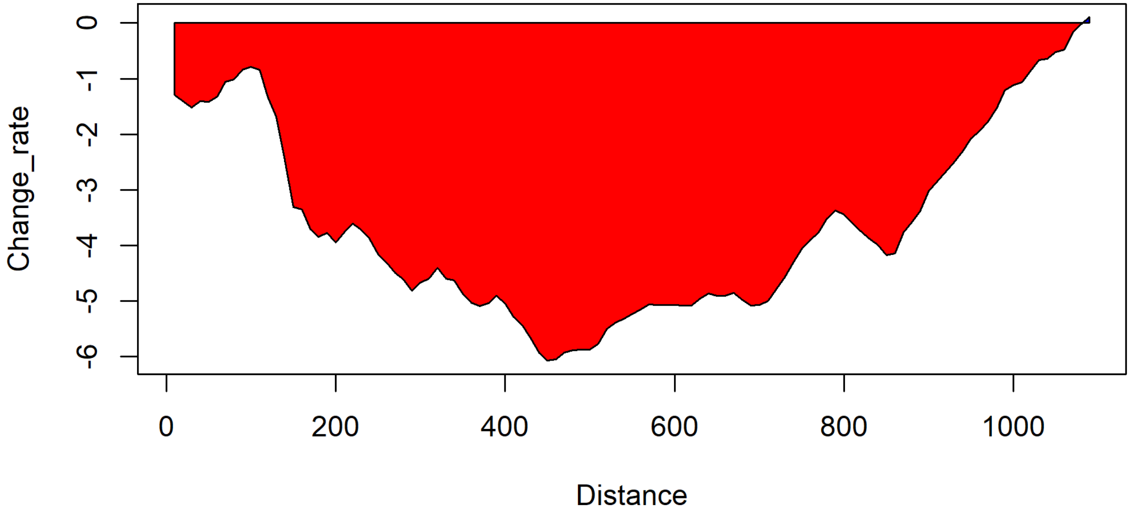
Data pre-processing: *Net Shoreline Movement*

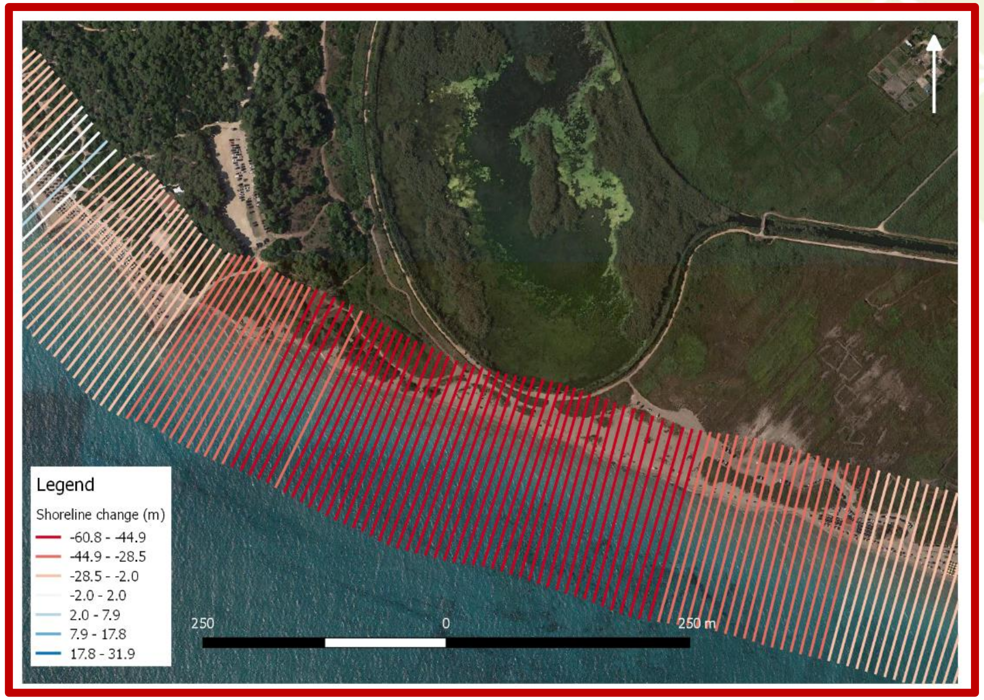
Torre Mozza



Data pre-processing: *Net Shoreline Movement*

Torre Mozza

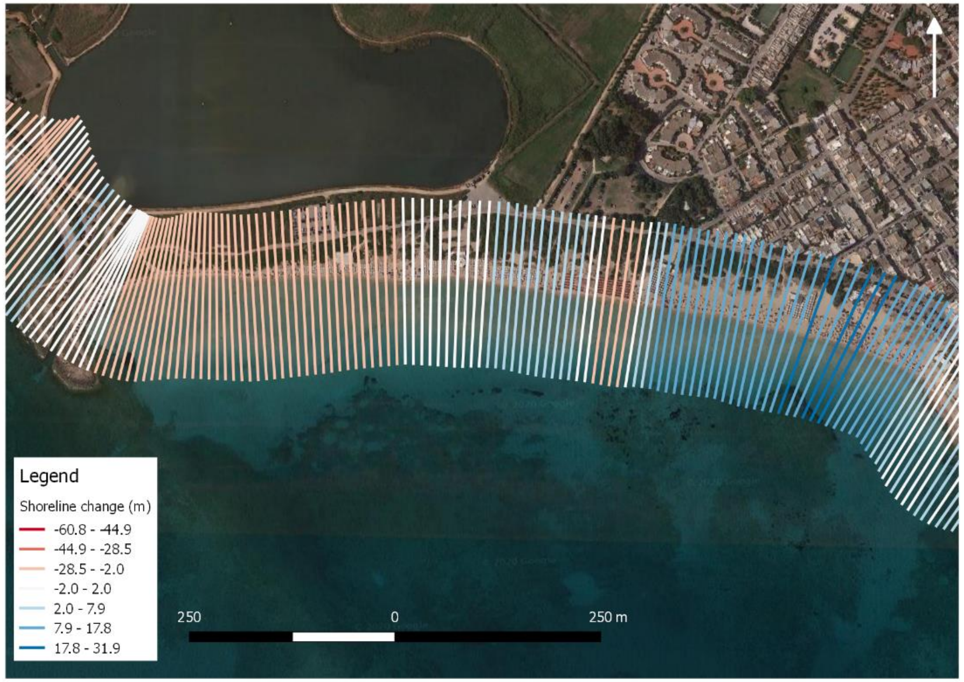




The sandy shoreline of Torre Mozza is **RETREATING**.

Data pre-processing: *Net Shoreline Movement*

Lido Marini



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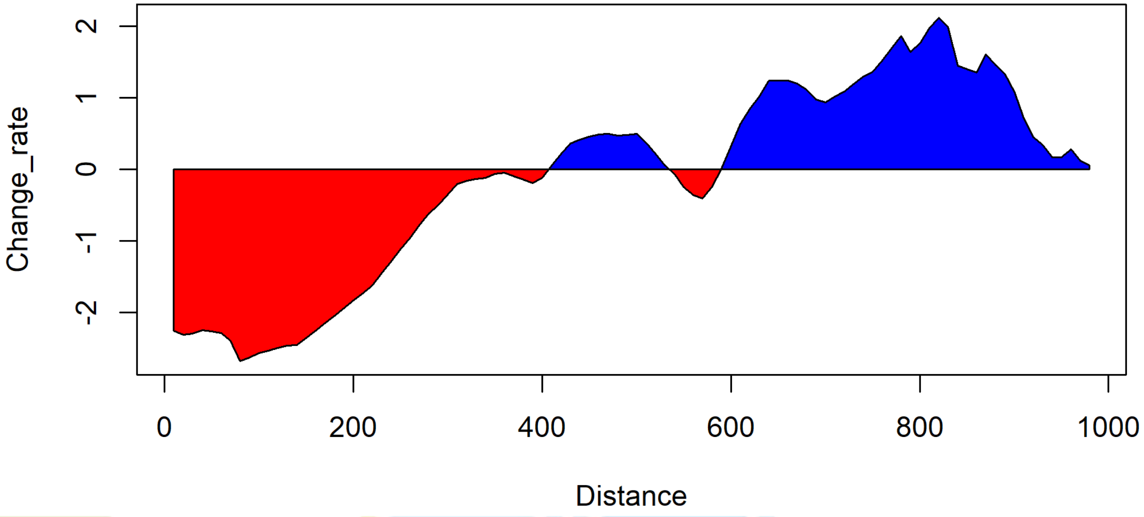
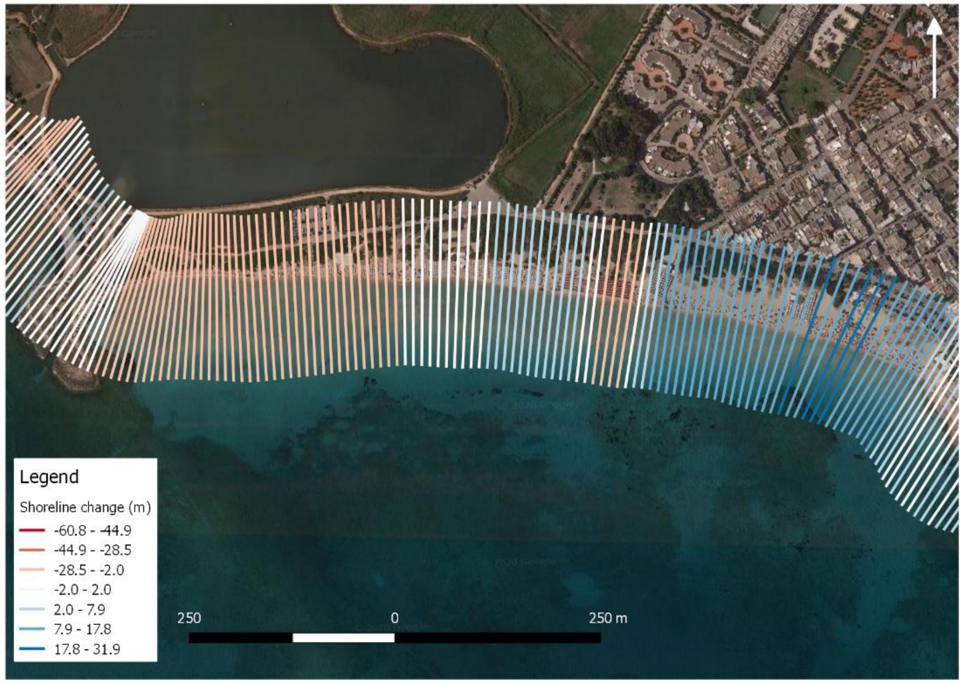
Data pre-processing: *Net Shoreline Movement*

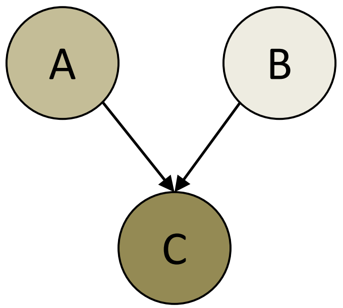
Lido Marini

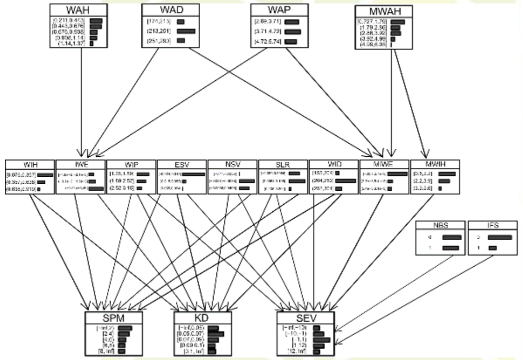


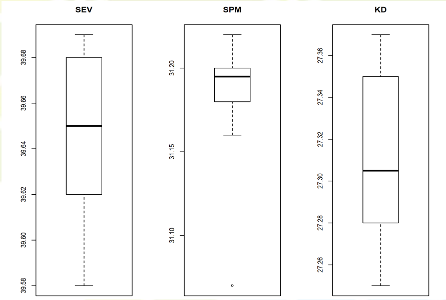


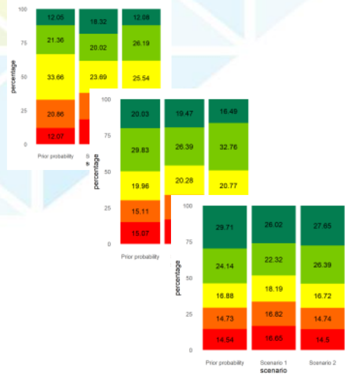
The sandy shoreline of Lido Marini has a mixed trend: **RETREATING** and **ADVANCING**.

Methodological steps for BN implementation









CONCEPTUAL MODEL:

Define the structure of the network and identify its main variables and relationships represented by using a conceptual/ influence **'nodes and arrow'** diagram, and by applying different learning processes to automatically extract the network structure.

MODEL PARAMETRIZATION:

Define **states** for all variables (interval, boolean, labelled) and calculate the associated **prior probability** resulting from data distribution as well relationships between nodes described by the **conditional probability** distributions.

CALIBRATION and VALIDATION:

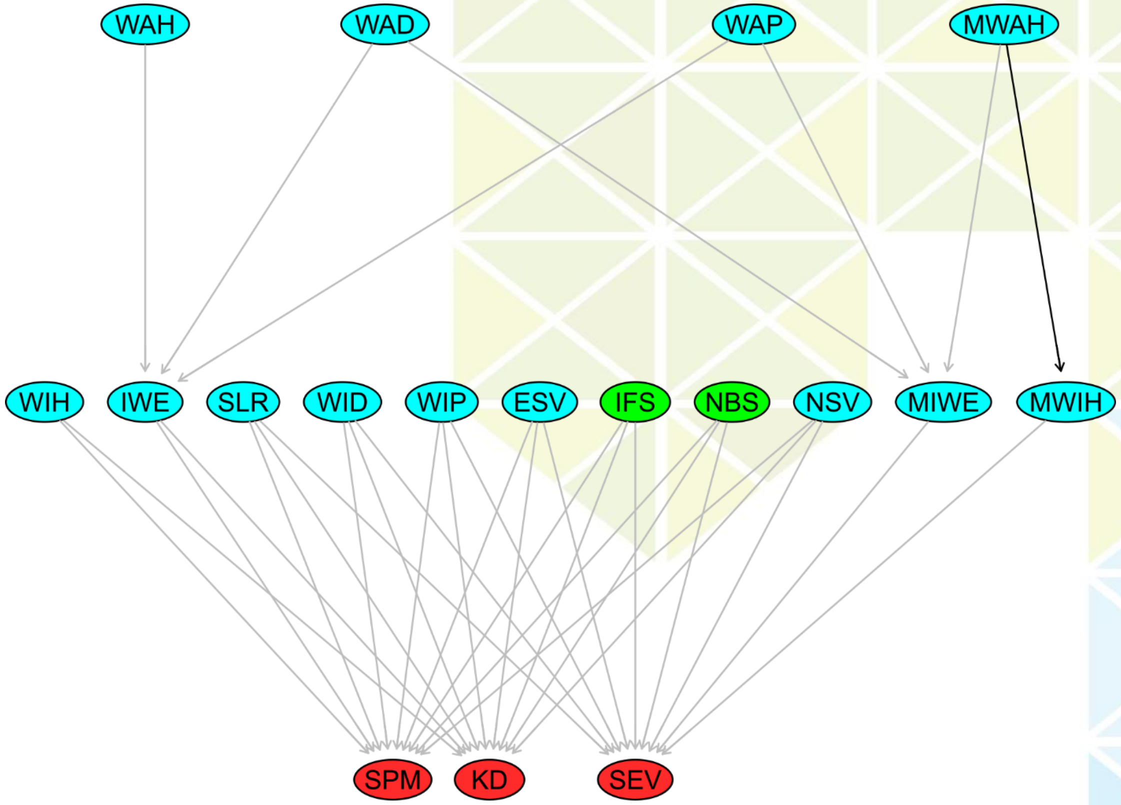
Evaluate the performance/ prediction accuracy of the BN model through two different types of validation methods:

- the data-based validation;
- the qualitative evaluation.

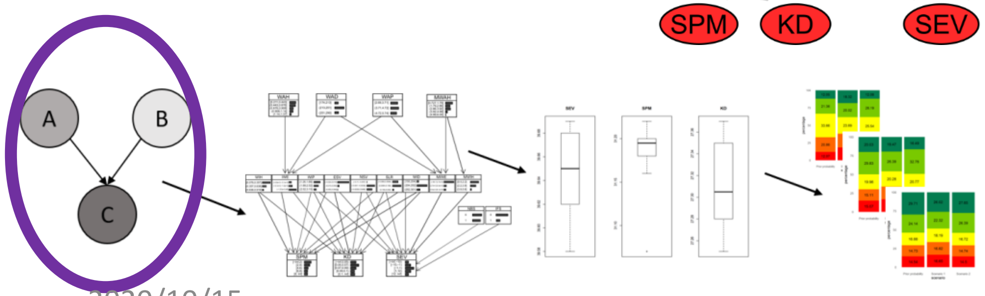
SCENARIOS ANALYSIS:

By inferring behavior of the variables at stake against different conditions defined by setting specific state/s of a node/s (**evidence**) and then propagating information between nodes based on the Bayes theorem, thus resulting in **the posterior probability.**

BN methodology – *BN design*



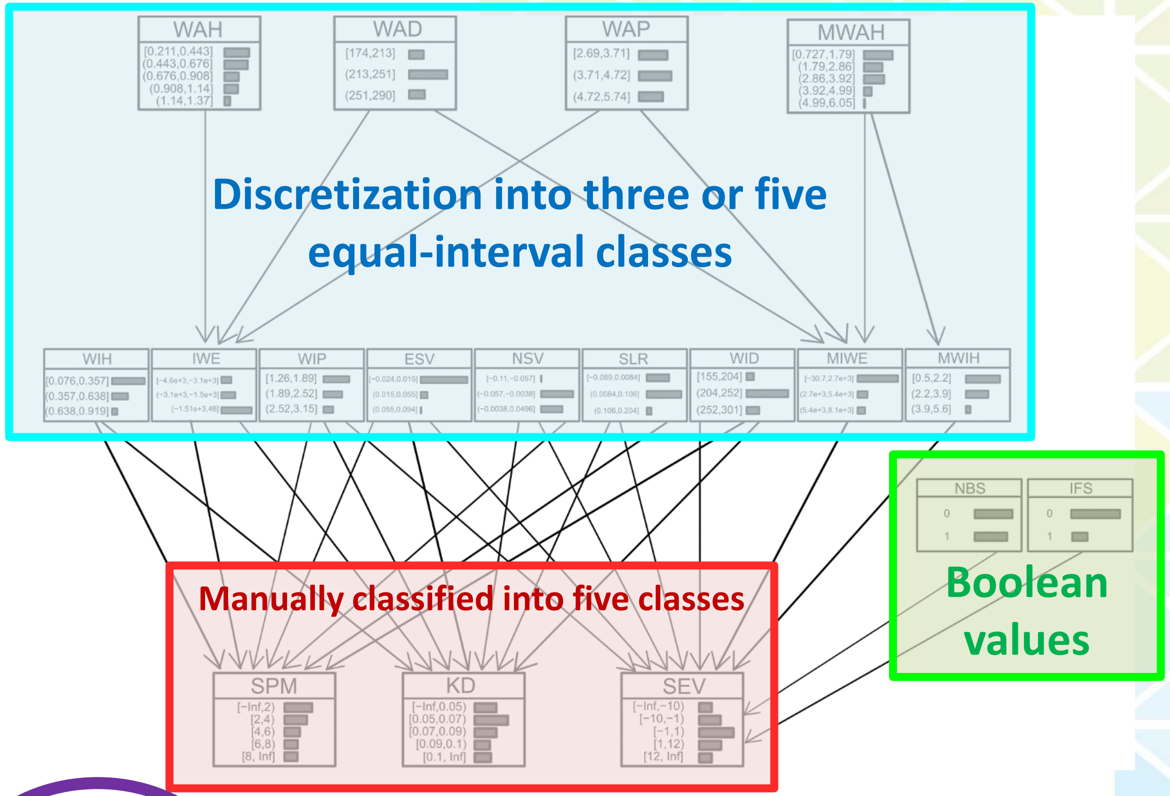
Acronym	Unit	Variable
KD	[m^{-1}]	Diffuse attenuation
ESV	[$m\ s^{-1}$]	Eastward sea water velocity
IWE	[$J\ m^{-1}\ s^{-1}$]	Incident wave energy at the breaker zone
IFS	[0 or 1]	Infrastructures
MWAH	[m]	Max significant wave height
MWIH	[m]	Max significant wind wave height
MIWE	[$J\ m^{-1}\ s^{-1}$]	Max incident wave energy at the breaker zone
NBS	[0 or 1]	Nature-based solutions
NSV	[$m\ s^{-1}$]	Northward sea water velocity
SSH	[m]	Sea surface height
WAP	[s]	Sea surface wave mean period
WIP	[s]	Sea surface wind wave mean period
SEV	[m/year]	Shoreline evolution
WAH	[m]	Significant wave height
WIH	[m]	Significant wind wave height
SPM	[$g\ m^{-3}$]	Suspended matter
WAD	[degree]	Wave direction from
WID	[degree]	Wind wave direction from



Oceanographic drivers
Management measures
Assessment endpoints

Project co-funded by European Union, European Regional Development Funds (E.R.D.F.) and by National Funds of Greece and Italy

BN methodology – *BN parametrization*



Acronym	Unit	Variable
KD	[m^{-1}]	Diffuse attenuation
ESV	[m s^{-1}]	Eastward sea water velocity
IWE	[J m^{-1} s^{-1}]	Incident wave energy at the breaker zone
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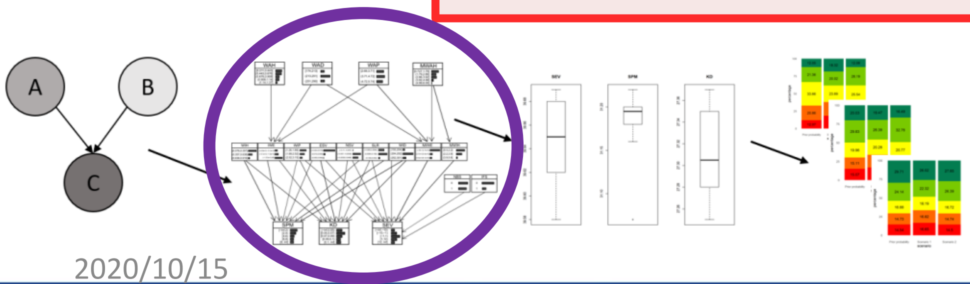


Oceanographic drivers
Management measures
Assessment endpoints

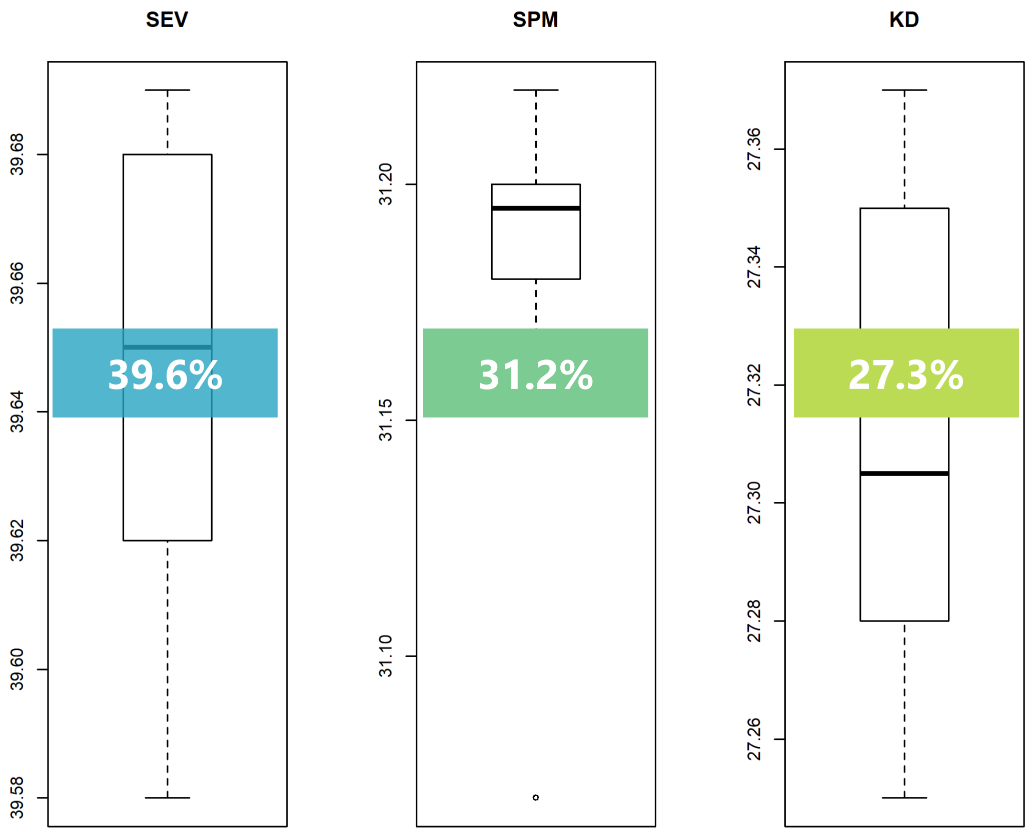
Project co-funded by European Union, European Regional Development Funds (E.R.D.F.) and by National Funds of Greece and Italy

BN methodology – *BN calibration and validation*

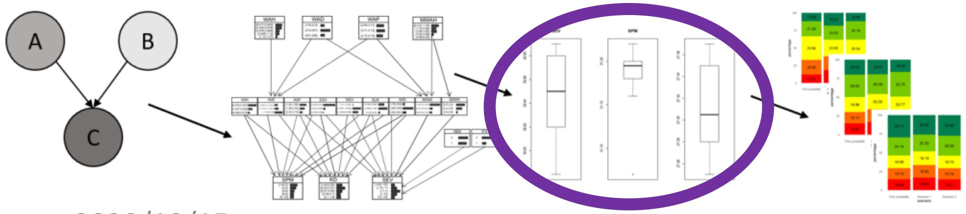
Model validation

✓*k-fold cross-validation (k-cv)*

✓*mean classification error vs. 10-folds*



Mean prediction error



BN methodology – *Scenario analysis*

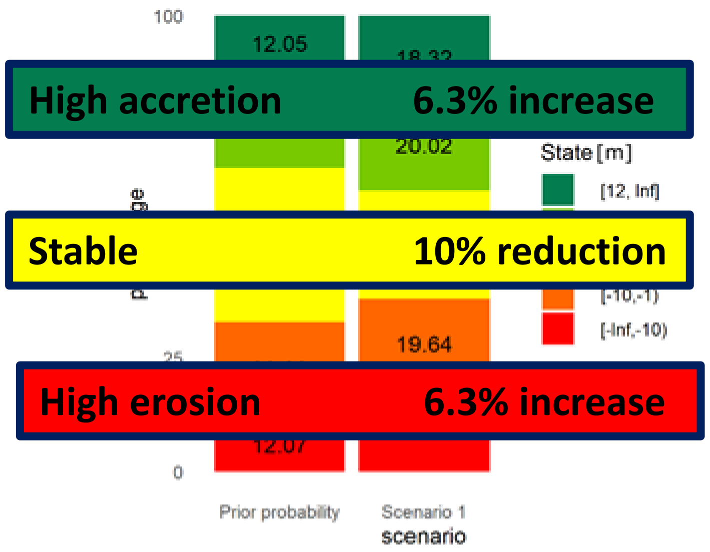
Scenario 1: ***A rapid changing world***

100% probability of the highest state related to:

- maximum significant wave height (4.99, 6.05] m
- mean significant wave height (1.14, 1.37] m

Scenario 2: ***Green is the new black***

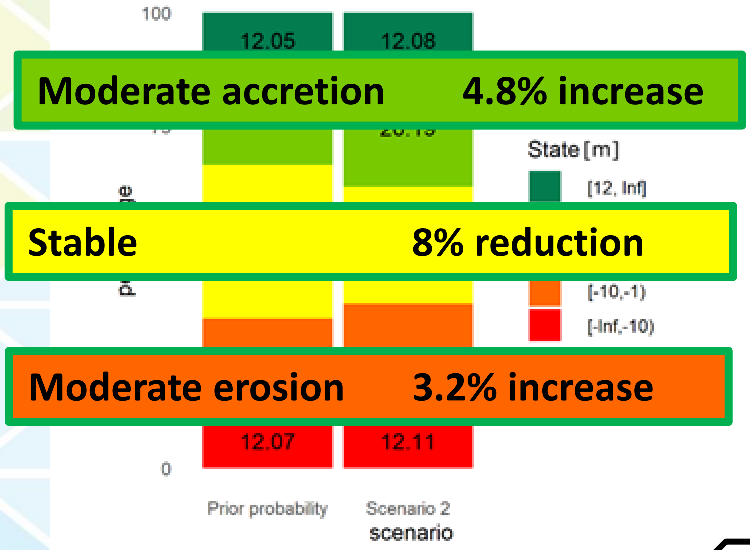
100% probability of implementing NBSs along the shoreline



High accretion 6.3% increase

Stable 10% reduction

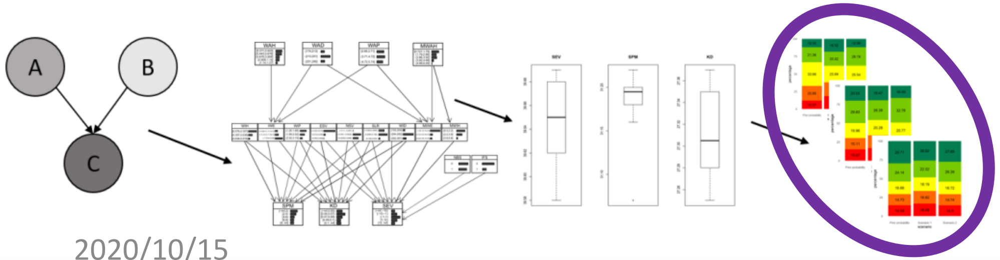
High erosion 6.3% increase



Moderate accretion 4.8% increase

Stable 8% reduction

Moderate erosion 3.2% increase



SHORELINE EVOLUTION

BN methodology – *Scenario analysis*

Scenario 1: ***A rapid changing world***

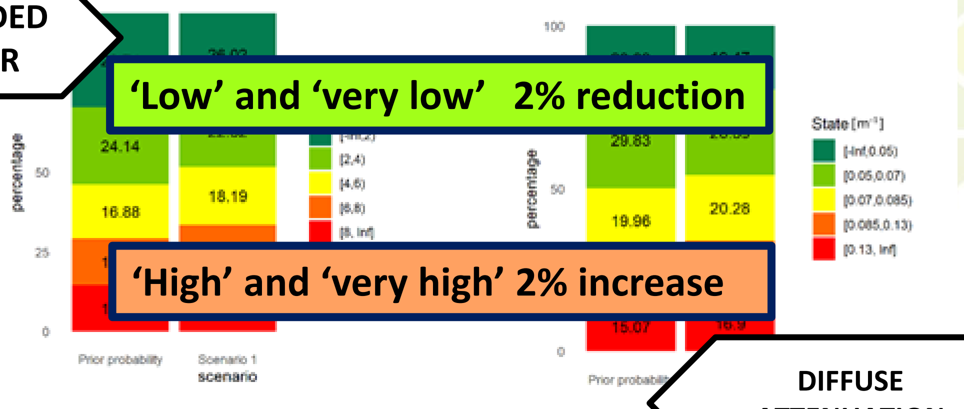
100% probability of the highest state related to:

- maximum significant wave height (4.99, 6.05] m
- mean significant wave height (1.14, 1.37] m

Scenario 2: ***Green is the new black***

100% probability of implementing NBSs along the shoreline

SUSPENDED MATTER

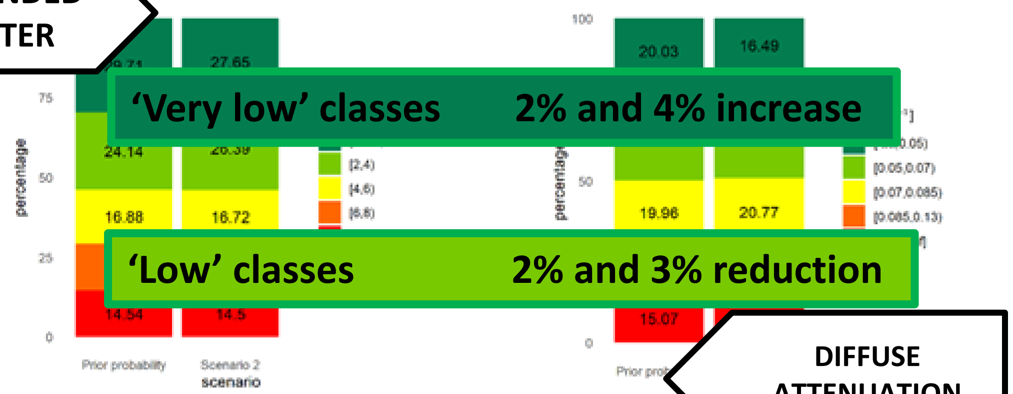


'Low' and 'very low' 2% reduction

'High' and 'very high' 2% increase

DIFFUSE ATTENUATION

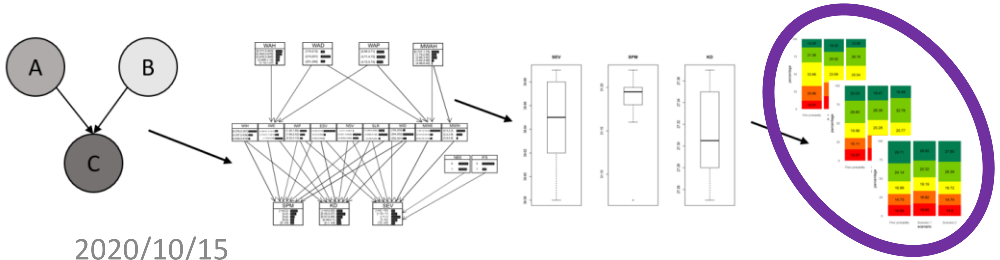
SUSPENDED MATTER



'Very low' classes 2% and 4% increase

'Low' classes 2% and 3% reduction

DIFFUSE ATTENUATION



WP4 CONCLUSIONS

- Climate change impacts across the shoreline, mapping and prioritization of coastal erosion risk and influence on coastal morphodynamics are among the tests and studies that were performed in the selected pilot areas.
- In the Region of Western Greece, a pilot erosion observatory was established in the Gulf of Patras, operating as a joint tool with local operators for future development in the coastal zone.
- In the Apulia region, indicators and a decision support system for coastal erosion was applied in the pilot areas of Bari and Ugento, operating as a joint tool with local operators for future development in the coastal zone.
- Remote sensing and GIS-based techniques were used as a risk-based joint tool blending for the multi-temporal detection and analysis of shoreline evolution across the TRITON pilot cases (Gulf of Patras, Messolonghi in Greece and Ugento in Italy), identifying hotspots risk areas requiring urgent intervention in terms on management and adaptation measures.
- Numerical modelling and Bayesian network for evaluating coastal erosion has been performed in the selected pilot areas with promising results for detecting the shoreline evolution.