Project ID: 10252001

AdriaClim

Climate change information, monitoring and management tools for adaptation strategies in Adriatic coastal areas

D5.3.2

FVG Pilot Site insights from case studies

Pilot Area: Friuli Venezia Giulia coast and lagoon area

PP 11 – ARPA FVG

30th April 2023

Table of contents

About this Deliverable

Here we report, in an integrated manner, the results from three case studies coordinated by ARPA FVG. The integration in a single deliverable should allow to better meet stakeholders' needs for clarity and comprehension of the complex interaction of multiple factors in climate change and impacts, also stressing the link between risk analysis and policy making for resilience.

Aim

- Outlining a methodology for surveying actual climate change local impacts in specific sectors through participatory process and an evidence-based bottom-up approach.
- Analysing specific impacts in local contexts in order to identify risk and vulnerability factors to be taken into account for the future development of local and/or sectorial adaptation plans.

Methodology

- Survey of existing information and tools.
- Drafting tailored tools that enable knowledge collection and sharing among stakeholders and experts.
- Participatory process (engaging, informing and consulting stakeholders and experts).
- Validating tools, collecting information, building common knowledge.

Case studies: which and why

The case studies were identified on the basis of the expressions of interest collected during the four informative-participatory webinars held in May-June 2021 (see the Deliverable 5.3.1 - Chapter 7 - *Participatory process*):

- Impacts on cultural heritage in the UNESCO archaeological site of Aquileia.
- Impacts on ecosystems and biodiversity.
- Coastal erosion and beach drowning.

Chapter 1 - Impacts on cultural heritage in the UNESCO archaeological site of Aquileia

As part of AdriaClim Activity 5.3, a specific case study was dedicated to the impacts of climate change on the cultural heritage in the coastal and lagoon area of Friuli Venezia Giulia. The activity focused in particular on the impacts affecting the archaeological site of Aquileia, which since 1998 is registered by UNESCO in the Word Heritage List for its "outstanding universal value".

The choice of this sector and of the site arose from the interest that both the Autonomous Region of Friuli Venezia Giulia - Directorate of Cultural Heritage and Sport and the Municipality of Aquileia had shown on the occasion of the informative-participatory webinars held between May and June 2021 (see the Deliverable 5.3.1 - Chapter 7 - *Participatory process*).

The aim of the activity was to take a step forward in understanding the phenomena, which could subsequently be useful for planning actions to adapt to climate change in the cultural heritage sector and in particular in the management of the UNESCO site of Aquileia. This was meant to be a first step in a process that tends to make the cultural assets of the Friuli Venezia Giulia region more resilient to the effects of a climate that is already changing and will change even more in the future.

The activity was carried out through a participatory process in which various bodies and operators involved in the management, protection and enhancement of the UNESCO site of Aquileia took part.

The activity:

- was preceded by a preparatory phase shared with the Regional Administration of Friuli Venezia Giulia;
- was developed through a workshop and subsequent targeted meetings with various experts and stakeholders;
- was supported by a specifically designed tool - the matrix of impacts on cultural heritage - which formed the basis for the discussion between the various participants and for the collection and sharing of information.

1.1 – The Aquileia UNESCO archaeological site

The UNESCO site "Archaeological area of Aquileia and Patriarchal Basilica" preserves the remains of one of the largest and richest cities of the Roman Empire, most of which still remains to be excavated below the agricultural fields and the more recent urban nucleus plant. It is therefore the largest archaeological reserve of its kind, also in relation to the key role that the city and its Basilica have played in the process of evangelization in part of central Europe. Aquileia, in fact, is mainly known as a Roman city of the late republican and imperial age, whose foundation dates back to 181 BC, but it must be remembered that, already before the end of the Western Roman Empire, it assumed a role of absolute importance as episcopal seat. The vitality of the Aquileian Church contributed substantially to the spread of Christianity, placing itself throughout history as a meeting point between the Balkan area, Central-Eastern Europe and the Mediterranean area.

The Archaeological Area and the Patriarchal Basilica of Aquileia are located within an area of 155.43 hectares, which represents the core zone subject to UNESCO protection.

The Basilica of Aquileia (photo: Ester Curci)

The archaeological heritage of Aquileia visible today is only a small part of that existing underground. In the past centuries excavations were carried out with the aim of ascertaining the presence of large ancient structures such as the amphitheatre, the circus, the Christian basilica complex, the defensive walls and many of these excavation areas were then appropriately closed. The various archaeological areas that have been studied and made accessible to visitors, on the other hand, are relatively recent, as the first explorative investigations date back to the 1920s and many are still ongoing.

Mosaic in the Domus of Tito Macro (photo: Ester Curci)

In Aquileia, currently, the historical and archaeological heritage is scattered throughout the territory in a sort of "patchy" distribution. The architectural complexes of the Roman and late antiquity, left exposed following the excavations, lay next to the evidence of later eras, from the Middle Ages to today, both in a juxtaposition on the horizontal plane and in an overlap on the vertical plane, i.e. within the same urban sector. Undoubtedly, this mixture is a direct consequence of the particular richness and vitality that the city has had in the past, as well as of its continuity of life over the centuries, in a progressive growth of the city upon itself and in a constant transformation of the older structures.

The overall area of the site covers 155.43 hectares; it is one of the most important archaeological sites in northern Italy.

Aquileia: the river port (photo: Federica Flapp)

Aquileia: the Roman forum (photo: Federica Flapp)

Aquileia: Domus of Tito Macro (photo Sara Menon)

1.2 - Participatory process

The participatory process involved the experts and stakeholders that are listed in **Table 1**.

Table 1. *List of stakeholders (SH) and experts involved in the Aquileia case study.*

SH/Expert	**Denomination**	**Institution**	**Area of influence**	**What**
SH	Central Directorate for Culture and Sport - Department of *Cultural Heritage and Legal Affairs*	Regione Autonoma Friuli Venezia Giulia	Regional	Focus on cultural heritage impacts and co-operation in involving other participants and organising the workshop
SH	Fondazione Aquileia	Multi-Partnership Foundation (Italian Ministry for Cultural Heritage and Activities; Autonomous Region FVG; Province of Udine; Municipality of Aquileia; Archdiocese of Gorizia)	Local	Focus on impacts on archaeological areas and historical artefacts such as mosaics
SH	So.Co:Ba Aquileia	Society for the conservation of Aquilaie's Basilica	Local	Focus on impacts on archaeological areas and historical artefacts such as mosaics
Expert	Superintendence of *Archaeology, Fine Arts and Landscape for Friuli Venezia Giulia*	Italian Ministry of the Culture	Regional	Focus on impacts on archaeological areas
Expert	professionals in the field (geology, archaeology)			Focus on local impacts

The preparation of the activity

Between 2021 and 2022, various interlocutions were carried out with the Municipality of Aquileia and the Region, with some interruptions due to the succession of various people in the key roles of these entities. In June 2022 it was agreed with the contact person of the Regional Culture Directorate to prepare the ground for the start of the activity by informing and engaging potential participants. ARPA FVG therefore produced a document of an informative nature (**Figure 1 A-D**), which the Region then sent to all interested experts and stakeholders to inform them about the AdriaClim project and motivate them to participate in a specific activity on the impacts of climate change on cultural heritage. Having collected the expressions of interest and the availability of the various respondents, ARPA FVG and the FVG Region then co-planned the activity.

A

Progetto AdriaClim: proposta per attività pilota Beni culturali - Aquileia

prima nota informativa – luglio 2022

Il progetto AdriaClim

AdriaClim è un progetto INTERREG Italia – Croazia, avviato nel 2020 con l'obiettivo di promuovere e supportare lo sviluppo di piani di adattamento ai cambiamenti climatici nelle aree costiere del mare Adriatico, fornendo solide conoscenze scientifiche. Il progetto si concluderà a giugno 2023.

In AdriaClim, ARPA FVG è responsabile di azioni progettuali focalizzate **sull'area pilota rappresentata dalla fascia costiera e lagunare del Friuli Venezia Giulia**.

Nell'ambito delle attività tecnico-scientifiche del progetto, l'Agenzia sta perfezionando un **modello oceanografico ad alta definizione** per simulare lo stato, passato e futuro, del Golfo di Trieste e, novità in questo campo, della Laguna di Marano-Grado. La simulazione interessa le caratteristiche fisiche del mare e della laguna: le correnti, la temperatura, la salinità e il livello marino.

Nell'ambito delle attività di supporto all'adattamento locale, che si ricollegano a quelle tecnico-scientifiche, ARPA FVG può contribuire a **migliorare le conoscenze su specifici impatti**, sviluppando alcuni segmenti di lavoro che siano utili alle pubbliche amministrazioni e ai portatori di interesse locali per affrontare più efficacemente le minacce dei cambiamenti climatici nelle aree costiere e lagunari del FVG.

Su quali impatti può focalizzare l'attenzione AdriaCim?

- sulle attività antropiche
  trasporti, acquacoltura e pesca, turismo, siti di valenza storica e culturale, ...
- sugli ecosistemi
  siti Natura 2000, specie aliene, biodiversità, ...

Uno dei focus del progetto nell'area pilota per il FVG potrebbe essere dedicato agli **impatti sui beni culturali collegati ai cambiamenti del mare**, come l'innalzamento del suo livello medio.

B

L'innalzamento del livello del mare: cosa sta accadendo e cosa ci aspetta in futuro?

I dati disponibili per Trieste dal 1875[1] evidenziano che **il livello medio del mare** su scala secolare è aumentato alla velocità media di 1.3±0.2 mm/anno e che **dagli anni '90 del secolo scorso sta aumentando a una velocità molto maggiore** (**4.4 mm/anno** nel 1992-2016 a Trieste).

Secondo le più aggiornate proiezioni climatiche globali (IPCC, 2021) **il livello del mare continuerà ad aumentare**, **in diversa misura a seconda degli scenari relativi alle emissioni di gas climalteranti**: ad emissioni maggiori corrisponderanno cambiamenti del clima molto più rilevanti, mentre una forte e immediata riduzione delle emissioni consentirà di contenere le variazioni di temperatura, precipitazioni, caratteristiche del mare entro livelli con cui riusciremo a convivere adattandoci.

L'aumento del livello del mare avrà una serie di **conseguenze**, che si manifesteranno sia in modo graduale che in occasione di eventi estremi. Ad esempio, partendo da un livello del mare più elevato, sarà più facile che si verifichino **eventi di "acqua alta"** e sarà ancora **più difficoltoso lo smaltimento delle acque** in eccesso in occasione di precipitazioni intense.

Acqua alta a Muggia. Foto: Protezione Civile FVG (Social Media Communiti FVG)

Innalzamento del livello del mare e beni culturali nelle aree costiere e lagunari del FVG

A titolo di esempio, le due mappe seguenti rappresentano la **superficie di territorio** (area pilota AdriaClim FVG) **che si potrà trovare al di sotto del livello del mare al 2050 e al 2100, in due diversi scenari**: uno scenario corrispondente a una rapida e forte riduzione delle emissioni climalteranti (SSP1-2.6), e uno scenario ad alte emissioni (SSP5-8.5).

Alle mappe di scenario di variazione del livello marino sono stati poi sovrapposti i **beni culturali** presenti nell'area pilota (da catalogo regionale dei dati ambientali e territoriali IRDAT).

I valori di innalzamento del livello marino indicati in queste **mappe preliminari** non derivano dall'attività di modellistica di AdriaClim, tuttora in corso, ma da fonti internazionali con riferimento alla realtà locale*[2]

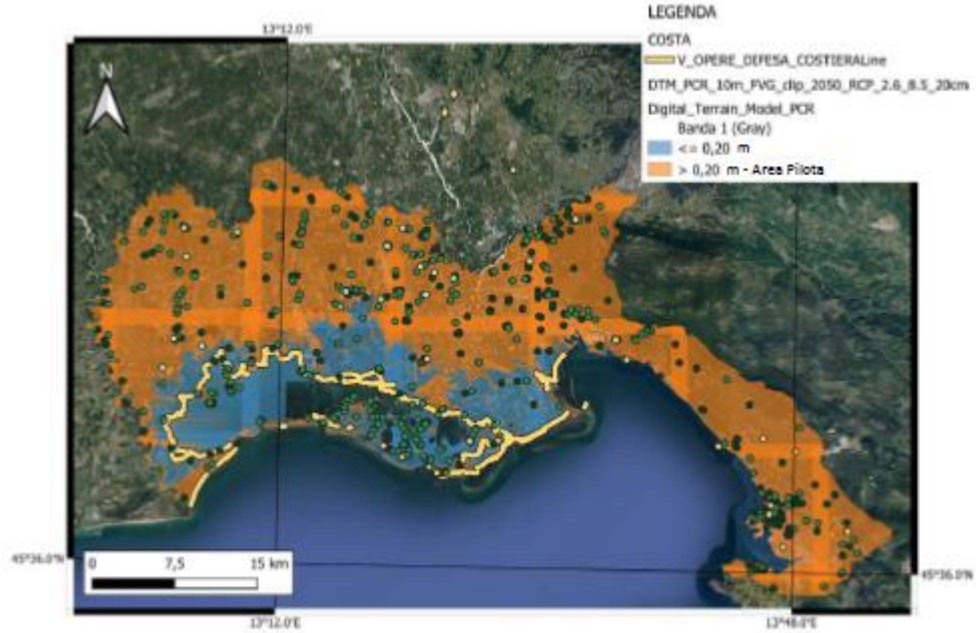
Per queste mappe preliminari, che hanno solo l'obiettivo di fornire **una base di partenza per riflettere su come i cambiamenti climatici potranno impattare sui beni culturali nelle aree costiere e lagunari del FVG**, abbiamo scelto un approccio semplificato, rappresentando solo il valore medio per ciascuno scenario e arrotondando i valori delle proiezioni alla decina di centimetri:

- nella mappa 1 è rappresentato un innalzamento del mare **al 2050** di **20 cm**, che approssima quello di entrambi gli scenari, che fino a metà secolo non divergono in modo rilevante;
- nella mappa 2 è rappresentato un innalzamento del mare **al 2100** di **40 cm** per lo scenario a emissioni fortemente ridotte (SSP1-2.6) e di **70 cm** per lo scenario ad alte emissioni (SSP5-8.5).

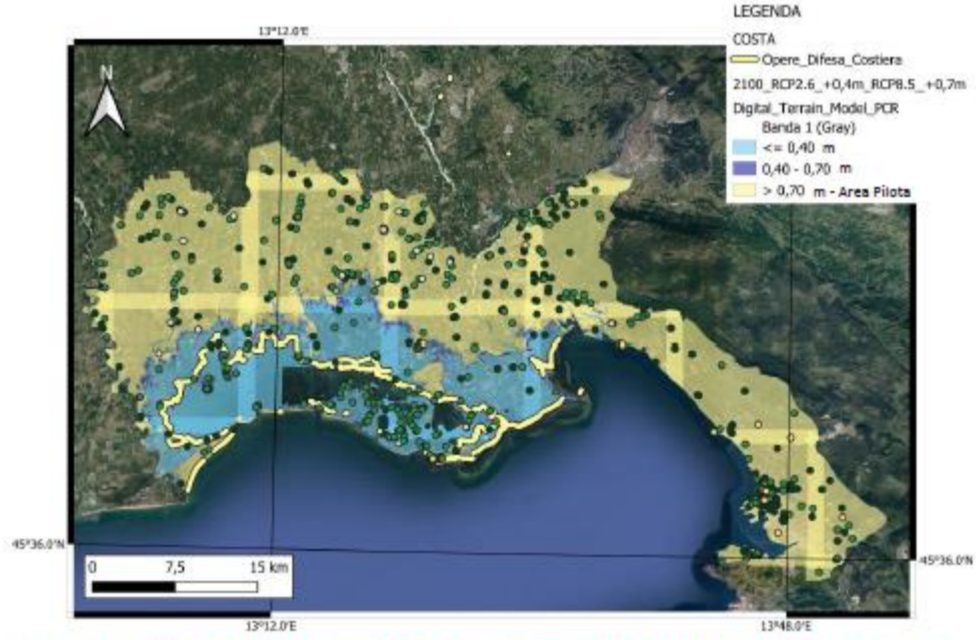
---

[1] CNR-ISMAR http://www.ts.ismar.cnr.it/node/36
[2] *(NASA/IPCC Projected Sea-Level Rise Under Different SSP Scenarios: TRIESTE https://sealevel.nasa.gov/ipcc-ar6-sea-level-projection-tool?psmsl_id=154)

C



Mappa 1. Superficie dell'area pilota AdriaClim-FVG che si troverebbe a una quota sotto il livello del mare al 2050, considerando un innalzamento medio del livello del mare di 20 cm per entrambi gli scenari emissivi *(elaborazione cartografica preliminare basata su dati medi arrotondati da fonte NASA/IPCC)*



Mappa 2. Superfici dell'area pilota AdriaClim-FVG che si troverebbero a una quota sotto il livello del mare al 2100, considerando un innalzamento medio del livello del mare di 40 cm per lo scenario a emissioni fortemente ridotte e di 70 cm per lo scenario ad alte emissioni *(elaborazione cartografica preliminare basata su dati medi arrotondati da fonte NASA/IPCC)*

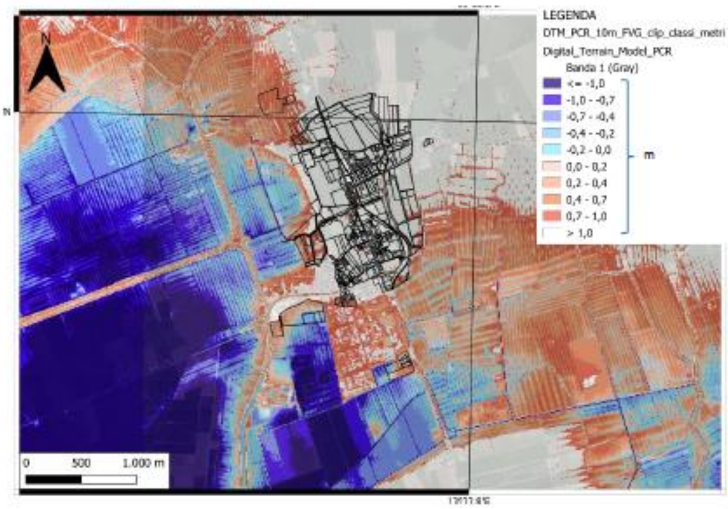
D Aquileia: criticità attuali e future collegate al clima

https://www.ilfriuli.it/articolo/cronaca/maltempo-allagata-la-basilica-di-aquileia/2/232766

http://www.arte.it/notizie/udine/il-sito-unesco-di-aquileia-archeologia-vulnerabile-di-fronte-ai-cambiamenti-climatici-1651

Aquileia e il suo **Sito UNESCO** sono già soggetti ad **impatti derivanti da eventi meteorologici che tenderanno ad aggravarsi** con i cambiamenti del clima già in corso e attesi per il futuro, tra i quali l'aumento del livello del mare.

Nella mappa 3 è rappresentata l'area di Aquileia, con **evidenziata l'area archeologica e le altimetrie**: i colori nella gamma dell'azzurro-blu indicano aree che già attualmente si trovano a una quota al di sotto del livello del mare, mentre i colori dal rosa al rosso corrispondono alle aree che via via si troveranno al di sotto di esso secondo proiezioni di aumento del livello del mare di **20 cm** (**al 2050** in entrambi gli scenari considerati), **40 cm** (**2100**, aumento medio nello scenario con forte riduzione delle emissioni climalteranti), **70 cm** (2100, aumento medio nello scenario ad alte emissioni), **1 metro** (2100, aumento massimo nello scenario ad alte emissioni).



Mappa 3. Area di Aquileia con quote rispetto al livello del mare

fonte: cartografia Regione FVG

(elaborazione cartografica preliminare con intervalli di valori basati su dati arrotondati di proiezioni di aumento del livello mare da fonte NASA/IPCC)

La proposta di AdriaClim

Con il coinvolgimento e la partecipazione degli enti interessati e degli stakeholders locali, il progetto **AdriaClim** potrà **contribuire a migliorare la conoscenza e comprensione degli effetti** che i cambiamenti del mare avranno sui beni culturali esposti a questa sorgente di pericolo: un passo in avanti nel percorso **verso azioni di adattamento** che riducano i rischi e accrescano la resilienza del territorio e del settore.

Contatti: dario.giaiotti@arpa.fvg.it, federica.flapp@arpa.fvg.it

***Figure 1 A-D**. The document of informative nature designed to engage Shs in the context of Aquileia case study.*

The first goal of the activity was to build a common ground of knowledge, where those who study the climate of our region and those who, with different roles and skills, discover, conserve and manage its cultural heritage can meet halfway.

A meeting was therefore organized in December 2022, which was proposed in the form of a workshop to be developed with the active contribution of all the participants. In preparation for the workshop, ARPA FVG therefore suggested that the participants collect the information they had, of any nature, which could be useful to start answering some questions on which they could then work together:

- What types of damage do you find on the site?
- Which agents/causes of the damages do you consider most relevant?
- What hazards of a meteorological-climatic nature are associated with the aforementioned damages and causes of damage?
- What are the sensitivity factors that make sites and cultural heritage vulnerable to different impacts? (e.g. construction materials, structural characteristics, management aspects…)
- What tools/measures to reduce impacts are already available and/or could be proposed to protect the sites/assets?

In preparation for the activity, digital cartographic elaborations of the Aquileia area were also carried out to highlight:

- the local hydrography (surface and ground water) and the artesian wells (**Figure 2**);
- the altitude of the archaeological site and surrounding areas with respect to mean sea level (**Figure 3**), as a basis for considering the effects of the different sea level rise scenarios (see Chapter 1.3 - *Climate change impacts and related hazards*).

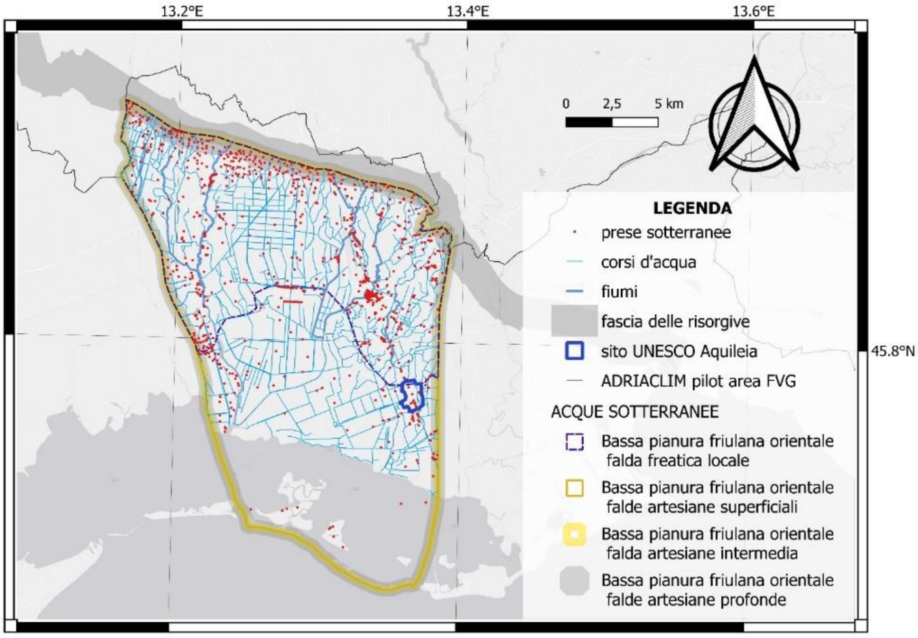


Figure 2. *Local hydrography (surface and ground water) and the artesian wells in the area of Aquileiea.*

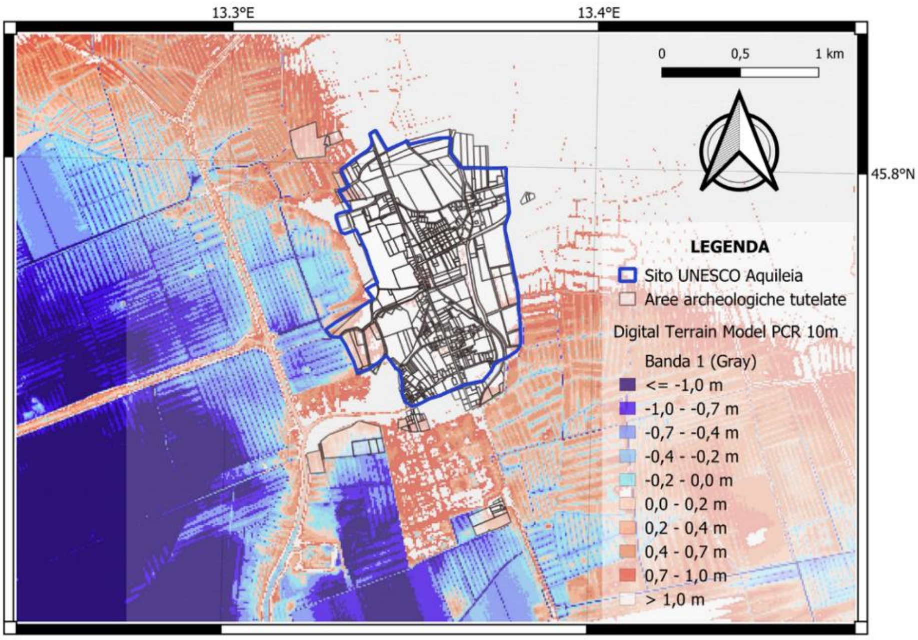


Figure 3*. Altitude of the archaeological site of Aquileia and surrounding areas with respect to mean sea level.*

A tailor-made impact matrix for cultural heritage operators

As a basis for answering the above questions, ARPA FVG prepared a synoptic table ("impact matrix") which allows for a broad range of possible impacts of climate change on cultural heritage to be framed.

This table differs somewhat from the synoptic table of multi-sector impacts (attached to Deliverable 5.3.1 and illustrated therein in Chapter 6 – *Climate change impacts*) and also from the impacts matrix prepared for ecosystems (see in this Deliverable Chapter 2: *Impacts on ecosystems and biodiversity*). In fact, it was decided to look for an approach that was more in line with the working method that archaeologists and conservators of cultural heritage use in classifying information in their field of work. We therefore carried out a survey to identify other European projects developed on the theme of natural and climatic risks that threaten cultural heritage and we examined the different terms, concepts and schemes used.

The "matrix of impacts on cultural heritage" that we prepared takes up the approach adopted by another project specifically dedicated to this theme (ARCH Saving Cultural Heritage https://savingculturalheritage.eu/). This is a good starting point, but it is not a tool calibrated for our specific regional context: therefore, one of the objectives of the activity carried out in AdriaClim was to integrate and modify the table to obtain a better-contextualized matrix with respect to our climate and our cultural heritage. The table was sent to the participants before the workshop so that they could view it and use it as an outline to collect useful information to bring to the meeting.

The structure of the table is described in Chapter 1.3 - *Climate change impacts and related hazards*.

During the face-to-face meeting, we integrated the various contributions of the participants into the table, with the aim of building a shared tool and at the same time carrying out a survey of the available knowledge, as well as knowledge gaps that should be filled in order to carry out a proper evaluation of risks and vulnerabilities.

The workshop

On 5 December 2022, ARPA FVG organised a workshop focusing on the impact of climate change on cultural heritage, as part of the participatory process included in Activity 5.3. The day program included an introductory session dedicated to climate literacy, classroom discussion, field inspections and workshop activity on the impacts-hazards-vulnerability matrix.

The workshop took place in Aquileia, in the town hall. During the whole day, climate experts, archaeologists, geologists and civil servants worked together, in order share their diverse expertise and to build a common knowledge basis to address the challenges the archaeological site faces in terms of climate crisis.

The technical meeting involved several regional and local stakeholders, primarily the Central Directorate of Culture and Sport of the Friuli Venezia Giulia Region and the Joint Bureau that coordinates the activities at the UNESCO site, both represented by Paola Pavesi. The workshop was also attended by the Municipality of Aquileia with the Mayor, Emanuele Zorino, and the Town Planning and Budget Councillor, Daniela De Marchi. In addition, Luciana Mandruzzato, archaeologist, and Giovanni Pietro Pinzani, geologist, gave their contribution in pointing out the effects of climate change and the vulnerabilities of the site. Last but not least, the workshop also involved the management body of the UNESCO site, namely the Aquileia Foundation, represented by its director, the archaeologist Cristiano Tiusso.

Regarding the practical activities carried out during the workshop, ARPA FVG technicians first reported on what is happening to the climate in Friuli Venezia Giulia region, showing observed trends and future projections in temperature, rainfall, sea level rise. Then they introduced conceptual frameworks and methodologies that, according to the national guidelines (see Deliverable 5.3.1 – Chapter *2.3 – Conceptual framework, methodologies and guidelines for adaptation planning*), can be used in assessing the risks of climate change and tackling it.

Dr. Tiusso, after a brief introduction in which he explained what is happening to the Aquileia site, led the workshop participants on a field tour, showing places and peculiarities to be considered in possible adaptation planning, i.e. the most vulnerable points and areas of the archaeological site.

Finally, all participants worked to identify the damages suffered by the site and link them to climate hazards. An effort was made also to point out the factors that play a role in the cultural heritage's sensitivity and the solutions that can reduce its vulnerability.

Climate literacy, classroom discussion, field inspections and workshop activity

Further meetings were then organized to gather the views and knowledge of the Superintendence of Archaeology, Fine Arts and Landscape for Friuli Venezia Giulia and of So.Co.BA, the Society for the conservation of Aquilaie's Basilica

1.3 - Climate change impacts and related hazards

The above mentioned "matrix of impacts on cultural heritage" is organized in three blocks:

- FRAMEWORK OF POSSIBLE IMPACTS (DAMAGE-CAUSES-HAZARDS):
- IMPACTS ACTUALLY FOUND and AVAILABLE INFORMATION
- VULNERABILITY

In the first block, the terms in English are the original ones of the ARCH project, to which we have added our translation into Italian and also, preliminarily, some first integrations. The original table includes damages caused by non-climatic hazards as well: in order not to lose the overall view of the original work, we left them (distinguishing them with an attenuated colour), but for our AdriaClim activity we asked the participants to consider only the damages related to climatic hazards.

Structure of the table, objectives and working method

In the "matrix of impacts on cultural heritage" (see Annex 1) columns A-F are taken from the original table of the ARCH Saving Cultural Heritage project, in the double version in English and in Italian, while the following columns have been added to develop a tool suitable for the activities of the AdriaClim project and subsequent developments.

INQUADRAMENTO DEI POSSIBILI IMPATTI (DANNI-CAUSE-HAZARDS): tabella precompilata da adattare al contesto locale con eventuali integrazioni e correzioni (da inserire preferenzialmente in rosso) ed evidenziando (es. con sfondo colorato) i fenomeni riscontrati nel nostro contesto			IMPATTI RISCONTRATI e INFORMAZIONI DISPONIBILI: da compilare segnalando, ove possibile, fenomeni/eventi riscontrati e fonti (banche dati, studi ecc.) utili per analisi quantitative e/o qualitative					VULNERABILITÀ: da compilare riportando, ove possibile, pareri esperti e ipotesi sui fattori che rendono i siti/beni più o meno vulnerabili a determinati impatti specifici	
danni al patrimonio culturale	**cause** (collegate a hazards climatici o non collegate a hazarda climatici)	**sorgenti di pericolo (hazards)** climatiche e non climatiche	**esempi concreti nel sito di Aquileia:** descrizione più specifica del danno	**esempi concreti nel sito di Aquileia:** indicazione di siti / strutture in cui si verifica	**dati / documenti disponibili per Aquileia**	eventuali esempi concreti in altri siti/beni culturali in aree costiere e lagunari FVG	eventuali dati / documenti disponibili per altri siti	**fattori che determinano la vulnerabilità: sensitività**	**fattori che riducono la vulnerabilità: capacità di risposta (azioni o misure già attuate o ipotizzabili per il futuro)**
processi fisici/meccanici di erosione e degradazione meteorica* dei materiali lapidei	cicli gelo/disgelo	temperature estreme							
	Impatto fisico di piogge intense/grandine	precipitazioni estreme							
	abrasione	venti molto forti							
	impatto fisico delle onde	azione delle onde							
		eventi di acqua alta							
	bio-vaiolatura/puntinatura	azione di funghi							
		azione di batteri							
	scalzamento radicale	azione vegetale							
	formazione di gallerie e	azione animale							
	impatto di armi/oggetti	conflitti armati							
		danni intenzionali							
	smottamenti, colate di fango, frane	movimenti di massa							
		precipitazioni estreme							
		uso del suolo estremo							
	altre cause:	*hazards collegati:*							
processi chimici di alterazione e degradazione meteorica* dei materiali lapidei	cicli di bagnatura/asciugatura	precipitazioni estreme							
		allagamenti pluviali (causati da piogge intense e sovraccarico dei sistemi di smaltimento delle acque)							
		allagamenti fluviali (causati da esondazioni dei corsi d'acqua)							
		allagamenti costieri (causati da eventi di acqua alta)							
		allagamenti costieri (causati da							

The matrix of impacts on cultural heritage

Columns A-F relate various categories of «damage to cultural heritage» with the «hazards» which are at the origin, through the specific phenomena that actually occur and cause the damage (“causes”).

The first objective of the activity was to verify whether the list of "damages" (columns A/B), of the "causes" (columns C/D) and of the hazards (columns E/F) was complete, well-structured and consistent with the knowledge and experiences of local experts and stake holders.

Participants were invited to add and/or modify some items (damages, causes, hazards) where they considered it appropriate: as ARPA FVG we set the example by adding beforehand some impacts (for example those relating to educational-tourist activities).

The second objective was to highlight the impacts and the related "hazards" which according to the participants are found in Aquileia: that was done by colouring the background of the cells in columns D and F.

The third objective was to add "actual examples" of the impacts occurring in the UNESCO site of Aquileia, by filling in columns G (more specific description of the damage) and H (indication of sites/structures where it occurs).

With respect to the impacts that were actually found on the site, the participants were also invited to report any available sources of information of which they were aware (documents, photos, data, etc.) in column I.

Finally, a final objective was to indicate and/or hypothesize, if possible, the factors that make the property particularly sensitive to impacts (column L) and the factors that instead can make it less vulnerable (column M) and that may be understood as indicative of an adaptive capacity.

The table was compiled both directly during the workshop and during subsequent meetings, verifying that the information provided by the participants had been correctly entered and interpreted and making further additions.

The table, as tested and compiled together with the participants in the activity, is attached as Annex 1.

Examples of already occurring impacts

In Aquileia there have always been changes in the territory and landscape from the Roman age to today and we find many of the problems that Roman Aquileia had even today. There are changes in the landscape that are natural and take place over a fairly long period of time: the main issue is the speed with which the change is taking place now.

The Roman forum

A first criticality is given by the progressive rise of the mean sea level. The reconstructions show that the coast line in Roman times was more advanced and the current lagoon area was dryland. This means that sea level has risen by about 1.5 m in 2000 years. In the area there are still Roman lagoon canals, such as the Anfora Canal, which still constitutes the fulcrum of the old (Teresian reclamation) and new reclamations. In the archaeological area, the Roman forum is 50 cm below mean sea level and is currently kept dry through an important pumping system.

The other critical aspects that the site is facing, in addition to the rise in mean sea level, are the events of intense precipitation and the very short time rise of the groundwater level under the input of heavy rainfall.

Domus of tito Macro

On the day of the inauguration of the Domus di Tito Macro in September 2020, 45 mm of rain fell from 7 to 8, i.e. more than it rained from 1 September to 25 September of the same year.

Even non-exceptional rains pose important problems on an open structure such as excavations and gutters are not sufficient.

Domus of tito Macro: bakery oven and metal plate (photos above and below)

The metal plate of the Domus of Tito Macro is a sort of groundwater level gauge, placed in an area that in ancient times was the shop and where the bakery oven is located. The oven is made of gravel, directly in contact with the ground.

In November 2020, when the mosaics in the basilica went under water, the oven (the point from which water came out of the ground) also went completely under water: the water level rose by 70-80 cm in 7- 8 hours, the water also climbed over the walls, then with the help of the pumps the water descended (the pumps are always active, but during that episode it was necessary to add extra help with manual dewatering pumps).

In the inspection carried out during the AdriaClim workshop, it was highlighted that in Roman times the place of the domus oven was always dry, testifying to how the situation has changed over time.

For the preservation of the mosaics, several techniques have been used that involve the detachment from the original substrate and the transfer of the mosaic on a new support: until the '70s -'80s cement and iron were used, from the '90s aerolam was used, a lighter and non-walking material.

In open-air mosaics there is a physical effect of the rain, but it is much less aggressive if the tiles are on a concrete support, while if they are on the original substrate the mosaic is more vulnerable.

Roofing reduces the exposure of mosaics to the "precipitation" hazard, but has a number of implications to consider carefully (e.g. what types of coverage? what costs?)

For mosaics under a protective covering, the type of materials used in the substrates onto which the mosaics are transferred can make them more or less susceptible to damage deriving from the wetting and drying cycles caused by fluctuations in the groundwater level: iron pins and concrete make them more vulnerable, while steel pins and aerolam make them less vulnerable.

Many indoor mosaics have a rising groundwater effect which wets the dust already present on the mosaic. In those on aerolam (more recent technique) the water from underneath manages to permeate the substrate, while if the support is concrete (solution adopted in the past) the slab blocks the ascent. However, in the cocrete support there are iron pins which, when wet, rust, crack and break the mosaic. Nowadays steel pins are used instead.

Roofing, gutters and drainage systems are among the solutions adopted to reduce the exposure of mosaics to the effects of rain, but they are not always sufficient.

In the Domus and Bishop's Palace, different levels of flooring dating back to various periods are visible. The oldest remains are located below current sea level and are kept dry by a dedicated pump system.

To protect the mosaics from the proliferation of plant organisms which would form a green patina, special biocidal lamps are used.

Even the Basilica of Aquileia is subject to flooding during particularly heavy rains.

In 2020 there was a flooding of the Crypt of the frescoes (at the end of the main nave) which had never occurred in the last 20 years: it was necessary to intervene with extra pumps to drain the crypt.

In the "Crypt of the excavations" or "North Hall" of the Basilica there are various phenomena connected to intense rainfall, which determine the entry of both rainwater and water from below resulting from the raising of the water table.

In the photo, you can see on the left some frescoes that risk being damaged when it rains a lot because the water from above infiltrates along the wall of the above garden of the rectory: the water permeates the inside of the wall, but it also flows along the wall to wet the fresco. The frescoes still attached to the wall are already covered by a green patina; those reported (ie those that have been removed, attached on a different support, concrete, and replaced on the wall) have a cavity in which water infiltrates.

But water also drips from the ceiling and in this case the damage is also mechanical. The water enters between two layers of panels (visible in the photo) that are slightly sloping and form small pools: from here, through the joints, the water drips down and wets the fresco.

At the bottom right there is a small door (security door) from which rainwater enters because in front of the door they made an exploratory excavation that acts as a funnel and conveys water.

Also from the bell tower (of which you can see the base on the right in the photo) rainwater enters.

The rain that descends from the bell tower wets the mosaics that are on the ground at the base of the bell tower, bringing mud that smears them. Instead, salts rise from below and form a whitish patina. Periodic cleaning interventions are therefore necessary, which must be carried out by expert personnel and with great care so as not to damage the mosaics. On the other hand, no green patina is noticed because a biocidal treatment is carried out twice a year and UV lamps are used (as in the Domus and Episcopal Palace)

In the photo below you can see the three levels of the excavations in the North Hall: the lower levels flood when the water table rises following heavy rains: at the bottom right you can see the whitish patina (salts such as carbonates, not sea salt) which remains on the mosaics. In the far right corner you can see a stretch of mosaic in sharp colours, black and white, which is not covered by the patina because it is higher.

Other impacts concern the tourist and educational use of the area, which is affected by summer heat waves: the data of tickets sold reveal a significant decline in recent years in conjunction with the hottest periods.

1.4 - Lessons learnt, guidelines and future prospects for adaptation

Climate change ad adaptation in the existing knowledge basis and planning tools

We carried out a survey of local analysis and planning tools available and specifically drafted for the UNESCO site of Aquileia, to verify if these documents take into account climate change, its effects on the site and any adaptation measures

The main reference is the UNESCO World Heritage List - MANAGEMENT PLAN of the Archaeological Area of Aquileia and the Patriarchal Basilica (2017)[1]:

- it is the culmination of a process that has been going on for several years, in continuity with the methodological and programming path undertaken by the Aquileia Foundation and the local authorities in the last decade;
- it represents a tool that organizes the choices and wishes expressed by the subjects involved in the management of the UNESCO site.

The specific objectives of the Management Plan are:

- Systematize knowledge of the site
- Implement strategies for the protection and conservation of the site
- Implement actions to enhance the site
- Strengthen the participation and awareness of the local community, also through training activities
- Carry out communication and promotion actions for the UNESCO site

The Management Plan's actions and measures are:

- Numerous projects activated by the inclusion of the Site in the UNESCO World Heritage List (p.101)
- Towards the establishment of an Archaeological Park through (p.105):
    - Planning actions for the definition of the Park areas
    - Drafting of various plans for the 360° management of the site (Conservation Plan, Communication Plan, Archaeological Risk Plan, etc.)
    - Maintenance, rehabilitation, restoration, redevelopment of different areas/elements of the archaeological area
    - Implementation of actions transversal to the conservation of the site concerning teaching, tourism, the involvement of local actors

[1] https://www.fondazioneaquileia.it/files/documenti/pdg_aquileia.pdf

- Enhancement of the site through the organization of various exhibitions and events of a cultural nature

Does the Management Plan refer to climate change and its impacts?

- No, climate and climate change are not topics covered by the Plan.
- In the SWOT analysis, however, reference is made to the height of the water table, which causes flooding in some areas of the archaeological site as Threat (p.94).
- In Chapter 6 - Tthe factors affecting the site (p.87), there is no reference to the impacts deriving from climatic hazards, nor to important physical and geological factors such as subsidence. At the same time, reference is made to the rise of the aquifer as a source of alteration.

Another relevant document is the GEOLOGICAL REPORT - All. 4 - Enhancement and musealization interventions of Fondo Cossar[2]: a report that was drawn up in order to investigate the geological-technical aspects relating to the project «Interventions for the enhancement and museumization of the Cossar Fund». The project essentially involves the construction of a roofing system resting on a series of foundation micropiles, inserted in the center of the masonry and in the ground, for depths between 4 and 6 meters (p.37).

Does the Geological Report refer to climate change and its impacts?

- No, Climate and Climate Change are not topics covered by the Report with dedicated parties.
- The water, surface and subsoil context in which the site is located is well described (p.30).
- Subsidence, however, is an element present as an active natural process and which must be taken into account when planning interventions (p.10)
- The lowering of the ground level is related to «the ascertained rise of the sea level» (p.17)
- The raising of the groundwater level is presented as problematic, in relation to future trends that will worsen the situation (past-present comparison) (p.18), with possible filtration phenomena (p.34)

[2] https://www.fondazioneaquileia.it/files/documenti/04_relazione_geologica.pdf

AdriaClim’s outcomes and the potential for adaptation’s mainstreaming within Aquilaia’s UNESCO site’s planning tools

The Management Plan of the UNESCO site of Aquileia is currently (2023) under revision: this represents an important opportunity to include climate change and adaptation in the new version of the Plan. The bodies responsible for managing the site, which have participated in the activities of the AdriaClim project described above, intend to make use of the experience gained in the project to continue collecting and processing the information necessary for the assessment of risks and vulnerabilities in order to then identify the most effective adaptation measures. The results of the activity carried out in AdraClim will therefore be used to draw up the new Management Plan.

It will be important to seize the opportunity of the Technical Table set up for the revision of the Management Plan to continue the participatory process started in AdriaClim and progress in the construction of shared knowledge to plan adaptation actions that allow to safeguard the UNESCO site of Aquileia from the impacts deriving from climate changes.

Suggestions to fill in knowledge gaps and foster adaptation

With regard to climate hazards, it will be essential, in particular, to investigate how sea level rise could accentuate the risks associated with other climatic hazards and especially with heavy rains. In this sense, it would be very useful to monitor the fluctuations in the groundwater level, which is already detected daily by a sensor, but which is not recorded: a simple device would allow the measurements to be recorded by feeding a precious data base for better understanding the phenomena in course and therefore future scenarios.

In order to understand the dynamics of the groundwater level in relation to the sea level, also with a view to future projections, a survey of the knowledge and modelling tools available in universities and regional research bodies should also be carried out.

With regard to vulnerability analysis, in the process participated with experts and stakeholders it emerged that in the future it will be important to involve also restorers: the sensitivity of cultural heritage is in fact closely linked to the construction materials and techniques used for the preservation of artifacts.

With regard to the impacts on the tourist use of the site, given the climate projections for the area, which also indicate an increase in maximum temperatures in the coming decades, one line of action to be pursued is the enhancement of site openings and public events in the evening, which have been launched recently and are giving interesting results.

The effectiveness of this solution could be monitored in the future by installing additional technological devices that allow you to count the number of visitors in the areas accessible for free (these devices have been installed only very recently and for a limited area).

Most of the photos (and the most beautiful ones) in this chapter are of Ester Curci.

Chapter 2 - Impacts on ecosystems and biodiversity

2.1 - The ecosystems involved

As already mentioned in D5.3.1-*General knowledge framework for local adaptation plans* (cf. section 5.1 - Context analysis), the high climatic, geological, geomorphological and hydrographic differences within the FVG region are reflected in its high biodiversity, which is also due to the intersection of three biogeographical regions (Alpine, Continental and Mediterranean) right at the FVG.

In 2021, the FVG Region has updated its *Carta della Natura*[3] (FVG Nature Map) following the ISPRA methodology (manual 48/2009)[4]. Habitats have been mapped (1:25000 scale) with reference to the Corine Biotopes legend, adapted to the regional ecology. The FVG Nature Map is a dynamic representation of the regional natural heritage and a fundamental information tool for assessing the state of ecosystems, as well as for planning and programming policies for the management of natural resources.

Regarding the FVG Pilot Site (PS), nature wild areas such as the Marano and Grado lagoon and the Karst, coexist with rural landscapes in the Friuli plain. In **Figure 4** are shown the habitats from the FVG Nature Map within the PS (for the map legenda, see section Appendixes). Categories such as *Urban and industrial areas* and *Crops* were excluded from the representation in order to show habitats characterised by greater naturalness.

As highlighted by the recent magazine *Segnali dal clima*[5] drafted by the technical-scientific working group "Clima FVG" and coordinated by ARPA FVG (2023), marine-coastal and karst habitats may be severely affected by climate change.

In particular, the authors highlight how rising sea levels could affect the salt marshes of the Marano and Grado lagoon and compromise the acclimatisation capacity of the vegetation growing on them (Boscutti & Vuerich 2023)[6]. Furthermore, salt marshes are already undergoing sediment

[3] Regione Autonoma Friuli Venezia Giulia (2021). Carta della natura del FVG. Edited by Direzione Centrale Difesa dell'ambiente, Sviluppo Sostenibile e Energia - Servizio Valutazioni Ambientali.
[4] https://www.isprambiente.gov.it/files/pubblicazioni/manuali-lineeguida/cartanatura_manuale_2009_48_50mila.pdf
[5] ARPA FVG (2023). *Segnali dal clima in FVG – Cambiamenti, impatti, azioni*. Edited by ARPA FVG on behalf of Gruppo di Lavoro tecnico-scientifico C-lima FVG, May 2023, 116 pp.
[6] Boscutti F & Vuerich M (2023). *L'acqua sale, le piante soffrono: le barene lagunari e il cambiamento climatico*, in: ARPA FVG. *Segnali dal Clima in FVG – Cambiamenti, impatti azioni*. Edited by ARPA FVG on behalf of Gruppo di Lavoro tecnico-scientifico Clima FVG, May 2023, pp. 54-57.

loss and in the time period 1954-2007 there were a total surface reduction of 16% (from 760 ha to 144 ha) (Bezzi et al. 2019)[7].

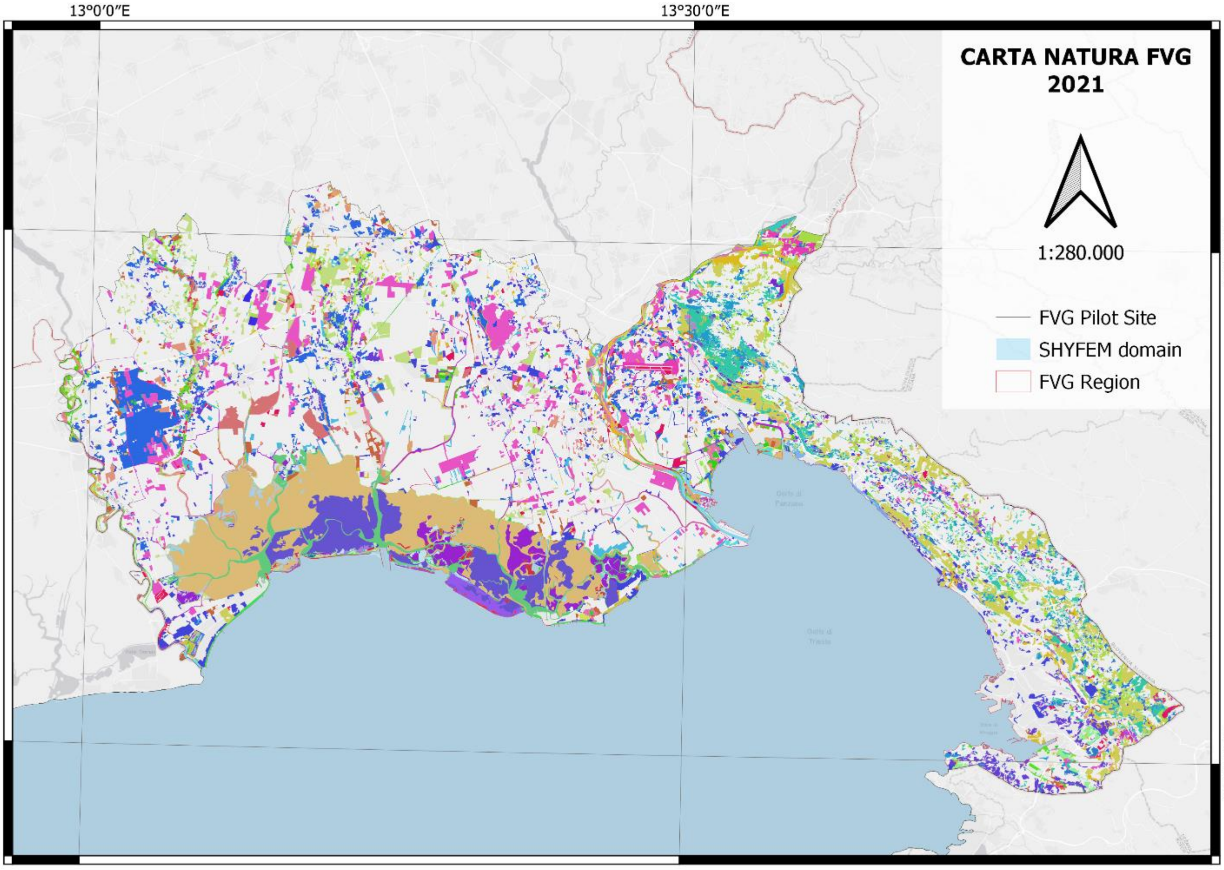


Figure 4*. Corine Biotope habitats in the FVG PS according to Carta della Natura (RAFVG 2021). For the map legenda, see Appendix 1.*

Lagoon ecosystem is quite fragile and the rising sea level is contributing to a change in the balance between the organisms and the environment. In fact, the increasing submergence of salt marshes affects the adaptability of the halophilous plants that colonise these lagoon morphologies. The latter are subject to regression and potential disappearance as the stabilising effect of vegetation disappears (Boscutti & Vuerich 2023). The IMPACT SUMMARY CARD No. 3.4 covers this subject[8].

[7] Bezzi A, Martinucci D, Pillon S, Sponza S, Petti M, Bosa S, Pascolo S, Triches A, Cosolo M & Fontolan G (2019). Sediment budget analysis, critical issues and perspectives for a morphological restoration in a deficit lagoon. Conference paper of the 34th IAS-International Meeting of Sedimentology (Rome, Italy, 10-13 September 2019).

[8] Annex 3.4 *D532_AdriaClim_Annex_3.4_DisSalt*

In addition, the SLR interacts with the sediment balance: if the latter is in deficit, then it is the SLR that prevails and contributes to the drowning of the entire lagoon system. This leads to the so-called 'marinisation' of the lagoon and the disappearing of lagoon typical morphologies such as channels, mudflats and salt marshes (Fontolan et al. 2023)[9]. The IMPACT SUMMARY CARD No. 3.3 covers this subject[10].

Marine phanerogams are also particularly vulnerable to the effects of climate change and other anthropogenic factors (e.g. eutrophication). In the Marano and Grado lagoon, the grasslands of *Cymodocea nodosa, Zostera noltii* and *Nanozostera noltii* are in decline. This is affecting the simultaneous provision of many ecosystem services, such as the production of organic carbon, regulation of the nutrient cycle, stabilisation of sediments, support of biodiversity and trophic transfer to adjacent habitats (Boscutti et al. 2023)[11].

Nevertheless, Solidoro (2023)[12] reported how marine heatwaves have serious consequences for benthic organisms. In fact, during prolonged heat waves, the heat that characterises the surface layer of the sea also spreads to the deeper layers, reaching the benthic organisms that live on the seafloor and are accustomed to colder waters.

In addition, benthic species are less mobile and find it difficult to migrate to cooler waters in the way that pelagic organisms can. Suffice it to say that between 2015 and 2019, up to 5 mass mortality events affecting at least 50 species have been recorded in the Mediterranean.

2022 was a particularly hot year, especially in the Western Mediterranean, with temperatures well above the seasonal average as early as May and anomalies that lasted uninterrupted for more than 70 days into August. Also in the northern Adriatic, large areas experienced temperature anomalies of more than 5°C for more than 50 days. However, research into the effects of marine heatwaves on benthic organisms is still ongoing. The IMPACT SUMMARY CARD No. 3.1 covers this subject[13].

According to Castello & Bacaro (2023) [14], 2022 was also a dramatic year for the Karst region, which was hit by numerous devastating fires. Globally, the heat waves and droughts of recent decades

---

[9] Fontolan G, Bezzi A, Pillon S, Martinucci D, Sponza S, Popesso C, Casagrande G (2023). *La marinizzazione della laguna di Marano e Grado*, in: ARPA FVG. *Segnali dal Clima in FVG – Cambiamenti, impatti azioni*. Edited by ARPA FVG on behalf of Gruppo di Lavoro tecnico-scientifico Clima FVG, May 2023, pp. 43-46.

[10] Annex 3.3 *D532_AdriaClim_Annex_3.3_ChanLag*

[11] Boscutti F, Trevisan F, Scagnetto I (2023). *Le fanerogame sommerse viste da vicino*, in: ARPA FVG. *Segnali dal Clima in FVG – Cambiamenti, impatti azioni*. Edited by ARPA FVG on behalf of Gruppo di Lavoro tecnico-scientifico Clima FVG, May 2023, pp. 58-59.

[12] Solidoro C (2023). *Ondate di calore marine: la situazione generale e il caso del 2022*, in: ARPA FVG. *Segnali dal Clima in FVG – Cambiamenti, impatti azioni*. Edited by ARPA FVG on behalf of Gruppo di Lavoro tecnico-scientifico Clima FVG, May 2023, pp. 33-34.

[13] Annex 3.1 *D532_AdriaClim_Annex_3.1_MME*

[14] Castello M & Bacaro G (2023). *Il carso, un paesaggio vulnerabile agli incendi*, in: ARPA FVG. *Segnali dal Clima in FVG – Cambiamenti, impatti azioni.* Edited by ARPA FVG on behalf of Gruppo di Lavoro tecnico-scientifico Clima FVG, May 2023, pp. 64-69.

have contributed to an increase in the frequency and severity of these phenomena. In particular, the combined effects of human activities, land-use change and climate change are likely to increase the frequency, scale and adverse impacts of fires, posing an increasing threat to human populations and biodiversity.

The Karst is a particularly problematic area, due to factors such as (*i*) the urban structure, characterised by the widespread presence of built-up areas, agricultural areas, road infrastructures compressed in a small area; (*ii*) the high use and frequentation of natural areas; (*iii*) the climate, characterised by the cold, dry Bora wind and a marked tendency towards drought in summer; (*iv*) the lack of a surface hydrographic network and (*v*) the state of the vegetation cover (Castello & Bacaro 2023). Together, these factors make the area more vulnerable to fire and more likely to cause serious damage to people, infrastructure and property.

Fires change the composition of forests and new approaches are needed to prevent or mitigate these disturbances, involving not only public but also private forest owners (Alberti & Tomao 2023)[15].

The IMPACT SUMMARY CARD No. 3.6 covers this subject[16].

Nonetheless, the biodiversity of the FVG is partly protected by the regional system of protected areas, which includes 2 Regional Nature Parks, 3 State Nature Reserves (including an MPA-Marine Protected Area), 13 Regional Nature Reserves and 38 Regional Biotopes. There are also 72 Natura 2000 sites of EU interest[17], some of which overlap partially or completely with regional protected areas. Together, these sites cover about 20% of the FVG's territory.

The establishment of regional protected areas pursue the conservation of nature and biodiversity as well as the tourism promotion through innovative and sustainable practices (RAFVG 2020)[18]. Traditional production activities are also promoted in Natura 2000 sites, such us sustainable fishing or extensive farming and agriculture.

---

[15] Alberti A & Tomao A (2023). *L'equilibrio perduto tra foreste e incendi alla luce della crisi climatica*, in: ARPA FVG. *Segnali dal Clima in FVG – Cambiamenti, impatti azioni*. Edited by ARPA FVG on behalf of Gruppo di Lavoro tecnico-scientifico Clima FVG, May 2023, pp. 70-73.
[16] Annex 3.6 *D532_AdriaClim_Annex_3.6_Wildf*
[17] https://www.regione.fvg.it/rafvg/cms/RAFVG/ambiente-territorio/tutela-ambiente-gestione-risorse-naturali/FOGLIA203/FOGLIA1/, visited on 22/06/2023.
[18] Regione Autonoma Friuli Venezia Giulia (2020). Aree naturali protette del Friuli Venezia Giulia. Edited by Direzione Centrale Risorse Agroalimentari, Forestali e Ittiche – Servizio Biodiversità, 25 pp.

Figure 5 highlights the protected areas which fall partially or totally under the FVG PS, including 3 Ramsar sites (*Foce dell'Isonzo – Isola della Cona, Valle Cavanata* and *Laguna di Marano: Foci dello Stella*) protected by the Convention on Wetlands[19].

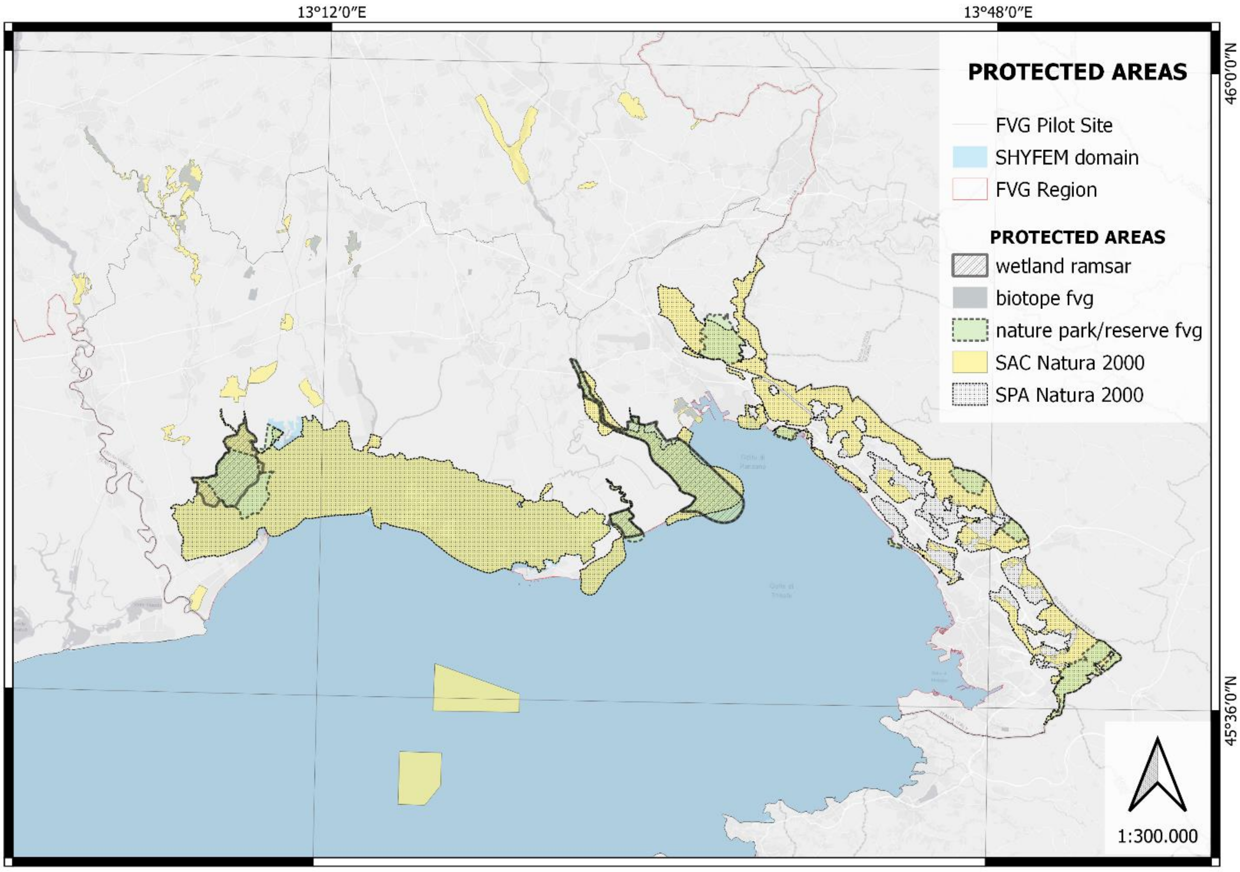


***Figure 5**. FVG network for protected areas: Nature Park and Reserves, biotopes, wetlands and Natura 2000 sites (SCA=Special Area of Conservation; SPA=Special Protection Area). For the map legenda, see Appendix 2.*

As far as the Natura 2000 network is concerned, **Figure 6** shows the habitats of community interest as defined in the Habitats Directive (92/43/EEC) (for the map legenda, see section Appendixes). Note the extensive karst areas on the eastern side of FVG SP and the lagoon and wetlands on the western side.

[19] Ramsar Convention on Wetlands of International Importance Especially as Waterfowl Habitat (1971), https://www.ramsar.org

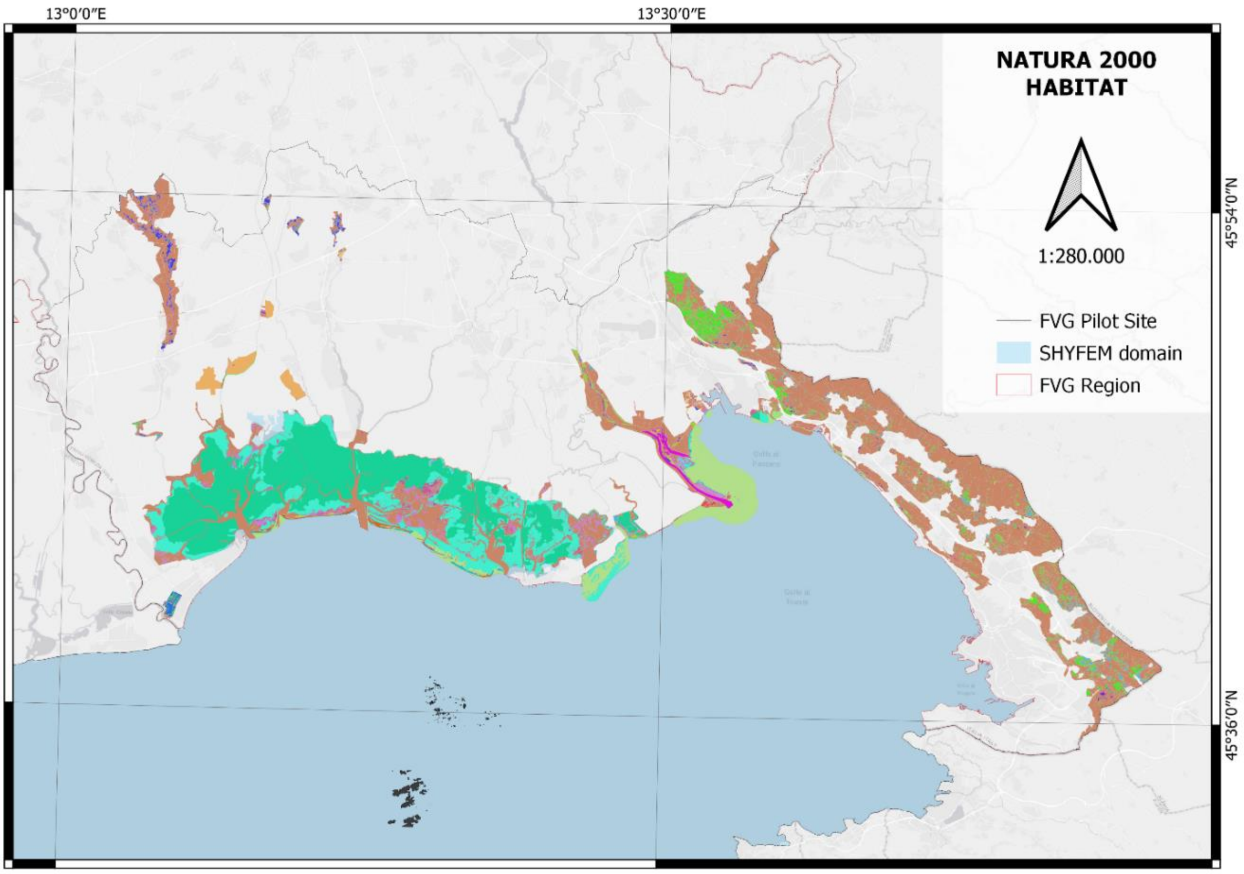


Figure 6. *Natura 2000 habitats falling under the FVG Pilot Site.*

Protected areas within the FVG PS are listed in **Table 2** (Regional Nature Reserves, Natura 2000 sites, Biotopes, Ramsar wetlands).

Table 2. *Protected areas falling under the FVG Pilot Site (RNR=Regiona Nature Reserve; MPA=Marine Protected Area; SAC=Special Area of Conservation; SPA=Special protection Area; N2K=Natura 2000). Areas in orange are partially included in the FVG PS.*

PROTECTED AREA (PA)		**OVERLAPPING WITH OTHER PAs**
NAME	**TYPE**	
Foce dell’Isonzo	RNR	Partially with N2K site IT3330005 Foce dell'Isonzo-Isola della Cona
Foci dello Stella	RNR	None

PROTECTED AREA (PA)		OVERLAPPING WITH OTHER PAs
NAME	TYPE	
Valle Canal Novo	RNR	None
Valle Cavanata	RNR	Partially with N2K site IT3330006 Valle Cavanata e Banco Mula di Muggia
Falesie di Duino	RNR	Partially with N2K sites IT3340006 Carso Triestino e Goriziano and IT3341002 Aree Carsiche della Venezia Giulia
Laghi di Doberdò e Pietrarossa	RNR	Partially with N2K sites IT3340006 Carso Triestino e Goriziano and IT3341002 Aree Carsiche della Venezia Giulia
Val Rosandra	RNR	Partially with N2K sites IT3340006 Carso Triestino e Goriziano and IT3341002 Aree Carsiche della Venezia Giulia
Monte Lanaro	RNR	Partially with N2K sites IT3340006 Carso Triestino e Goriziano and IT3341002 Aree Carsiche della Venezia Giulia
Monte Orsario	RNR	Included in N2K sites IT3340006 Carso Triestino e Goriziano and IT3341002 Aree Carsiche della Venezia Giulia
Miramare	MPA	Totally with IT3340007 Area Marina di Miramare
IT3320037 Laguna di Marano e Grado	SAC/SPA (N2K)	None
IT3320038 Pineta di Lignano	SAC (N2K)	None
IT3330005 Foce dell'Isonzo-Isola della Cona	SAC/SPA (N2K)	Partially with RNR Foce dell’Isonzo
IT3330006 Valle Cavanata e Banco Mula di Muggia	SAC/SPA (N2K)	Partially with RNR Valle Cavanata
IT3330007 Cavana di Monfalcone	SAC (N2K)	None
IT3330008 Relitti di Posidonia presso Grado	SAC/SPA (N2K)	None
IT3330009 Trezze di San Pietro e Bardelli	SAC/SPA (N2K)	None
IT3340007 Area Marina di Miramare	SAC/SPA (N2K)	Totally with MPA Miramare

PROTECTED AREA (PA)		OVERLAPPING WITH OTHER PAs
NAME	TYPE	
IT3340006 Carso Triestino e Goriziano	SAC (N2K)	Partially with RNR Falesie di Duino and N2K site IT3340006 Carso Triestino e Goriziano
IT3341002 Aree Carsiche della Venezia Giulia	SPA (N2K)	Partially with RNR Falesie di Duino and N2K site IT3341002 Aree Carsiche della Venezia Giulia
IT3320036 Anse del fiume stella	SAC (N2K)	None
IT3320034 Boschi di Muzzana	SAC (N2K)	None
IT3320035 Bosco di Sacile	SAC (N2K)	None
IT3320033 Bosco Boscat	SAC (N2K)	None
IT3320032 Paludi di Porpetto	SAC (N2K)	None
IT3320031 Paludi di Gonars	SAC (N2K)	None
IT3320028 Palude Selvote	SAC (N2K)	None
IT3320027 Palude Moretto	SAC (N2K)	None
IT3320026 Risorgive dello Stella	SAC (N2K)	None
Laghetti delle Noghere	Biotope	None
Studenec	Biotope	None
Risorgive di Schiavetti	Biotope	Partially with N2K site IT3330007 Cavana di Monfalcone
Palude del Fiume Cavana	Biotope	Partially with N2K site IT3330007 Cavana di Monfalcone
Torbiera Groi	Biotope	None
Palude Fraghis	Biotope	Partially with N2K site IT3320032 Paludi di Porpetto
Paludi del Corno	Biotope	Partially with N2K site IT3320031 Paludi di Gonars
Torbiera Selvote	Biotope	Partially with N2K site IT3320028 Palude Selvote
Selvuccis e Prat dal Top	Biotope	None
Risorgive di Zarnicco	Biotope	Partially with N2K site IT3320026 Risorgive dello Stella
Laguna di Marano: Foci dello Stella	Ramasar wetland	Partially with RNR Foci dello Stella and included in N2K site IT3320037 Laguna di Marano e Grado
Valle Cavanata	Ramasar wetland	Partially with RNR Valle Cavanata and N2K site IT3330006 Valle Cavanata e Banco Mula di Muggia

PROTECTED AREA (PA)		OVERLAPPING WITH OTHER PAs
NAME	TYPE	
Foce dell'Isonzo – Isola della Cona	Ramasar wetland	Totally with RNR Foce dell'Isonzo and partially with N2K site IT3330005 Foce dell'Isonzo-Isola della Cona

2.2 – Stakeholder and expert consultation

In order to involve key stakeholders in the study of the impact of climate change on ecosystems, a series of meetings have been organised with various institutions (**Table 3**).

Above all, the meetings at the Department of Life Sciences of the University of Trieste were particularly productive, as researchers and doctoral students provided us with information on the knowledge and studies they are carrying out, also in collaboration with the University of Udine (**Figure 7 A-B**).

In addition, with the support of ARPA's marine biologists from *SOS Marine and Transitional Water Quality*, the operational structure in charge of monitoring marine and transitional ecosystems, we gathered information on the evidences which could be linked to climate change effects on marine environments.

The information gathered in this way was useful for the compilation of the so-called "impacts matrix" (see section 2.3 - Climate change impacts and related hazards).

Table 3*. Stakeholders (SH) and experts involved in the study of the impact of climate change on ecosystems.*

SH Expert	Denomination	Institution	Area of influence	What
SH	Central Directorate of agri-food, forestry and fisheries resources - Department of *Biodiversity*	Regione Autonoma Friuli Venezia Giulia	Regional	Focus on biodiversity impacts and management of protected coastal areas
Expert	Department of *Life Sciences* - Plant Community Ecology and Diversity Group	University of Trieste	Sub-regional	Focus on terrestrial ecosystems and forests impacts; contribution to mapping existing knowledge (ecology)
Expert	SOS *Quality of marine and transitional waters*	ARPA FVG	Regional	Focus on marine and transitional ecosystems impacts; contribution to mapping existing knowledge (marine biology)

Figure 7 A-B. Meeting at the Department of Life Sciences of the University of Trieste.

2.3 - Climate change impacts and related hazards

As it was done for the checklist in D5.3.1, an effort has been made to produce a synoptic table also for the potential impacts that could affect ecosystems, according to 4 impact sectors classified by the Italian National Climate Change Adaptation Strategy and Plan:

- terrestrial ecosystems (ET);
- marine ecosystems (EM);
- freshwater and transitional ecosystems (EA);
- forests (FO).

Different lists of impacts from existing recent national and regional sources were compared, matched and clustered, and cross-referenced with climate hazards.

With regard to the checklist content, we focused only on impacts that could interest the Pilot Site, i.e. those affecting the coastal area of Friuli Venezia Giulia and the lowlands behind (for example, impacts on alpine environments have been excluded).

In preparing the checklist, we consulted the following sources:

- *Climate change in FVG, first study* (ARPA 2018)[20];

[20] ARPA FVG (2018). *Studio Conoscitivo dei cambiamenti climatici e di alcuni loro impatti in Friuli Venezia Giulia. Primo Report – Marzo 2018. Supporto alla predisposizione di una strategia regionale di adattamento ai cambiamenti climatici e per le azioni di mitigazione*. In collaboration with RAFVG, ICTP, CNR-ISMAR, OGS, UNITS, UNIUD, 348 pp.

- *Report on climate change impact indicators* by SNPA (2021)[21], i.e. the Italian National System for the Environmental Protection;
- *Climate-related hazard indices for Europe* edited by the European Environmental Agency (Crespi et al. 2020)[22];
- *Italian National Climate Change Adaptation Strategy* (the so-called SNAC, MATTM 2015[23]), i.e. the reference document at national scale for planning local adaptations measurements.

The table includes potential impacts to which further information can be linked, such as examples; skills and knowledge available in the FVG for the different impacts; climate hazards involved; and factors that may increase or decrease vulnerability to the impacts.

The general objectives of the work can be illustrated as follows:

- identify which of the listed impacts are occurring or may occur in the future in the regional territory;
- fine-tune the synoptic table so that it can be used as a common tool by the various bodies that study, monitor and manage the impacts of climate change on the FVG's biodiversity and ecosystems;
- carry out an initial survey of the skills and knowledge available in the various bodies;
- link impacts to the climate hazards that cause them;
- collect some additional information or considerations (e.g. vulnerability factors, impacts on ecosystem services).

The structure of the table is such that the initial columns frame the impacts (A-J), which are detailed in column I. Columns A-F define the ecological units at which impacts may occur (species, population, community, habitat, ecosystem) and also define the scope of analysis at which any studies should be conducted.

The next column G indicates the macro-category into which the impact falls (physiology, life cycle-phenology, behaviour, geographical distribution, alien and/or invasive species, change in population dynamics and structure, ecological community composition, interspecific interactions, habitat modification/alteration, loss of ecosystem function). Column H lists a number of general impacts into which the specific impacts in column I fall.

---

[21] SNPA (2021). *Rapporto sugli indicatori d'impatto dei cambiamenti climatici – Edizione 2021*. Report SNPA 21/2021.
[22] Crespi A, Terzi S, Cocuccioni S, Zebisch M, Berckmans J, Füssel H-M (2020). *Climate-related hazard indices for Europe*. European Topic Centre on Climate Change impacts, Vulnerability and Adaptation (ETC/CCA) Technical Paper 2020/1. DOI: 10.25424/cmcc/climate_related_hazard_indices_europe_2020.
[23] Ministero dell'Ambiente e della Tutela del Territorio e del Mare (2015). *Strategia Nazionale di Adattamento ai Cambiamenti Climatici*.

Column J then allows for a more contextualisation of the impacts in relation to the regional territory and concerns concrete examples found in the FVG that can be linked to the impacts of climate change.

Columns K-M refer to the skills and knowledge available in relation to specific impacts. The former refer to the institutions involved and the activities they could (or already do) undertake to study impacts. The latter refer to the availability of studies, projects and data, with particular reference to FVG.

In the N-AH columns, one or more hazards are assigned to each impact. The climate hazard categories are the same as those used in Deliverable 5.3.1 (cf. D5.3.1 Chapter 6 – Climate change impacts) and are based, with some modifications, on those used in the EEA report "Climate-related hazard indices for Europe" (Crespi et al. 2020). As impacts on biodiversity and ecosystems are often determined by multiple drivers other than climate, column AI has been prepared to indicate other possible pressures.

The AJ-AK columns deal with receptors (species, communities etc.) that are more or less vulnerable to specific impacts, depending on their sensitivity and adaptive capacity. The AL-AO columns, on the other hand, provide an opportunity to indicate which ecosystem services may be affected by the impacts under consideration.

Finally, columns AP-BA indicate the impact sectors identified by the SNAC, both the main ones (ET, EM, EA, FO) and the secondary ones (e.g. fisheries, health, tourism, etc.).

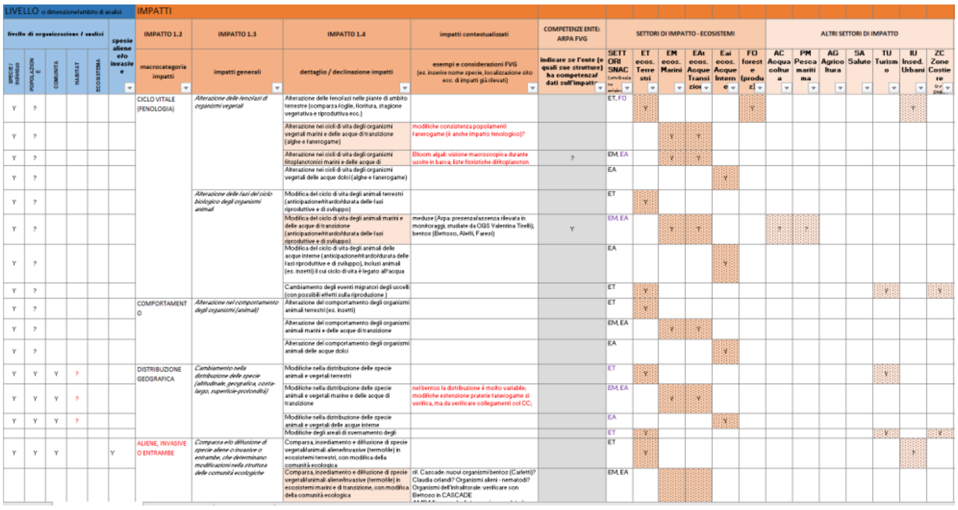


***Figure 8**. Screenshot of the synoptic table on impacts on ecosystems and biodiversity.*

The screenshot in **Figure 8** provide an example of the table, that is digitally attached in excel format as an annex to the present Deliverable (see Annex 2). The language of the table is Italian, as this is a product for and aimed at local policy makers.

The following are the lessons learnt from this effort:

- The purpose of the table is to provide an overview of the impacts on the territory and to lay the foundations for the definition of impact chains to be used for risk analysis;
- A great deal of knowledge exists in the field of biodiversity and ecosystems, but it is often collected for other purposes (e.g. ARPA monitoring, scientific research) and is therefore not directly functional for monitoring impacts and assessing risks related to climate change. Permanent monitoring and/or ad hoc research projects should therefore be set up and shared between the various bodies involved. The establishment of the working group "Clima FVG" is a step in this direction.
- For the future regional strategy for adaptation to climate change, it will certainly be necessary to involve several experts from different bodies with different competences, bearing in mind that the involvement of experts requires a lot of time and effort, as well as the subsequent work of comparing and linking information and opinions.

Soft-bottom macrozoobenthos of the Marano and Grado lagoon (NE Adriatic Sea): a comparison of the current status with early 90's

The following section details a study conducted by ARPA FVG on the macrozoobenthos of the Marano and Grado lagoon. It concerns the shift that occurred between biocenosis typical of transitional waters and others typical of the marine domain. Rising sea levels and the resulting marinisation of the lagoon ecosystem are likely to be the cause.

Coastal lagoon are peculiar environments that cover approximately 13% of the world's coastline and in the Mediterranean basin more than 50 are currently listed in the scientific literature (Barnes 1980[24]; Pérez-Ruzafa et al. 2011[25]). These environments represent an ecotone between continental and marine ecosystems, sharing common traits, species and ecological functions (Pérez-Ruzafa et al. 2011). Due to the host of numerous socio-economic activities (i.e., fisheries, tourism, aquaculture, harbour, navigation channel, urban settlements) (e.g., Pérez-Ruzafa et al. 2011;

---

[24] Barnes RSK (1980). *Coastal lagoons*. 1st ed.; Cambridge Univ. Press, New York, USA, 1980; pp. 106.

[25] Pérez-Ruzafa A, Marcos C, Pérez-Ruzafa IM & Pérez-Marcos M (2011). *Coastal lagoons: "transitional ecosystems" between transitional and coastal waters*. Journal of Coastal Conservation, 15, 369-392. DOI: https://doi.org/10.1007/s11852-010-0095-2.

Newton et al. 2014[26]), these sites are stressed and vulnerable to human impact (Pérez-Ruzafa et al. 2011).

Following the Water Framework Directive (WFD) implementation, lagoons are classified as transitional waters and subjected to the classification of the ecological status of selected Biological Quality Elements (BQEs) (McLusky and Elliott 2007)[27]. Among these, the soft bottom macrozoobenthos is a suitable ecological group sensitive to the effects of pollution (Newton et al. 2014), because of its rapid response to anthropogenic and environmental stress (Pearson & Rosenberg 1978[28]; Grall and Glemarec 1997[29]; Simboura & Zenetos 2002[30];). The evaluation includes the metrics Azti-Marine Biotic Index (AMBI, Borja et al. 2000[31]) and the multivariate AMBI (M-AMBI, Muxika et al. 2005[32]; 2007[33]), which are widely used European countries and WFD methodologies.

The Marano and Grado Lagoon is one of the largest (A = 160 km^2) and best conserved of the whole Mediterranean area: actually is recognised as a Site of Community Importance (SAC/SPA IT3320037). Previous studies report the spatial gradient of physico-chemical parameters (e.g., salinity) (Ferrarin et al. 2010[34]; Acquavita et al. 2015[35]), which delineates a biologically-based estuarine zonation responsible for the distribution of both macrozoobenthos species and fish fauna. Regarding the soft-bottom macrozoobenthos the first outlines on the composition of its macrofauna

---

[26] Newton A, Icely J, Cristina S, Brito A, Cardoso AC, Colijn F ... & Zaldívar JM (2014). *An overview of ecological status, vulnerability and future perspectives of European large shallow, semi-enclosed coastal systems, lagoons and transitional waters*. Estuarine, Coastal and Shelf Science, 140, 95-122. DOI: https://doi.org/10.1016/j.ecss.2013.05.023.

[27] McLusky DS & Elliott M (2007). *Transitional waters: a new approach, semantics or just muddying the waters?* Estuarine, Coastal and Shelf Science, 71(3-4), 359-363. DOI: https://doi.org/10.1016/j.ecss.2006.08.025.

[28] Pearson TH & Rosenberg R (1978). *Macrobenthic succession in relation to organic enrichmentand pollutionof the marine environment*. Oceanogr. Mar. Biol. A.Rev. 16, 229-331

[29] Grall J & Glémarec M (1997). *Bioévaluation des structures benthiques en rade de Brest*, in: Annales de l'Institut océanographique (Monaco). Vol. 73, No. 1, pp. 7-16.

[30] Simboura N & Zenetos A (2002). *Benthic indicators to use in ecological quality classification of Mediterranean soft bottom marine ecosystems, including a new biotic index*. Mediterranean Marine Science, 3(2), 77-111. DOI: https://doi.org/10.12681/mms.249.

[31] Borja A, Franco J, Pérez V (2000). *A marine biotic index to establish the ecological quality of soft-bottom benthos within European estuarine and coastal environments*. Mar. Pollut. Bull. 40, 1100–1114. DOI: https://doi.org/10.1016/S0025-326X(00)00061-8.

[32] Muxika I, Borj A, Bonne W (2005). *The suitability of the marine biotic index (AMBI) to new impact sources along European coasts*. Ecol. Ind. 5, 19-31. DOI: https://doi.org/10.1016/j.ecolind.2004.08.004.

[33] Muxika I, Borja A, Bald J (2007). *Using historical data, exert judgment and multivariate analysis in assessing reference conditions and benthic ecological status, according to the European Water Framework Directive*. Mar. Pollut. Bull. 55, 16–29. DOI: https://doi.org/10.1016/j.marpolbul.2006.05.025.

[34] Ferrarin C, Umgiesser G, Bajo M, Bellafiore D, De Pascalis, F, Ghezzo M, Mattassi G & Scroccaro, I (2010). *Hydraulic zonation of the lagoons of Marano and Grado, Italy*. A modeling approach. Estuar. Coast. Shelf Sci. 87, 561–572. DOI: https://doi.org/10.1016/j.ecss.2010.02.012.

[35] Acquavita A, Aleffi IF, Benci C, Bettoso N, Crevatin E, Milani L, Tamberlich F, Toniatti L, Barbieri P, Licen S & Mattassi G (2015). *Annual characterization of the nutrients and trophic state in a Mediterranean coastal lagoon: The Marano and Grado Lagoon (northern Adriatic Sea).* Reg. Stud. Mar. Sci. 2, 132–144. DOI: https://doi.org/10.1016/j.rsma.2015.08.017.

were reported by the pioneering study conducted by Vatova in the 1960s and the first comprehensive study was conducted by the University of Trieste (1993-1995) (Orel et al. 2001[36]).

In this work it is reported the comparison of this BQE ecological status before and after the entry in force of the WFD by considering sampling conducted with the same methodology (van Veen grab sampler of 0.047 m^2). The lagoon was divided into 17 water bodies on the basis of salinity: euhaline with salinity between 30-40, polyhaline (20-30) and mesohaline (5-20) (**Figure 9**).

__Figure 9__. The Marano and Grado Lagoon with the selected water bodies on salinity basis.

Samples were collected with constant frequency (2008, 2011, 2014, 2018 and 2021) with the same methods applied during the 1990s to permit a significant comparison of the dataset. The final dataset consists of 53 sites for a total of 159 collected samples from 1993 to 1995 and of 22 sites for a total of 106 collected samples from 2008 to 2021. This represent a good starting point to compare the evolution of the macrozoobenthos community over the last decades under the influence of anthropic and climate pressures.

The main results can be summarised as follows.

The comparison between the two periods showed that the system experienced a significant increase both in specific richness and Shannon-Wiener Diversity Index (**Figure 10**) and this was mainly due to the taxon Polychaeta, which is the most representative of muddy sediment also in terms of individual abundance.

[36] Orel G, Zamboni R, Grimm F, Zentilin A (2001). *Evoluzione dei popolamenti bentonici della Laguna di Marano e Grado (Adriatico Settentrionale) in un triennio di ricerche*. Biol. Mar. Medit. 8(1), 424-431.

Taking into account the degree of environmental disturbance (mean AMBI) it was found that macrozoobenthos was subjected to a slight disturbance for the most of water bodies and throughout the period considered (**Table 4**).

***Table 4**. Degree of environmental disturbance. Blue: undisturbed, green: slightly disturbed, yellow: moderately disturbed.*

	1993	1994	1995	2008	2011	2014	2018	2021
TME	3,13	2,7	2,95	3,05	3	3	3,22	3,1
TPO	2,67	2,66	2,15	3,49	3,07	3,29	2,78	3,03
TEU	2,68	2,11	0,69	3,13	3,11	3,09	2,94	2,27

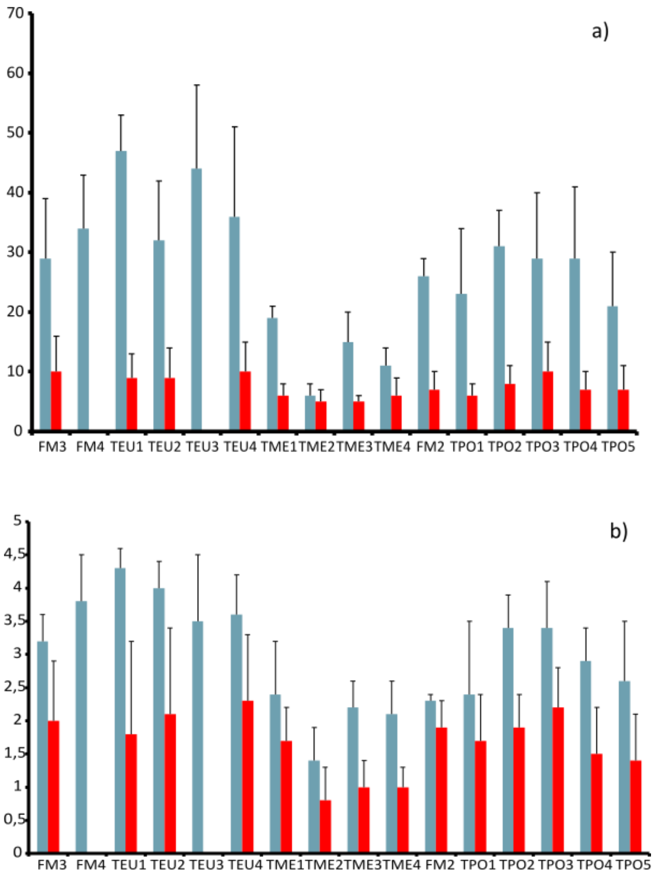


***Figure 10.** Mean number of taxa for water bodies (a) and mean Shannon-Wiener Index (b) in the periods 1993-1995 (red) and 2008-2021 (blue).*

The complete-linkage clustering regarding salinity/year (**Figure 11**) always grouped the mesohaline (TME) water bodies (group A), whereas the polyhaline (TPO) and euhaline (TEU) were grouped depending on the period: 1993-1995 (group B) and 2008-2021 (group C).

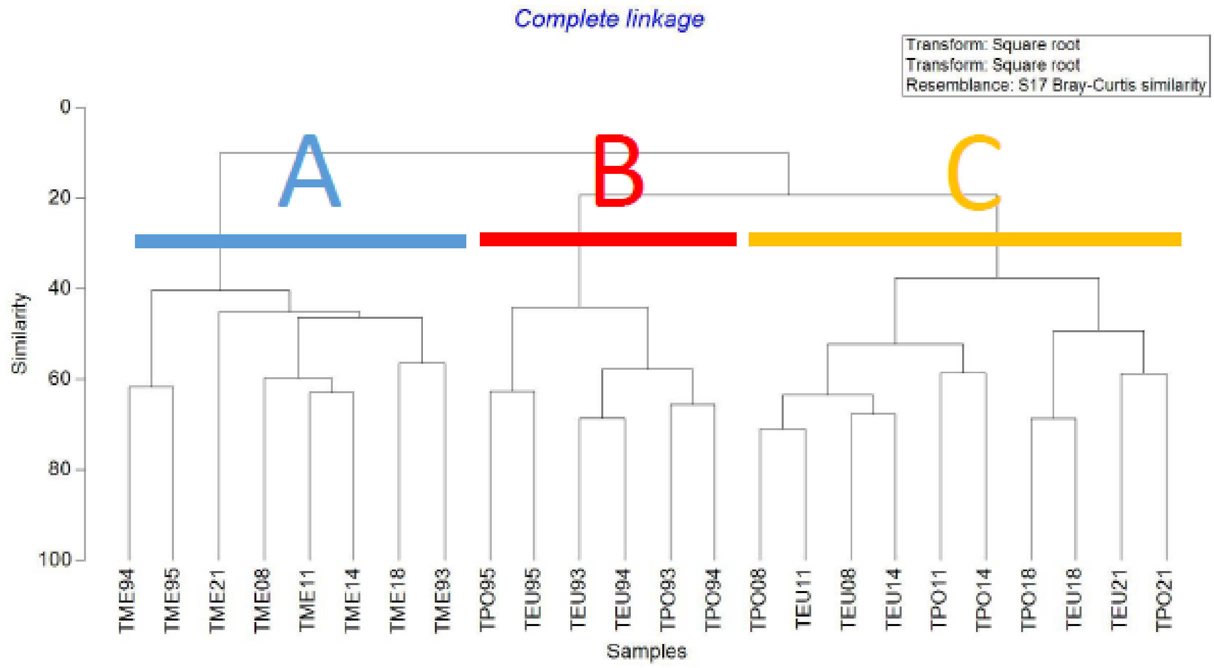


Figure 11*. Dendrogram typology salinity/year.*

The benthic zonation system of benthic biocenosis *sensu* Pérès and Picard (1964)[37] suggested that there was no substantial variation but an increase in biocenosis typical of the marine domain was recorded in the TEU water bodies such as a decrease of the LEE (Euryhaline and Eurythermal Lagoon biocenosis), which is well adapted to huge range of salinity and temperature (**Table 5**). It should be noted that this trend is not statistically significant.

[37] Pérès J, Picard J (1964). *Nouveau Manuel de Bionomie Benthique de la Mer Méditerranée*. Réc. Trav. Stat. Mar. Endoume 31, 5–137.

Table 5. Comparison of biocenosis sensu Pérès and Picard (1964).

TEU	1993_95	2008_21
Aff% DC	9,9	0,0
Aff% DE	0,0	1,3
Aff% LEE	38,8	23,4
Aff% SFBC	16,2	25,0
Aff% SFS	7,6	11,6
Aff% SVMC	27,5	29,6
Aff% VTC	0,0	9,1
Wilcoxon pair test		ns

In conclusion the analysis of macrozoobenthos in the Marano and Grado Lagoon system pointed out that:

- From 1993 to 2021 there is a significant increase in number of species especially in the area characterised by an active water renewal;
- The sea-level rising is inducing a marinization of the northern Adriatic lagoons. This evolution will probably improve the ecological quality of the water bodies *sensu* WFD. On the other hand, this trend could cause the loss of some peculiar characteristics of the lagoon environments. In fact, this latter display a lower bio-diversity but a higher productivity especially in terms of fishing and aquaculture activities;
- Finally, this study confirms the importance of mantainence of historical monitoring network conducted by standard methods.

Chapter 3 - Coastal erosion and beach drowning

According to the National Table on Coastal Erosion between the Italian Ministry of the Environment (MATTM) and the Regional Governments (with the technical coordination by ISPRA[38]), coastal erosion is the result of a of natural or induced process, or a series of processes, that modify the coastal morphology causing a loss of surface and a deficit in the sediment balance of the land over a given period of time relative to the mean sea level (MATTM-Regioni 2018[39]).

Therefore, when considering coastal erosion, spatial and temporal scales of observation should also be considered. This includes the issue of adaptation to the effects of climate change and projections of sea-level rise, which exacerbates coastal erosion.

A management perspective is necessary when talking about coastal erosion, as this phenomenon affects human activities and sometimes poses a real threat to human interests. If we consider infrastructure, urban settlements, agricultural and productive areas as rigid elements embedded in a highly dynamic context such as the coast, critical questions arise.

Coastal development over the last century has profoundly altered the morphology and functionality of coastal areas, stiffening an inherently dynamic system. According to Eurosion[40], the European Initiative for Sustainable Coastal Erosion Management, the number of people living in European coastal communities has doubled in 50 years, reaching almost 70 million in 2001 (Doody et al. 2007[41]). Economic interests in coastal areas are strong, with the total value of economic resources in terms of capital invested up to 500 metres from the coast rising to 500-1000 billion in 2000.

People and structures along the coast are exposed to a variety of risks, including (*i*) loss of areas of economic, social or ecological value, (*ii*) flooding from extreme events that can lead to the destruction of natural defences such as dunes, and (*iii*) the weakening of man-made defences whose protective function is compromised (Doody et al. 2007).

According to MATTM-Regioni (2018), the correct approach to the assessment and management of coastal erosion involves several steps (**Figure 12**):

- Identification and monitoring of morphological variations together with the evaluation of critical elements;

---

[38] Istituto Superiore per la Protezione dell'Ambiente (Italian Institute for the Environmental Protection).

[39] MATTM-Regioni (2018). *Linee Guida per la difesa della costa dai fenomeni di erosione e dagli effetti dei cambiamenti climatici. Versione 2018*. Edited by the National Table on Coastal Erosion MATTM-Regioni with the technical coordination by ISPRA, 305 pp.

[40] http://www.eurosion.org/

[41] Doody P, Ferreira M, Lombardo S, Lucius I, Misdrop R, Niesing H, Salman A, Smallengange M, Cipriani LE, Lanza S, Pranzini E & Randazzo G (2007). *Vivere con l'erosione costiera in Europa – Sedimenti e spazio per la sostenibilità. Risultati dello studio Eurosion*. Edited by the European Commission, 21 pp.

- Define a priority scale to identify the most urgent issues according to their level of criticality and risk;
- Estimation of economic needs and verification of available resources: the less resources are available, the fewer actions/measures can be implemented in the first phase of intervention;
- Planning of subsequent actions/measures, which should take into account the impact of climate change on the coastal unit under consideration. Annual or multiannual programmes must be based on the real resources, both economic and natural, available in a given period and on long-term planning;
- The objectives of planning and programming should be to identify and implement measures to solve or reduce the "unacceptable" critical problems.

Planning is a critical process in which analysis and assessment of the current situation helps to define a shared vision for the future between authorities and stakeholders, where planning, security and coastal development objectives also take into account the effects of climate change.

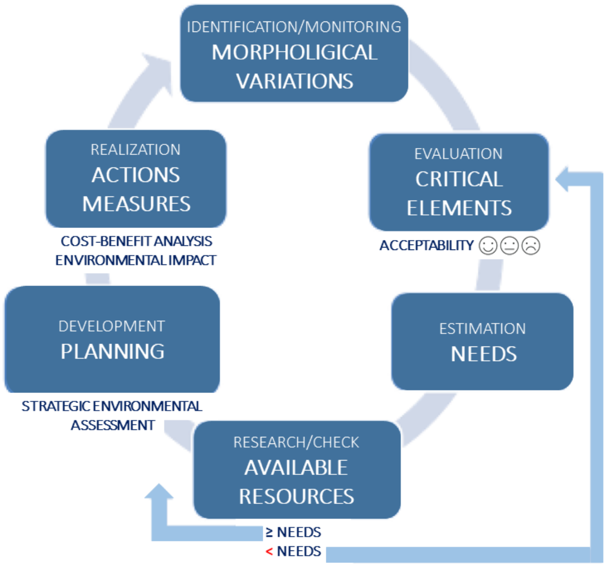


Figure 12*. Proposed scheme for a correct approach to coastal erosion assessment and management (from MATTM-Regioni 2018, modified).*

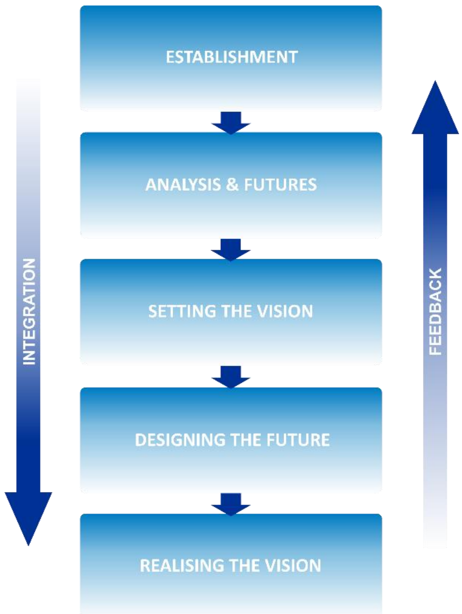


Figure 13*. Scheme of the ICZM process (from http://www.coastalwiki.org/wiki/The_ICZM_Process_-_a_Roadmap_towards_Coastal_Sustainability_-_Introduction)*

Since the Barcelona Convention (1976), Integrated Coastal Zone Management (ICZM) has been established for the Mediterranean. The ICZM provides a unified and integrated vision, taking into account the anthropic and natural elements that interact in coastal and transitional systems, and emphasising the issue of adaptation to climate change.

Integrated coastal planning (**Figure 13**) is the approach by which public administrations, economic actors, businesses, stakeholders and citizens establish common principles and guidelines to achieve a good state of sustainability in coastal development.

In the framework of the AdriaClim project, the Emilia Romagna region has developed its *Integrated Management Strategy for Coastal Protection and Adaptation to Climate Change* (GIDAC) following the ICZM guidelines. The GIDAC aims to reduce the vulnerability of the coastal area to make it a safe and resilient place where development and environmental sustainability are considered together.

In addition, an important participatory process was carried out to implement the ICZM principle of a unified and integrated vision, involving various stakeholders, both public and private, at local and regional level. The GIDAC is available here, https://ambiente.regione.emilia-romagna.it/it/suolo-bacino/argomenti/difesa-della-costa/gidac/gidac-dicembre-2022/, and is an important reference for the application of ICZM principles in other areas.

As far as beaches in tourist areas are concerned, they are natural resources that generate value and capital (Chelleri 2020, Master's thesis[42])). Beaches are not only places of entertainment, but also play a multiple role as a land-sea interface:

- Limitation of potential damage to natural coastal habitats due to wave action and erosion;
- Sediment reserve allowing natural beach nourishment through the continuous beach-dune recharge system;
- Dunes also protect the land behind them from wind, salt spray and storm surges.

The beach is practically the territory's first line of defence against seawater intrusion, thanks to its ability to effectively dissipate wave energy (MATTM-Regioni 2018).

Today, dune systems have largely been replaced by urban development, and the remaining dune environments are threatened by anthropisation and coastal erosion, as coastal retreat is often associated with dune demolition. In addition, climate change is exacerbating coastal erosion through sea level rise and extreme events. On the other hand, anthropisation interferes with natural beach dynamics and increases the phenomenon of subsidence (Chelleri 2020, Master's thesis and references therein).

[42] Chelleri A (2020). *Assetto ed erosione del litorale di Lignano: analisi e proposta di ripascimento* [Unpublished master degree thesis]. Università degli Studi di Udine and Università degli Studi di Trieste, 103 pp.

An important issue is the sediment budget. The supply of sediment from rivers is the main source of replenishment to coastal areas. However, since the industrial revolution, and especially during the 20th century, human activities have strongly influenced the sediment transport system. In particular, afforestation, damming of rivers, diversion of tributaries, damming and sand mining on the riverbed are responsible for the reduction of fluvial sediment loads, which have become insufficient to counteract natural subsidence, leading to delta drowning and erosion processes (Bezzi et al. 2021[43] and references therein).

3.1 – Lignano Sabbiadoro and the delta of the river Tagliamento

We focused on the area of Lignano Sabbiadoro (UD), which is an important hotspot for the regional economy in terms of summer tourism and the tertiary sector. Naturally, the most productive sectors in economic terms are hospitality, trade and services.

In 2019, the number of tourist arrivals[44] was 689,229 and the total number of presences[45] was 3,495,081 (**Figure 14**), confirming the strong tourist vocation of the town. On the other hand, the resident population in 2019 was 6837 units (Comune di Lignano Sabbiadoro 2022). Considering these values, it is easy to understand the importance of preserving the sandy beaches and the facilities related to the tourist experience, in view of the effects of climate change, such as coastal erosion.

	2010	2011	2012	2013	2014
ARRIVI	605.897	613.596	619.181	590.690	603.728
PRESENZE	3.750.216	3.801.194	3.700.435	3.463.232	3.409.896
	2015	**2016**	**2017**	**2018**	**2019**
ARRIVI	624.859	640.307	659.866	691.154	689.229
PRESENZE	3.427.889	3.497.306	3.584.952	3.573.934	3.495.081

Figure 14*. Tourist arrivals and total presences in Lignano Sabbiadoro in the time period 2010-2019 (from Comune di Lignano Sabbiadoro 2022).*

[43] Bezzi A, Pillon S, Popesso C, Casagrande G, Da Lio C, Martinucci D, Tosi L & Fontolan G (2021). *From rapid coastal collapse to slow sedimentary recovery: The morphological ups and downs of the modern Po Delta*. Estuarine, Coastal and Shelf Science, 260, 107499. DOI: https://doi.org/10.1016/j.ecss.2021.107499.

[44] Number of customers hosts in accommodation establishments, hotel or complementary establishments during the period in question.

[45] Number of nights spent by customers in accommodation establishments.

In addition to tourism, Lignano Sabbiadoro's economy is based on agriculture (grain and fodder production), industry (food, shipbuilding, construction, mechanical engineering, textiles, water treatment and distribution) and other tertiary sectors (banking, insurance, IT consultancy) (Comune di Lignano Sabbiadoro 2022).

An overview of land use is shown in **Figure 15**. The orange areas correspond to cultivated land (both intensive and extensive), brown areas correspond to urban settlements, gardens and parks are shown in blue, and active industrial sites are grey. The Corine biotopes[46] are shown in green and the wetlands in pink, as regards natural or semi-natural habitats. On the other hand, the areas marked with a black dotted line represent the Natura 2000 sites (or part of them) included in the municipal territory.

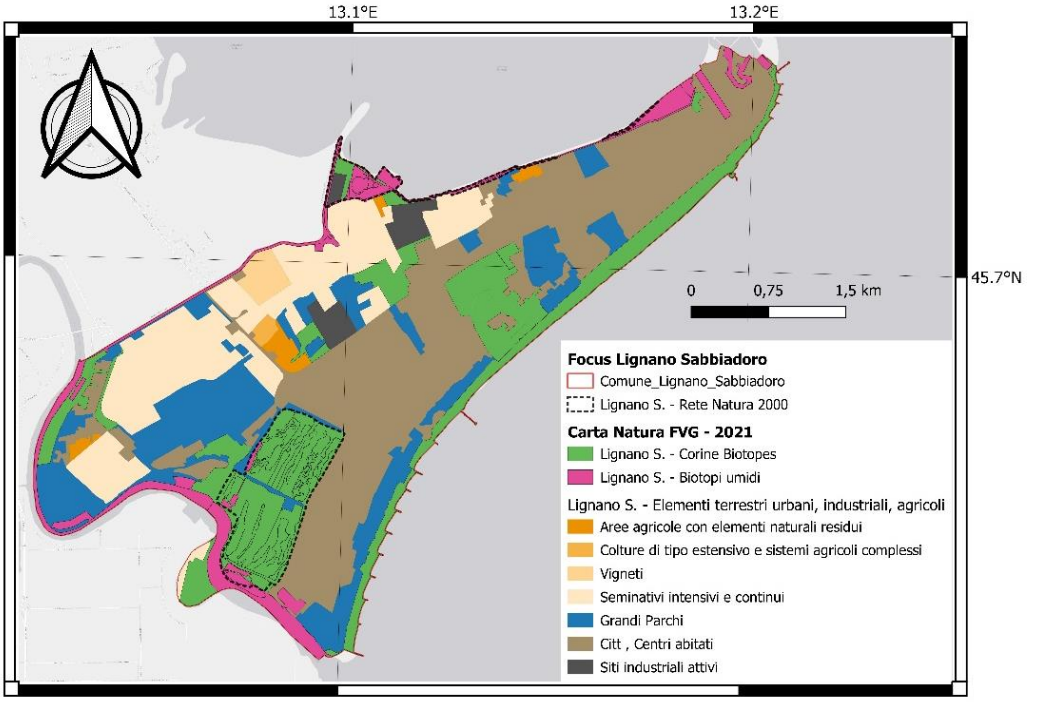


__Figure 15__. Land use according to the Corine biotopes classification in Lignano Sabbiadoro. The cartographic information is taken from Carta della Natura del Friuli Venezia Giulia ed. 2021[47].

---

[46] CORINE Biotopes is an EU initiative that was established to identify and define biotopes of major importance for environmental conservation in the European Community, https://www.isprambiente.gov.it/it/attivita/biodiversita/ispra-e-la-biodiversita/attivita-e-progetti/elenchi-degli-habitat-italiani.

[47] Regione Autonoma Friuli Venezia Giulia (2021). *Carta della Natura del Friuli Venezia Giulia*. Edited by Direzione centrale Difesa dell'ambiente, sviluppo sostenibile e energia - Servizio Valutazioni ambientali.

From a geographical point of view, the territory of Lignano lies between the mouth of the Tagliamento river and the Lignano inlet, the latter connects the Adriatic Sea to the Marano lagoon. The mouth of the Tagliamento River is the natural border between Friuli Venezia Giulia and Veneto regions.

Mirroring the Lignano littoral, beyond the Tagliamento delta to the west, is located the tourist resort of Bibione (VE) (**Figure 16**). Both Lignano and Bibione owe their fortunes to the Tagliamento river, which over time has created a coastline lined with attractive beaches. It should be noted that when considering the Lignano area and its coastal dynamic processes, it is necessary to take into account the entire Tagliamento Delta system in order to understand how sediment transport and deposition work.

Figure 16. *The Tagliamento delta between Friuli Venezia Giulia and Veneto. With respect to the mouth of the Tagliamento, Lignano Sabbiadoro (UD) lies to the right and Bibione (VE) to the left.*

The following is a simplified description of the formation of the Tagliamento Delta and some of the dynamic processes affecting the considered coastline, taken from Fontolan 2006[48].

The origin of the Tagliamento Delta goes back about 2000 years, through the progressive growth of the delta towards the sea ("progradation" in technical terms). Evidence of this growth can still be seen in the most apical part of the delta, where a series of dunes, interspersed with low ground, follow the coastal profile. The typical vegetation that has colonised these structures makes them easy to recognise, being arboreal in the dunes and shrubby in the depressions.

In any case, the progradation of the delta has been intermittent, with a succession of depositional moments of growth and stasis (**Figure 17**). There have also been periods of shoreline retreat due to anthropogenic pressures such as land use and modification.

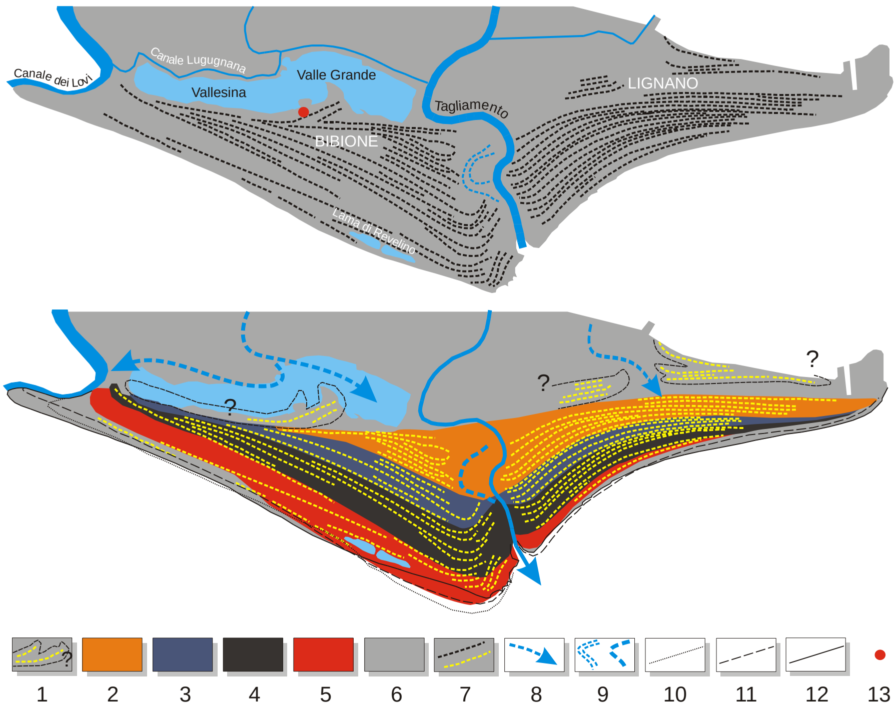


***Figure 17**. Reconstruction of the evolution of the Tagliamento delta: 1) hypothesis of an island system before the delta formation, Roman era; 2) Late Roman-medieval delta; 3) XVI-XVII century delta; 4) XVIII century delta; 5) XIX century delta; 6) current delta; 7) beach ridges and dune alignments; 8) ancient channels and lagoon waterways before the delta formation; 9) abandoned meander; 10) 1937 shoreline; 11) 1951 Bibione shoreline and 1954 Lignano shoreline; 12) 1998 shoreline; 13) archaeological remains of a seaside Roman villa (from Fontolan 2006).*

[48] Fontolan G (2006). *Il nastro litoraneo tra banchi di sabbia e moto ondoso*, in: Bianco F, Bondesan A, Paronuzzi P, Zanetti M & Zanferrari A. *Il Tagliamento.* Università di Udine, Circolo Menocchio - Cierre edizioni, Sommacampagna (VR), pp. 152-159.

The shape of the Tagliamento, the only modern example in the Adriatic, is due to the predominance of wave action over river action. Specifically, the ability of the waves to redistribute the sedimentary material transported by the river to the mouth is at the origin of this particular delta conformation. It is no coincidence that the mouth of the Tagliamento river is exposed to the Sirocco wind, which is responsible for the strongest sea storms in the northern Adriatic.

In any case, it is the river that is responsible for transporting sediment to the sea; for a long time, the river carried huge quantities of sand, which contributed to the growth of the seabed and the formation of the typical submerged sand bars that later became the dunes.

Dunes are morphologies that are typically anchored and fixed to the ground by the action of vegetation. In fact, when the wind blows on the first part of the beach, it carries a load of sand that it deposits about ten metres from the foreshore, where the vegetation grows and acts as a trap for the sediment.

Here, in the backshore area, the dunes can grow and stabilise, functioning as a sediment reservoir during the beach's winter crisis periods, where the erosive action of the waves returns sand to the foreshore and uppermost shoreface. This system, in which the sand moves back and forth from the foredunes to the beach and vice versa, allows the beach to be in a dynamic state of equilibrium.

This is true for natural dynamic processes, but coastal areas have been profoundly altered by human activities and constructions (such as coastal defences), both at the mouth and along the river bed, exacerbating the phenomenon of erosion. A coastal zone is in equilibrium when there is a mutual balance between sediments transported towards the delta and those distributed along the coast or removed from the sea.

Since the post-war reconstruction (World War II), human activities have massively interfered with the transport of river sediments. New economic activities, especially in agriculture, have led to coastal areas no longer being seen as marginal areas but as resources for tourism and development, resulting in the irreversible destruction of large parts of the dune system.

In the post-war period, the exploitation of the river intensified, especially the mining activities, which removed sediments intended to be transported by the river itself. This significantly reduced the amount of solid material entering the river’s mouth, as well as the ability of wave action to redistribute this material along the coast.

One of the most important indicators of coastal evolution processes is the behaviour of the coastline, whose changes can reveal the real trend of the coast (regression or progression of the beach). As far as the Tagliamento Delta is concerned, in the last two centuries the western of the Delta (Bibione) has undergone major changes, becoming concave or convex according to the different phases of accretion and erosion over time. The eastern side of the delta (Lignano), on the other hand, has maintained its usual trend, i.e. a clearly concave shape in the first part of the littoral.

In any case, the two 'wings' of the delta (the cusp sides) have been modified by the rotation of the system around two central fulcrums, one for each side. In fact, due to the limited input of solid material from the river, the coasts tend to self-adjust through the rotation of the beaches. Both the beaches of Lignano and Bibione have a point of rotation (black dots in **Figure 18**), which defines the areas where beach regression and progradation occur. For the Lignano area, it is in correspondence of Lignano Pineta resort.

It is clear that erosion (shoreline retreat) is occurring in the apical parts of the delta (Fig. 7, red arrows), in contrast to shoreline progression at the two opposite ends (Fig. 7, blue arrows), where sediments are being transported (Fig. 7, green arrows). This phenomenon is clear evidence of a recent process of self-balancing of the shoreline due to the lack of solid input from the river.

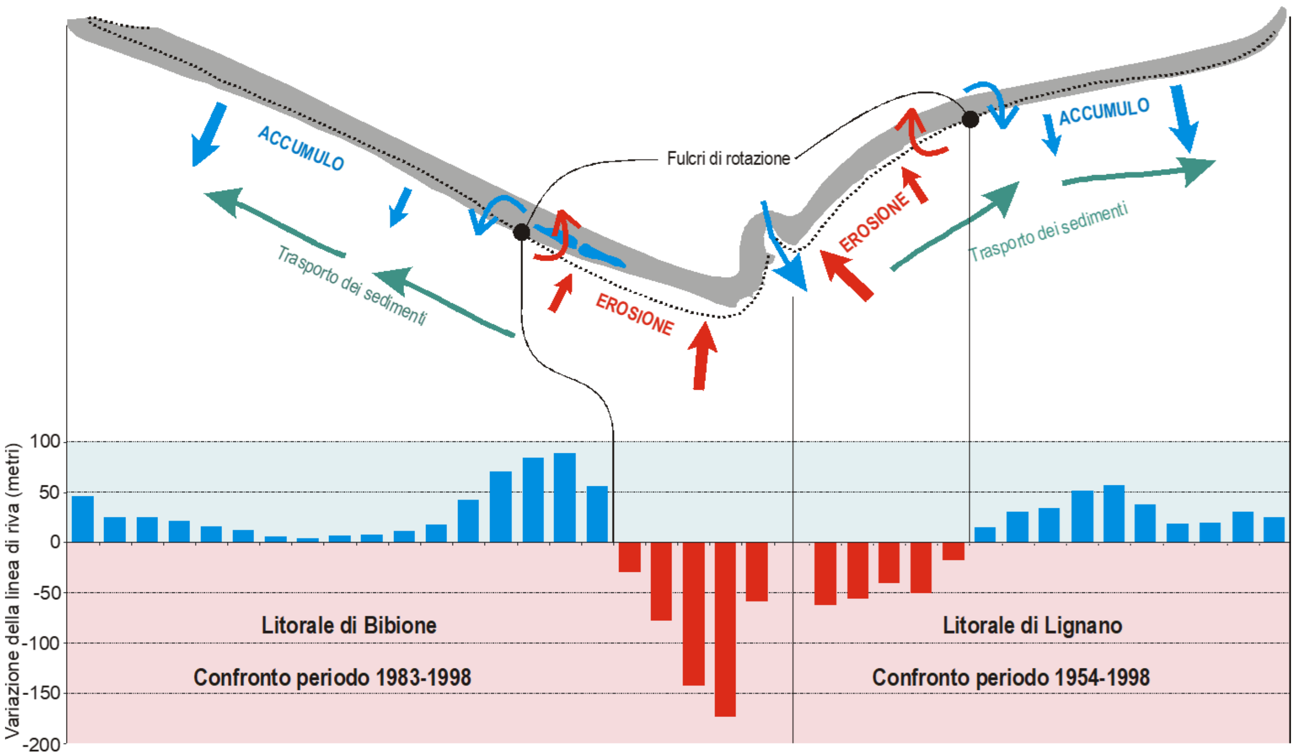


***Figure 18**. The recent evolution of the shoreline near the Tagliamento delta. Blue arrows = growth, red arrows = erosion, green arrows = sediment transport, black dots = beach rotation points, grey line = current shoreline, black dotted line = ancient shoreline. The histogram shows the shoreline variation in meters for Bibione on the left (reference period 1983-1998) and Lignano on the right (1954-1998) (from Fontolan 2006).*

In numerical terms, the overall sediment balance on the Lignano side is lower than that of Bibione, i.e. less sediment is being moved. In qualitative terms, however, Lignano, like Bibione, confirms the sediment deficit, as the material deposited does not compensate for the loss of sand. Again, the new solid input from the river is not enough to compensate for the wave action.

In the context of global sea level rise projections, the loss of riverine sediment transport could lead to 'beach drowning'. This would result in the loss of both the natural resource itself and the structures built directly on the beach, with severe consequences for local and regional economies.

In terms of adaptation, it is clear that the best possible solutions need to be studied, taking into account both the preservation of the beach and the environmental impact of the measures taken.

Available information from recent studies

There are two main winds that affect the Lignano coast: the north-eastern Bora, especially in autumn and winter, and the southern Sirocco and Libeccio. Although the Bora is the prevailing wind (the wind that blows for more days), the Sirocco is the dominant wind (the wind that blows with greater intensity) (Fontolan et al. 2005)[49].

Since sediment transport is controlled by wave action, it occurs in a north-easterly direction and is therefore influenced by southerly winds. In fact, most of the sediments come from the Tagliamento river basin (Fontolan 2006). This longshore transport is also evidenced by the sands trapped by the sea defences (groynes) on the western side of the Tagliamento estuary.

Since the 1950s it has been recognised that Lignano's coastline is subject to erosion. This phenomenon can be attributed both to a lack of sediment supply and to the action of storm surges. The latter has been exacerbated by the rigidity imposed on the coastline by the coastal defence works and by the high level of coastal urban development in the following decades (Chelleri 2020, Master's thesis and references therein).

Initially, coastal defences were built to contain the problem of erosion, in particular groynes and sea walls. However, the groynes contributed to beach accretion on the updrift side of the groin itself and to erosion on the downdrift side. This has contributed to the typical sawtooth pattern of the beach in the section immediately east of the mouth of the Tagliamento River (Brambati et al. 2004)[50].

---

[49] Fontolan G, Brambati A, Bezzi A, Delli Quadri F, Pillon S (2005). *Studio preliminare per la riqualificazione del litorale di Lignano Sabbiadoro*. Committed by the Lignano Municipality, 131 pp.

[50] Brambati A, Fontolan G, Pillon S, Schiozzi L, Gonella M, Atzeni P, Soldati M (2004). *Il litorale prospicente il lungomare Adriatico a Lignano: analisi dei processi di dissesto e proposte di intervento contro l'erosione marina*. 65pp.

In particular, the groynes located near the Lignano Riviera resort have led to a partial stabilisation of the beach between one groin and the next, and have therefore lacked the real effect of trapping sediment (Gordini et al. 2006)[51]. On the other hand, the retaining wall behind the beach, which runs along the entire coastline of the peninsula, has also favoured beach erosion during high tide and "acqua alta" conditions (Brambati 1985)[52]. In fact, the reflection of the waves contributes to the transfer of sand to the sea, especially in areas where the beach is very narrow.

In terms of the evolution of the Lignano coast, a recent study on the sedimentary balance was conducted, dividing the beach section into cells and comparing different time periods, beginning with historical data on the variation of the coastline, altimetric variation of the submarine beach, sedimentary balance, and sedimentological structure. Field studies have also been conducted to characterise the state of the shoreline and to provide macro-scale hypotheses about the treatments that will be implemented to counteract erosion.

The study started in 2018 with the signing of the implementation agreement between the Friuli Venezia Giulia Region (Central Directorate for Environment and Energy) and the University of Trieste, Department of Mathematics and Geosciences (Coastal Group). The collaboration was established to complete the “Study and morpho-sedimentological monitoring of the state of the coasts of the Friuli Venezia Giulia Region”, with the aim of integrated coastal zone management. (resolution n. 1995 by the Regional Council, 26 October 2018 and resolution by the Department Council, 14 November 2018). The cooperation agreement, in application of the framework agreement between the Friuli Venezia Giulia Region and the University of Trieste (DGR 264/2014), provides for the performance of a public service through an appropriate division of tasks between the University and the Region

Some of the study's findings, particularly those describing the coastal evolution of Lignano, are shown here, courtesy of the Coastal Group. The information below is drawn from the “Report on Activities - June 2022”[53], which reiterates the necessity for an institutional monitoring plan for Friuli Venezia Giulia's low sandy coastlines, as required by the Bologna Charter.

---

[51] Gordini E, Marocco R, Ramella R (2006). *Dinamica morfologica del litorale del delta del Fiume Tagliamento (Adriatico Settentrionale) in relazione ai possibili interventi di ripascimento*. Il Quaternario, 19, 45-65 pp.

[52] Brambati A (1985). *Studio sedimentologico marittimo costiero dei litorali del Friuli-Venezia Giulia, Regione Autonoma Friuli-Venezia Giulia*. 665 pp.

[53] RAFVG-Dir. Centrale Ambiente ed Energia & UNITS-Dip.to Matematica e Geoscienze (2022). *Accordo attuativo di collaborazione per lo studio e monitoraggio morfo-sedimentologico dello stato dei litorali della Regione Friuli Venezia Giulia finalizzato alla gestione integrata della zona costiera in applicazione alla Convenzione Quadro tra la Regione Autonoma Friuli Venezia Giulia e l’Università degli Studi di Trieste (DGR 264/2014). Relazione delle Attività - Giugno 2022*. Responsabili scientifici: Bratus A & Fontolan G. Gruppo di lavoro: Bieker F, Colombetta L, Gallitelli D, Lipizer M, Sgambati F, Bezzi A, Bussi M, Casagrande G, Fernetti M, Furlani S, Martinucci D, Pillon S, Sponza S; courtesy of Coastal Group.

SEDIMENT BALANCE

The sediment balance is calculated by comparing the volume of material entering and leaving a certain coastal area to the erosion or accretion that occurs as a result. It is usually represented as a cycle of positive (surplus) or negative (deficit) balance, rather than a state of equilibrium (stability). (Pranzini 1994)[54].

Using sediment cells[55] instead of assuming an overall sediment balance allows for a more precise examination of the balance of each individual section of the beach. The Tagliamento River is the main sediment tributary for Lignano, however the volume of material carried is unknown.

As a result of the use of sediment cells, a volumetric study, i.e. an examination of the temporal variation of the volume of sediment present on the beach, was carried out, beginning with topo-bathymetric profiles. It was also possible to compute how far the coastline had moved forward or backward over time.

Lignano's seashore is divided into three areas that correspond to the urban settlements that grew over time. From south-west to north-east, these are Riviera, Pineta and Sabbiadoro (**Figure 19**). Several beach replenishment programmes have been implemented over time (**Table 6Table 2**), demonstrating the necessity of keeping the area functioning for tourist purposes.

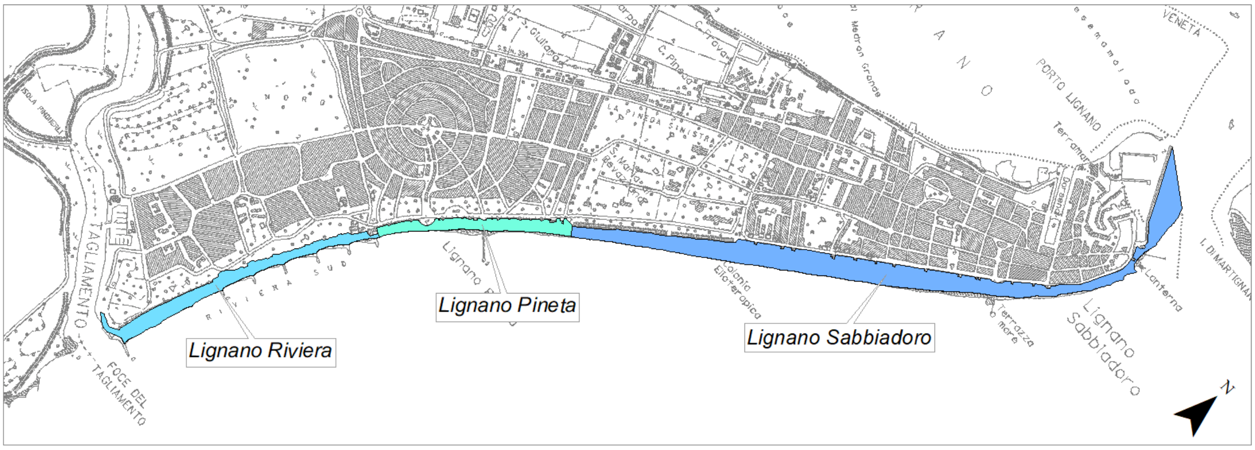


***Figure 19**. Subdivision of the littoral of Lignano in three areas (courtesy of Coastal Group).*

54 Pranzini E (2004). *La forma delle coste, geomorfologia costiera impatto antropico e difesa dei litorali.* Zanichelli, 245 pp.

55 The sediment cell is defined as a coastal compartment that contains a complete sediment cycle, including source, transport and deposition (Doody et al. 2007).

Table 6. *Beach nourishment interventions authorized by the FVG Region Lignano coast (courtesy of Coastal Group).*

YEAR	REGIONAL DECREE	BEACH NOURISHED	QUANTITY [mc] (authorized)
2016-2017	n. 217 18/02/2016	Pineta	76.000 total
2016-2017	n. 315 02/03/2016	Sabbiadoro	80.000 total
2015	n. 243 19/02/2015	Sabbiadoro	55.000
2014	n. 788 30/04/2014	Sabbiadoro	7.500
2013	n. 1829 05/08/2013	Sabbiadoro	37.500
2012-2013	n. 215 06/02/2012	Pineta	80.000 total
2011	n. 738 11/04/2011	Pineta	46.000
2009	n. 65 27/01/2009	Pineta	10.000
2008-2011	n. 2165 11/11/2008	Pineta	138.000 total
2007-2009	n, 69 23/01/2007	Sabbiadoro	104.000 total
2006-2008	n. 2913 23/11/2005	Pineta	max 50.000/year
2005	n. 639 30/03/2005	Pineta	24.000
2004	n. 437 24/03/2004	Pineta	20.000

Figure 20. *Planimetry of topo-bathymetric profiles of the Lignano coast (courtesy of Coastal Group).*

As concerns the surveys carried out by the Coastal Group of the University of Trieste, in April 2022 a topo-bathymetric campaign on the Lignano coast was organised. A series of profiles perpendicular to the coastline were produced, corresponding to the 2003 OGS[56] survey and, in 3 cases, to a previous survey dating back to 1968 (**Figure 20**).

The first step in fulfilling the Implementing Agreement for the assessment of the coast and its recent evolution, which includes the formation of a coastal database in a GIS environment (geodatabase), was to consider the variables that regulate the following aspects:

- altimetric variation of the seabed and sedimentary balance;
- geomorphological characteristics of the beach system, as the beach width and the slope of the upper shoreface;
- changes in the shoreline over time;
- sedimentology and colorimetry;
- coastal defences.

Figure 21*. Lignano coastal cells and their coding according to the corresponding 1968 section code, from 54 to 47 (courtesy of Coastal Group).*

[56] National Institute of Oceanography and Applied Geophysics based in Trieste.

The shoreline was then divided into sections based on the variables collected and entered into the geodatabase. Thus, for the Lignano coast, eight coastal cells were chosen and arranged so that each had a barycentric 1968 section (**Figure 21**). The coastal cells defined in this manner reflect the smallest unit of aggregation of the data gathered at the low, sandy coastal level in terms of the sediment budget and the evolution of the coastline.

Characterising the sediment balance of a specific coastal area can be done at different time scales to depict short-term conditions, or for longer periods by selecting appropriate time intervals. The sediment balance research is crucial and serves as the primary tool for coastal management and planning (RAFVG & UNITS 2022, and references therein).

Table 7 shows topo-bathymetric sections from the Lignano shoreline that were studied at various time scale levels..

Table 7. *Time intervals for comparing the Lignano shoreline at different time scales.*

<table>
<tr><th>COASTAL AREA</th><th colspan="15">TIME INTERVAL</th></tr>
<tr><td>Lignano Sabbiadoro and Riviera</td><td colspan="3">1968-2003</td><td colspan="3">2003-2018</td><td colspan="3">1968-2018</td><td colspan="3">2003-2022</td><td colspan="3">1968-2022</td></tr>
<tr><td>Lignano Pineta</td><td colspan="5">1968-2003</td><td colspan="5">2003-2022</td><td colspan="5">1968-2022</td></tr>
</table>

The sediment balance was calculated up to the closure depth of 6 m using a series of digital elaborations that included converting topo-bathimetric data into DTMs. Furthermore, time intervals were clustered in two-time classes, which improved the data's analytical and representational consistency:

- long-term (the longest time interval available on the stretch of coast in question);
- short-term (the most recent time interval available on the stretch of coast in question).

For the Lignano area, the long-term period is 1968-2022, while the short-term period is 2003-2022.

Table 8 presents the results, which are graphically represented in the figures below. **Figure 22** and **Figure 23** depict the sediment budget (m^3/m) and annual rate ($m^3/m*year$) for each reported coastal cell, i.e. the areas undergoing accretion (positive values) or erosion (negative values) across long and short time scales.

Table 8. The results of the sediment budget analysis for the Lignano coastline area (courtesy of Coastal Group).

SECTION	2022-2003 (m^3/m)	2022-2003 RATE $(m^3/m * year)$	2022-1968 (m^3/m)	2022-1968 RATE $(m^3/m * year)$
54	-227.06	-11.95	787.82	14.59
53	71.94	3.79	650.32	12.04
52	126.98	6.68	585.74	10.85
51	315.72	16.62	692.44	12.82
50	692.98	36.47	1076.86	19.94
49	447.26	23.54	448.70	8.31
48	237.24	12.49	83.14	1.54
47	703.14	37.01	241.56	4.47

It is important to note that the shorter the time interval, the more sensitive the data, because the range of values obtained is larger when fewer years are considered. However, the short term is also important since it may highlight the current trend, as illustrated in section 47 of **Figure 23**, which corresponds to the so-called "spiaggia dei cani," which has been subject to severe accretion processes in recent years.

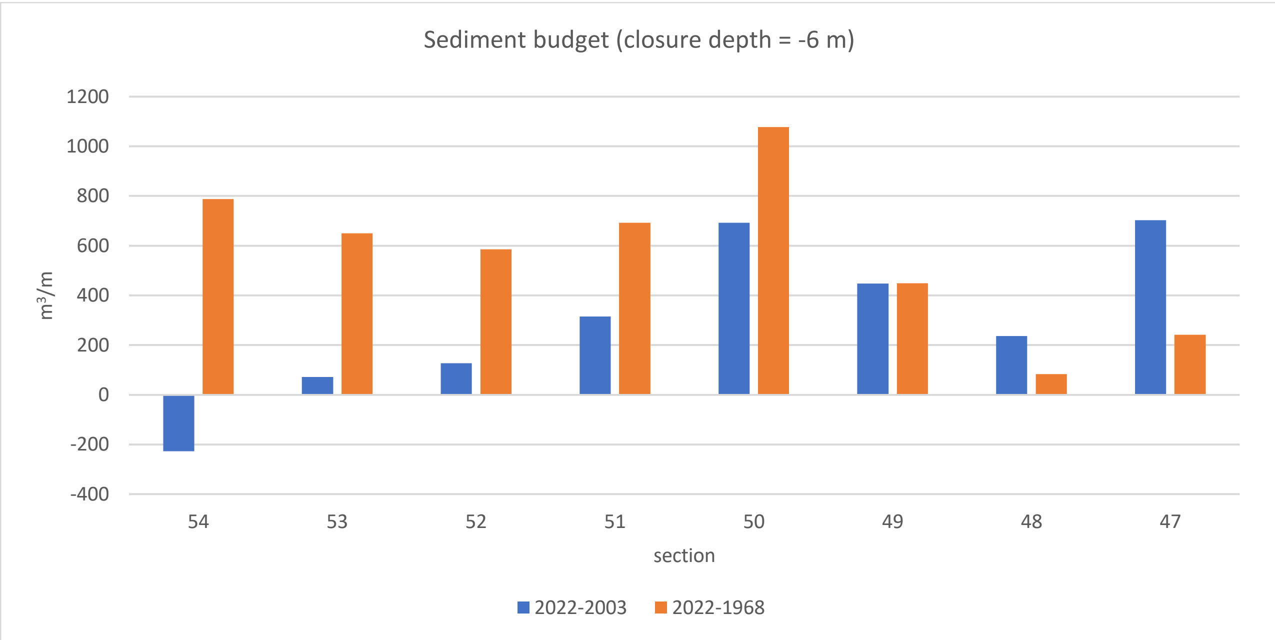


Figure 22. Long term (orange) and short-term (blue) sediment budget at a closure depth of -6 m for the physiographic units of the Lignano coastal area.

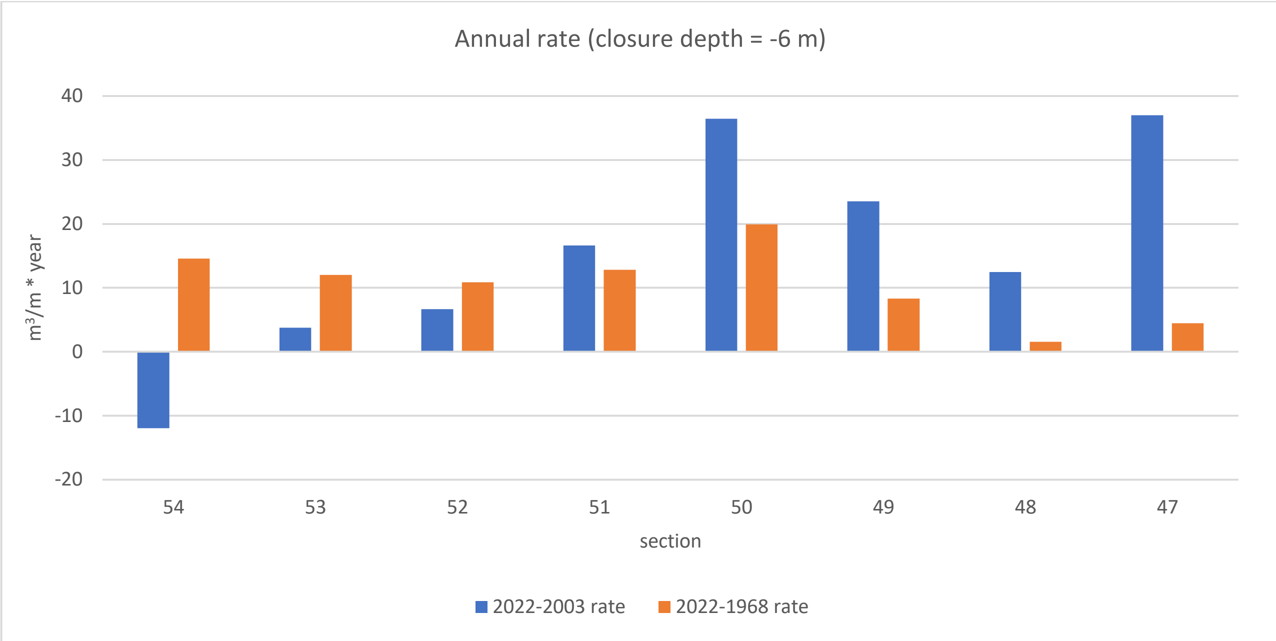


Figure 23*. Long term (orange) and short-term (blue) annual rate of accretion (positive values) and erosion (negative values) at a closure depth of -6 m for the physiographic units of the Lignano coastal area.*

SHORELINE EVOLUTION

Shoreline evolution has been calculated for the period intervals 1954-1978, 1978-1903, 2003-2012, 2012-2018, and 1954-2018, using the parameter *End Point Rate*[57], which is the annual rate of change between the oldest and most recent shoreline (**Figure 24**).

New transects were gathered using the DSAS[58] software and allocated to the reference coastal cell (54-47 in **Figure 21** are the cells for the Lignano coastal area). These elaborations resulted in a set of statistical values relating to the shoreline and coastal cell.

[57] «The End Point Rate is calculated by dividing the distance of shoreline movement by the time elapsed between the two shorelines. The rate is reported in meters per year with positive values indicating accretion and negative values indicating erosion» (USGS).
[58] Digital Shoreline Analysis System, an ESRI ArcGIS extension created by USGS (United States Geological Survey).

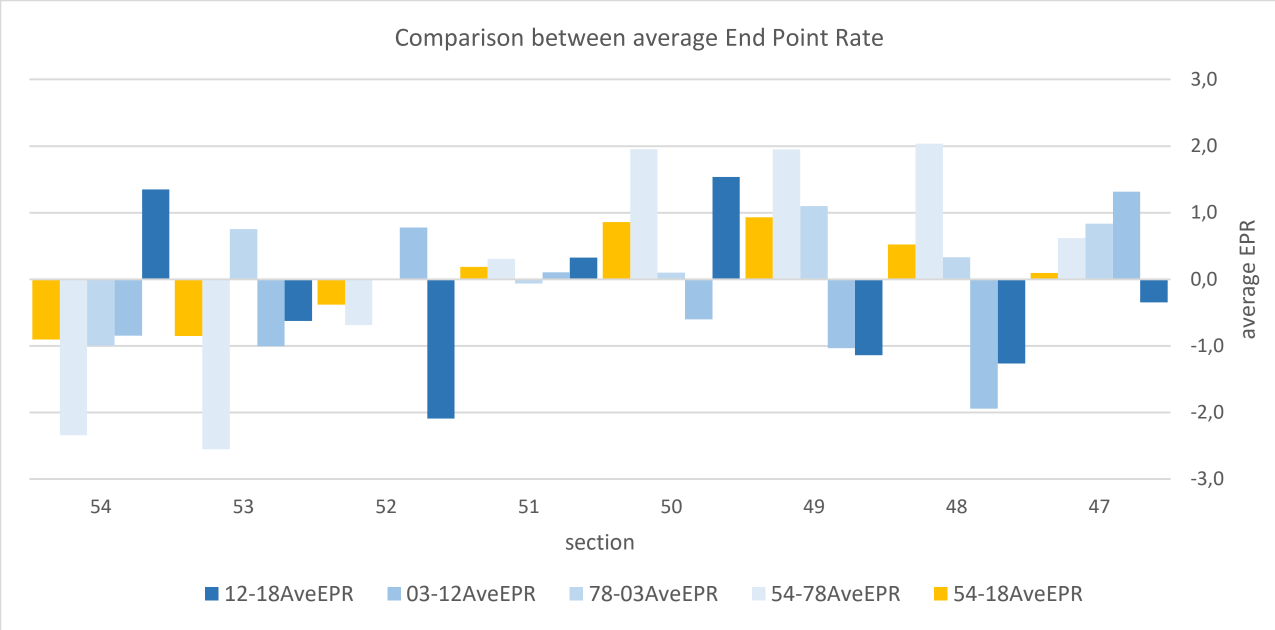


Figure 24. *Comparison of the average End Point Rate at various time intervals for each section of the Lignano area (courtesy of Coastal Group).*

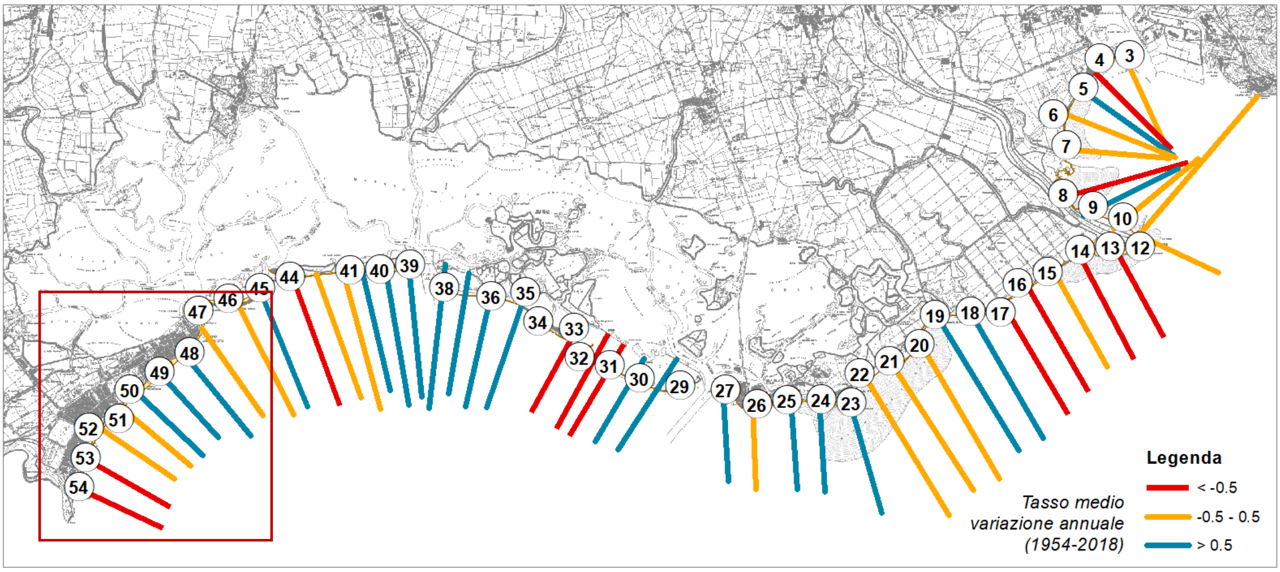


Figure 25*. Representation of the average End Point Rate (m) per coastal cell over the period 1954-2018. < -0.5 m (red), -0.5 – 0.5 m (yellow), > 0.5 (red). In the red square is the Lignano coastal area (courtesy of Coastal Group).*

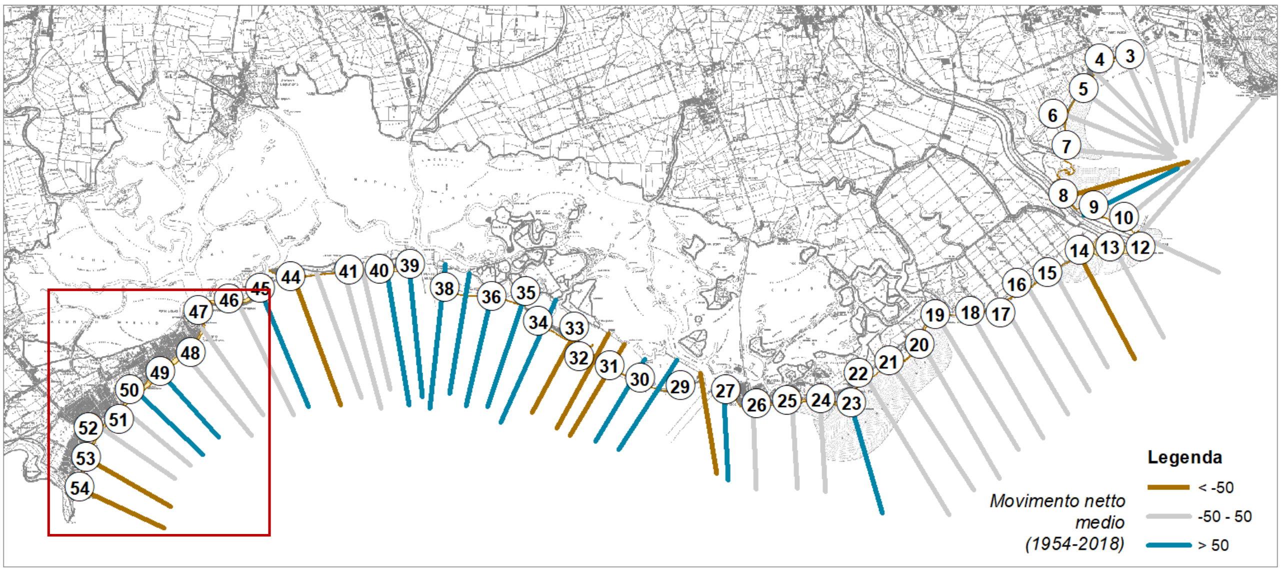


Figure 26. Representation of the average Net Shoreline Movement (m) per littoral cell in the interval 1954-2018. < -50 m (brown), -50 – 50 m (grey), > 50 (blue). In the red square is the Lignano coastal area (courtesy of Coastal Group).

Figure 25 shows the average annual rate of shoreline change per coastal cell from 1954 to 2018, whereas **Figure 26** shows the average Net Shoreline Movement per littoral cell during the same time period.

As it can be seen, the area where the coastline retreated in the period 1954-2018 was the area close to the Tagliamento Delta (Lignano Riviera), at a rate of < -0.5m/year. On the other hand, the area of Lignano Pineta has been characterised by a stable trend, without forgetting that in this area there is the pivot (point of rotation) of the entire Lignano coast (**Figure 18**).

On the one hand, a positive trend is confirmed for the peninsula's northeastern margin ("spiaggia dei cani"), where the average EPR shows more than 0.5 m/year coastal advance. Net Shoreline Movement data, on the other hand, show stability rather than advancement in this area. Between 1954 and 2018, the shoreline remained within a -50 - +50 m range. The positive trend in the area, as indicated by the short-term sediment balance estimate, is thought to have started more recently. These signals may not yet have been captured over a long time span, such as 1954-2018.

3.2 – Stakeholder and expert consultation

In 2021, a webinar series explaining the AdriaClim project was organised in partnership with the RESPONSe Italy-Croatia Interreg project (2019-2022). ARPA FVG (AdriaClim) collaborated with APE FVG and Informest (RESPONSe) to organise the event.

Four meetings were organised to discuss "Climate change and local adaptation in coastal and lagoon areas of Friuli Venezia Giulia" and represented an opportunity to establish initial contacts with some stakeholders on which we based subsequent interactions (for more specific information, see D5.3.1).

In particular, some key players were involved such as the Lignano Beach Management Consortium, the Municipality of Lignano and the University of Trieste with the Coastal Group of the Mathematics and Geoscience Department.

Discussions were held with the Lignano Town *Planning - Private Building Office* to better understand the needs and ambitions of local administrators and policy makers. As a result of these meetings, a possible working plan was drawn up to define some points in a shared management perspective between local partners, both public and private. Once the impact (coastal erosion) had been identified, the conceptual framework for taking action and adapting measures was established. (**Table 9**).

Table 9. *A possible work plan for the implementation of adaptation to the effects of climate change with regard to coastal erosion and the area of Lignano.*

IMPACT	Coastal erosion (beach erosion)		
GENERAL AIM	Adaptation: impact prevention and minimisation		
ADRIACLIM OBJECTIVE	Contributing in a shared Management and Development Plan		
FIELD OF ACTION	Knowing	Communicating	Acting
SPECIFICAL NEEDS	Improving the impact-related knowledge	Involving and raising awareness in stakeholders and local community	Improving impact management capacity Overcoming fragmented approaches and limited interaction between stakeholders

GENERAL ACTIONS	Generating the necessary knowledge		Information on possible adaptation measures, in order to be able to choose and evaluate their effectiveness in the future Disseminating knowledge in an effective and motivating way	Promote the integration and coordination of roles and competencies in the management of interventions by outlining and sharing hypotheses (Management and Development Plan)
	Understanding (the current impact)	Predicting (the future impact)		
AVAILABLE SOURCES AND/OR TOOLS	Studies already completed (University of Trieste; FVG Region) Documentation and testimonies from stakeholders	Modelling results and outputs (AdriaClim)		Available platforms and directories for adaptation measures (PNACC, ClimateMenu, ClimateAdapt, Adriadapt etc.) CReIAMO PA L5 methodological support on governance models
ACTIVITIES PRODUCTS TOOLS TO BE IMPLEMENTED	Survey and analysis of scientific sources Stakeholder interviews	Digital elaborations and cartography starting from modelling outputs (AdriaClim) Risk and vulnerability assessment	Fact sheets Slides	Survey on possible adaptation measures Coordination Plan among Agencies, Public Bodies and stakeholders and the planning and management tools of pertinence Sheets and extracts from the Management and Development Plan
SHARING - PARTICIPATION	Consulting experts and partners Stakeholder meetings		Public events Exhibitions and art installations	Sharing knowledge and vision through workshops involving all stakeholders

By the way, the Municipality of Lignano has already demonstrated that it is concerned about the effects of climate change by developing the SECAP-Sustainable Energy and Climate Action Plan in 2022, which analyses current and future energy consumption, creates an inventory of current and future CO_2 emissions (up to 2030), considers mitigation measures, assesses risk and vulnerability, and proposes adaptation measures to be implemented by 2030.

A number of priorities emerged from the meetings with Lignano Town Council officials:

- Beach erosion is a hot topic that is receiving a lot of attention from the municipality and beach managers.
- Municipal officials and beach managers feel that the seasonal distribution of storm events has changed compared to the past. In other words, extreme summer events seem to be on the increase, with a disruptive effect on the tourist season. In contrast, summer seasons seem to have been more stable in the past.
- It would be useful to understand how erosion will vary in the future and to assess how the risk varies in different sections of the beach. This would require tools and knowledge related to sediment and erosion dynamics in addition to the results of the AdriaClim modelling activities (which only address hazards, i.e. sources of hazards such as sea level and current variations).
- There is an urgent need for communication to spread information and increase awareness, both among stakeholders (e.g., beach managers) and the general public (mainly inhabitants, but also tourists).
- The municipality bears no specific responsibility for coastline conservation, and beach nourishment is the responsibility of the Friuli Venezia Giulia Region. In terms of beach protection, each beach manager has his or her own approach, and the Municipality is only barely involved, overseeing a few minor lengths of beach. The roles and actions of the many actors are fairly 'disjointed' when it comes to addressing an issue that, given the future trends and scenarios indicated, would increasingly demand a shared vision and strong synergy.

Experts guidelines on approaching coastal erosion management and climate change

A series of expert meetings were then planned in order to gather knowledge on coastal dynamics in the Lignano area. The Coastal Group, which is made up of geologists from the Department of Mathematics and Geosciences (DMG) at the University of Trieste who are experts in coastal dynamics, was consulted.

Key concepts were defined to guide coastal erosion assessments:

- **Bibliographical database and time series**
  Examining coastal erosion phenomena requires an approach that takes several factors into account. Some of them concern the bibliographical sources to be consulted, which must include technical and scientific studies based also on field surveys. For example, an important case study on coastal storms is featured in the Geological Atlas of the Province of Venice[59] (2011). The authors estimated the sensitivity of the Venetian coastline to the risk of coastal storms using a risk-vulnerability assessment

  It is not worth considering time series covering the last five years (starting from the year of assessment). In fact, time series that are too recent make a proper assessment impossible, as they cover too short a time span to assess a coastal evolution trend. A good dataset should cover at least the last ten years. Bezzi et al. (2021) provide a good methodological reference for assessing the morphological changes and trends of the modern Po Delta.

- **Discretization of coast sections**
  It is necessary to start from the subdivision of the coastline under consideration and to identify the homogeneous characteristics of each coastal section to be discretised. As a result, the risk analysis can provide various conclusions based on the features of each specified coastline sector. The most important forcing on a beach, wave energy, must be considered using the same methods. In essence, wave energy should be computed on a sectional basis, that is, for each of the recognised coastline sections (e.g., at a 1 km scale). This allows us to identify hotspots where wave energy has the most impact.

  For example, the beach of the Martignano island is the barycentre of the sediment balance between Lignano and Sant'Andrea Island. Periodically, the Martignano beach is subjected to overwash[60] because it has a very narrow sandy barrier that easily breaks. This represents a littoral hotspot.

[59] Provincia di Venezia - Assessore all'Ambiente Servizio Geologico, Difesa del Suolo e Tutela del Territorio (2011). *Atlante Geologico della Provincia di Venezia - Note Illustrative*. Edited by Andrea Vitturi. Arti Grafiche Venete srl – Quarto d'Altino (VE), 874 pp.

[60] «Overwash is the flow of water and sediment over the crest of the beach that does not directly return to the water body where it originated. Overwash occurs if either wave runup level or storm surge level exceeds beach crest height» (Donnelly C, Kraus N & Larson M (2006). *State of Knowledge on Measurement and Modeling of Coastal Overwash*. Journal of Coastal Research, 224, 965-991. DOI: https://doi.org/10.2112/04-0431.1.

- **Physical variables**
  What are the physical variables that describe and represent coastal erosion? First of all, the slope, which is a function of the grain size. The latter can be ignored because it is included in the slope. Then it is fundamental to consider the whole beach system, which includes the subaerial (beach) and the submerged (shoreface) parts. In fact, it is in the upper shoreface that the most important erosion and deposition processes take place. Moreover, if the shoreface has a very gentle slope, the energy of the waves is dissipated (the beaches of Lignano are dissipative[61]). As for the beach s.s., it is able to dissipate the energy of the waves or not according to its width.

  In general, a coastline that shows a negative evolutionary trend (coastline retreat) is due to the steep slope and narrow width of the beach. These are the factors that determine the greatest vulnerability of the beach to erosion. However, it is good to know that in erosion phenomena, most of the sediment is lost in the submerged part.

- **Depth of closure**
  In this context, it is necessary to assess the depth of closure, i.e. the point beyond which waves no longer have a measurable effect on the seabed. The depth of closure represents the point beyond which sediment no longer moves. It is a discrete variable and for the North Adriatic it is about 5 metres (Fontolan et al. 2011)[62]. It should not be confused with the wave base level, i.e. the thickness of the water layer affected by wave action. In shallow waters, the depth of closure is more important because it determines the depth at which, towards the coast, the waves begin to interfere and significantly modify the seabed.

- **Run up and set up**
  In terms of the emerged beach, it is useful to calculate the wave run-up, i.e. the measurement of the maximum vertical rise of the wave relative to the shore, which is a function of both the height of the wave hitting the shore and the characteristics of the shore on which the water mass hits. The wave set-up, on the other hand, is the rise in mean sea level due to the wave motion hitting the shore, tides and wind action (**Figure 27**). These parameters are useful in the context of sea level rise and storm surge assessments.

[61] Dissipative beaches: sandy beaches with a shallow slope and a large landslide zone. Beaches with one or more submerged bars (Chelleri 2020, Master's thesis).

[62] Fontolan G, Bezzi A, Pillon S (2011). *Rischio da mareggiata*, in: Vitturi A. *Atlante Geologico della Provincia di Venezia. Cartografie e Note illustrative*. Provincia di Venezia, ISBN 978-88-907207- 0-3, pp. 581–600.

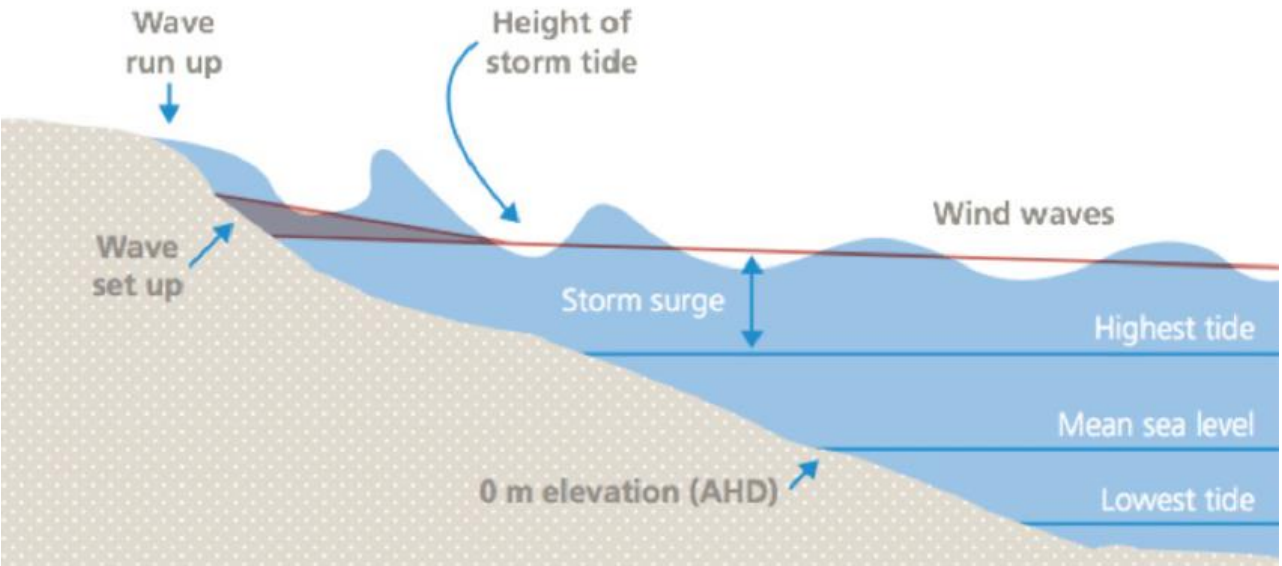


***Figure 27**. Representation of wave run up and wave set up (from https://www.davidegaeta.com/post/wave-setup-wave-setdown).*

- **Appropriate reference in shoreline assessment**
  The trend of the shoreline is an important variable in the coastal evolutionary dynamics of the beach. In this context, it is crucial to maintain the same reference point over the years. If the reference point is shifted from one year to the next, the shoreline assessment fails because the data are no longer comparable and therefore not reliable.

  As far as the Lignano area is concerned, the most recent surveys available date back to 2021, when the Coastal Group of the University of Trieste carried out a study commissioned by the Geological Office of the Friuli Venezia Giulia Region for the implementation of the Coastal Protection Plan currently being drafted. There are also other older studies (early 2000s), but the transects where the topographic surveys were carried out do not overlap with each other or with the recent DMG work and are therefore not usable.

- **Sediment budget**
  Information on the sediment budget of the beach is of fundamental importance as it considers both the beach and upper shoreface. The elements that affect sediment transport include not only human activities (as mentioned above) but also coastal defences, which are diverse and need to be discretized. There are rigid (such as groins,

breakwaters, artificial reefs and jetties), soft or mixed coastal defences. The dunes can be considered soft defences and, as well as protecting the beach from erosion, they also act as a sediment reservoir, returning sand to the beach during the winter crisis (dotted line in **Figure 28**).

In general, it is important to collect as much information as possible on the sediment budget of the coastline under consideration, which can be derived from estimates of the beach area or from sections of beach monitored over time. These can become real monitoring stations for future assessments.

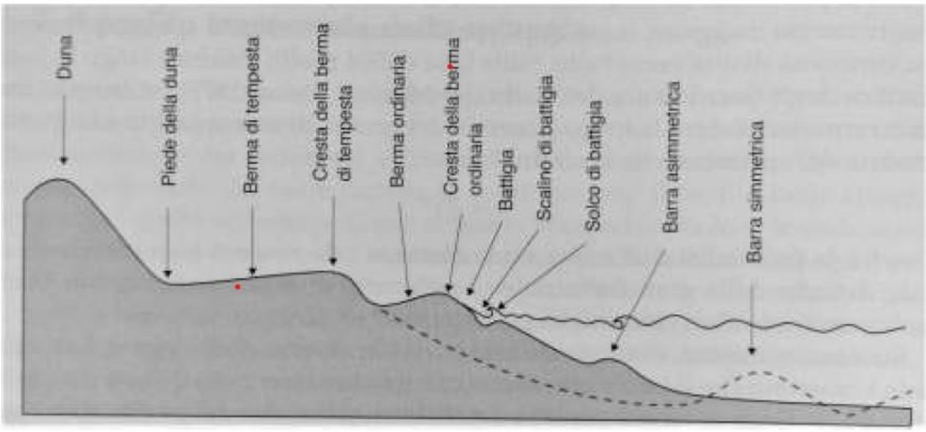


Figure 28*. Beach profile in its summer (black line) and winter (dotted line) configuration (from Pranzini 2004 in Chelleri 2020, master degree thesis)*

It is important to know that sediment does not disappear: the material lost at one point of the littoral is deposited at another. In this context, the SICELL[63] tool can help to assess sediment transport since it is a sediment budget model. For example, if a lagoon inlet becomes clogged due to accretion phenomena, excess sediment can be used for beach nourishment (provided it is not polluted). The value of a system that calculates the sediment budget is to know where to take sediment to nourish other sections of beach.

[63] Fontolan G, Bezzi A, Martinucci D, Pillon S, Popesso C, & Rizzetto F (2015). *Sediment budget and management of the Veneto beaches, Italy: An application of the modified Littoral Cells Management System (SICELL)*. Proceedings of the 3rd Coastal and Maritime Mediterranean Conference CM2, (Ferrara, Italy, November 2015), pp. 25-27.

- **General tips**
  If it is not possible to carry out a comprehensive analysis of the evolutionary dynamics of the coast, it is necessary to collect as much key information as possible to guide subsequent assessments.

  An example of key information is the presence of coastal hotspots as seen above. In this case, simple indices such as the Coastal Vulnerability Index (CVI) can also be used to make calibrations to the survey method that are generally effective (e.g. the CVI identifies coastal hotspots well).

3.3 - Climate change impacts and related hazards

Considering climate change and coastal erosion, the following issues are brought up:

- How do the consequences of climate change interact with coastal erosion?
- Are the effects of climate change evident along the coast?
- To what extent are the impacts of climate change currently apparent?

To answer these questions, it is important to remember that the coastal system is both a highly dynamic environment and one that has been heavily modified by human activities. Therefore, when considering these issues, the human presence cannot be ignored, as we are not dealing with a natural environment that evolves and changes naturally. In the current situation, if we compare the effects of climate change with those of anthropogenic pressures on the coastal environment, the human impact is probably currently the dominant effect.

In fact, when assessing climate change and erosion effects on the coast, we often talk about how to actively protect human products (infrastructure, houses, beach resorts, hotels etc.). **Figure 29** clearly shows that the "Do nothing" option is only feasible in the absence of human facilities. On the contrary, the so-called Soft, Grey or Green solutions[64] must be put in place to protect human life and well-being. Examples of adaptation solutions for coastal management, according to the Climate Menu platform[65] by the RESPONSe Interreg Italy-Croatia project, are:

[64] According to Climate ADAPT, the EU platform for adaptation, **Grey** measures refer to technological and engineering solutions to improve adaptation of territory, infrastructures and people. **Green** measures are based on the ecosystem-based (or nature-based) approach and make use of the multiple services provided by natural ecosystems to improve resilience and adaptation capacity. **Soft** options include policy, legal, social, management and financial measures that can alter human behaviour and styles of governance, contributing to improve adaptation capacity and to increase awareness on climate change issues (https://climate-adapt.eea.europa.eu/en/knowledge/adaptation-information/adaptation-measures).

[65] https://www.climatemenu.eu/en/climate-actions/

- Adaptation or improvement of dikes and dams (grey measure);
- Dune construction and strengthening (green measure or Nature-based Solution);
- Organise climate workshop (soft measure).

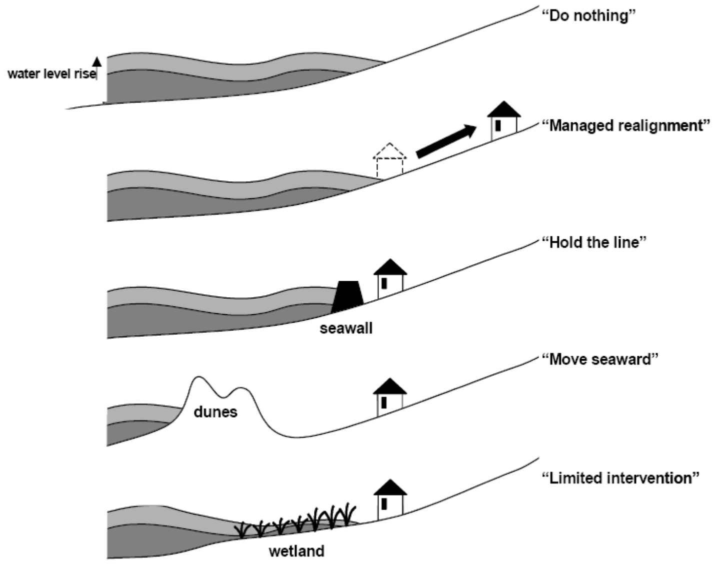


Figure 29*. Coastal erosion management scheme – Eurosion project (from MATTM-Regioni 2018).*

It is worth noting that Nature-based solutions (Nbs), or green measures, involve an approach based on ecosystems, green infrastructure and urban greening, with the aim of preserving nature and ecosystem services while improving societies response to climate change. These solutions offer multiple environmental, social and economic benefits, interweaving disaster risk reduction, climate change mitigation and adaptation, with the restoration and protection of biodiversity and ecosystems [66].

According to IUCN, the International Union for Conservation of Nature, "Nature-based Solutions are actions to protect, sustainably manage, and restore natural and modified ecosystems that address societal challenges effectively and adaptively, simultaneously benefiting people and nature"[67] (**Figure 30**). In these terms, the dunes restoration and preservation represent a Nbs in which benefits are, for example, the reduction of floods and coastal erosion and the increasing of biodiversity due to the hosted flora and fauna.

[66] https://ipccitalia.cmcc.it/nature-based-solutions/
[67] https://www.iucn.org/our-work/nature-based-solutions

Figure 30. Nature-based solutions according to IUCN (from IPCC-Focal Point for Italy, see footnote 20)

Regarding the assessment of coastal erosion in the context of climate change, experts suggest that one of the possible correct approaches could be a input-output model (**Figure 31**). It is a simple qualitative-quantitative model in which, given an input, the system responds in a certain way by giving an output. For example, when assessing a portion of a beach, one can enter the sediment load as input and observe the output, i.e. the response of the system.

As far as Lignano is concerned, another example could be the rising sea level: if the average sea level rises by 20-30 cm while maintaining the same sediment budget, by how many metres will the beach retreat? In other words, it is important to understand whether the output changes linearly as a function of the input or not. This helps to understand whether there are complex processes at work.

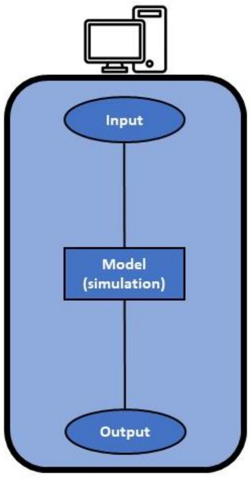


***Figure 31**. A simple input-output model scheme.*

In the AdriaClim Deliverable 5.3.1-*General knowledge framework for local adaptation plans* the modelling activities related to climate temperature projections were well explained, both in terms of the method and the positive impacts on local management. In these terms, the implementation of modelling activities also for the assessment and future projections of coastal erosion can be interpreted both as a soft adaptation measure and as a way of applying the input-output model.

Regarding the evolution of coastal erosion, another point concerns the submergence of geomorphologies (such as beaches) due to the effects of climate change. In fact, SLR results in an increase in the height of the seawater mass and a consequent upward shift in the sea/beach boundary.

In a situation of sea level rise, coastal erosion continues to act through wave action affecting the vulnerable part of the beach. This can lead to the so-called drowning of the beach in the absence of a sedimentary input to counterbalance its retreat due to both the loss of material caused by erosion and the SLR. Once again, it is necessary to include the contribution of river sediments in the coastal erosion assessment, otherwise the analysis (also including SLR) is incomplete.

In the perspective of adaptation, one of the possible measures regarding SLR in coastal areas is to give free rein to beach retreat as sea level rises ("Do nothing" option in **Figure 29**). On the one hand, a loss of beach volume could occur, on the other hand the beach would not be completely lost.

The problem arises when the beach is occupied by man-made structures and there is no space for the natural migration of the beach inland. In fact, cities built close to beaches act as real barriers and, when the natural retreat of the beach is obstructed, the problem of sea water entering the urban area arises, in addition to the complete loss of the beach due to submergence by the SLR, of course.

To prevent seawater from entering cities, there are several examples around the world of building barriers, but these are still grey options, i.e. physical interventions and/or constructions to make buildings, infrastructure, networks resilient to extreme events. A famous example is the MOSE[68] in the venetian lagoon (**Figure 32**), which prevents the city of Venice from being affected by the phenomenon of "*acqua alta"*, i.e. coastal flooding.

[68] https://www.mosevenezia.eu/project/?lang=en

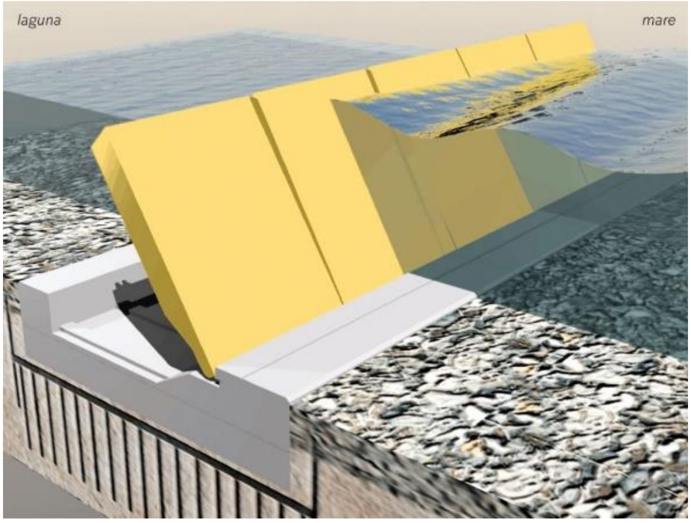


***Figure 32**. Operating scheme of the MOSE's floodgates; the lagoon is on the leftside and the sea on the of the rightside floodgates (from MOSE website – italian version).*

However, the context of Lignano is quite different from that of a real city, since the main vocation is tourism, where the beach represents the primary resource in economic terms on which the local economy is based. For this reason, the loss of the beach is a possibility to be avoided, at least until the SLR reaches levels impossible to manage.

From the point of view of adaptation, as just seen above, the free retreat of the beach is not an option, since the structures behind it do not allow its natural regression and the relocation of the sea/land boundary. A viable option, on the other hand, is the initiation of a positive sediment balance in which the reuse of sandy sediments from other areas compensates for the larger volume losses of the vulnerable beach.

Another (grey) options is the *configuration dredging*. According to Nielsen and Williams (2018)[69], "nearshore configuration dredging can be designed to divert destructive incident swell wave energy from an eroding foreshore. Such a project could result in winning sand that could be used to restore an eroded foreshore. In so doing the impact on other areas would need to be considered".

It is essentially an engineering work that changes the shape of the seabed (**Figure 33 A-B**). Through dredging activities, sea currents and wave direction are also modified. Because of the role played by wave action in transporting and depositing sediment, the phenomenon of erosion is also modified, stabilising the beach.

[69] Nielsen A & Williams B (2018). *Configuration dredging for beach stabilisation*. Conference paper. NSW Coastal Conference 2018.

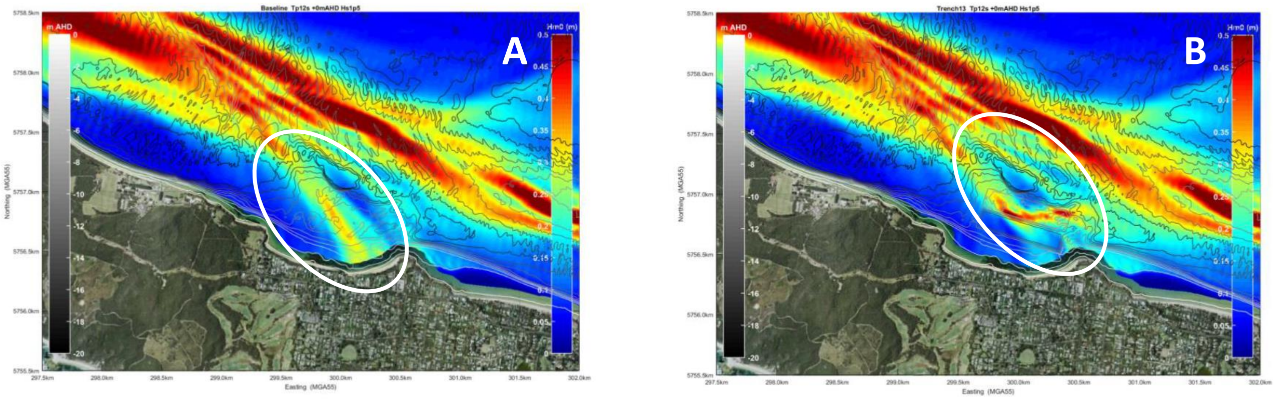


Figure 33 A-B*. (A) Wave transformation modelling of the existing baseline conditions showing focusing of wave energy onto Portsea Front Beach (Victoria, AUS). (B) Plan of a configuration dredging depression and its modification to the wave transformation processes, engendering swell wave reflection away from the beach (from Nielsen & Williams 2018).*

Focusing on Lignano, from a beach management perspective, the first point to clarify is the vocation of the coastal area, which, in this case, is tourism. The second point is to identify which are the priorities related to the coast and to establish an order of interventions (for example, beach preservation to save local economy is the priority and beach nourishment is the intervention). Nevertheless, it is important to assess the evolutionary dynamics of the coastline and to identify the sediment reservoir from which to draw material to compensate for beach volume losses, since, as seen above, other measures are impractical.

Basically, the focal point is to identify the needs of the coastal area under consideration and to envisage the relocation or reuse of sediments on the basis of the previously identified needs and the vocation of the coast. Furthermore, it should not be forgotten that Italian legislation on the relocation and reuse of sediments is rather complex and, consequently, sediments from a certain area cannot always be relocated in a tourist area.

As follows, two examples of possible reuse and relocation of sediment for the Lignano area:

- A large accumulation of sediment occurs at the mouth of Lignano. In fact, the sand storage capacity of the largest lagoon mouth is ca. 11 million m^3 in its ebb-tidal delta (Fontolan et al. 2007)[70]. In this point, the tidal energy is the force responsible for the accumulation of sediment and the inlet undergoes possible silting and occlusion, unless dredging is carried

[70] Fontolan G, Pillon S, Delli Quadri F, Bezzi A (2007). *Sediment storage at tidal inlets in northern Adriatic lagoons: ebb-tidal delta morphodynamics, conservation and sand use strategies.* Estuarine Coastal and Shelf Sciences, 75 (1-2): 261-277. DOI: https://doi.org/10.1016/j.ecss.2007.02.029.

out (**Figure 34 A-B**). The mouth of Lignano could represent a possible sediment reservoir from which the exceeding sand could be taken and redistributed to nearby beaches, as dredging work is needed to ensure boats the access to the lagoon. Figure 34-B shows the channel migration in the time period 1966-2018 (Chelleri 2020, Master's thesis and references therein).

- The so-called "*spiaggia dei cani*" (dog beach) located at the end of the Lignano peninsula, have been subject to a strong sediment accumulation over the years of 600.000 m^3 (Fontolan, personal communication), as the comparison between different aerial photos shows (**Figure 35 A-G**). This could represent another reservoir of sediment for beach nourishment. As already mentioned, Italian regulations for sediment reutilisation are complex and require a series of ecotoxicological tests on the sediment to be reuse. So, if the ecotox tests give positive results, i.e. the sediment is contaminated, it is not possible to use that sand to nourish tourist beaches.

One may also use the concept of the circular economy to expand on the justification for the reuse of sediments. In actuality, the fundamental idea is that raw materials are collected from a sediment pool that has been previously identified and is continuously replenished naturally. Lignano's sediment reservoir hasn't yet been identified, though. A database of sediment reservoirs for the next 50 years is also lacking at the regional level. In other words, there is still no "Sediment Regional Plan".

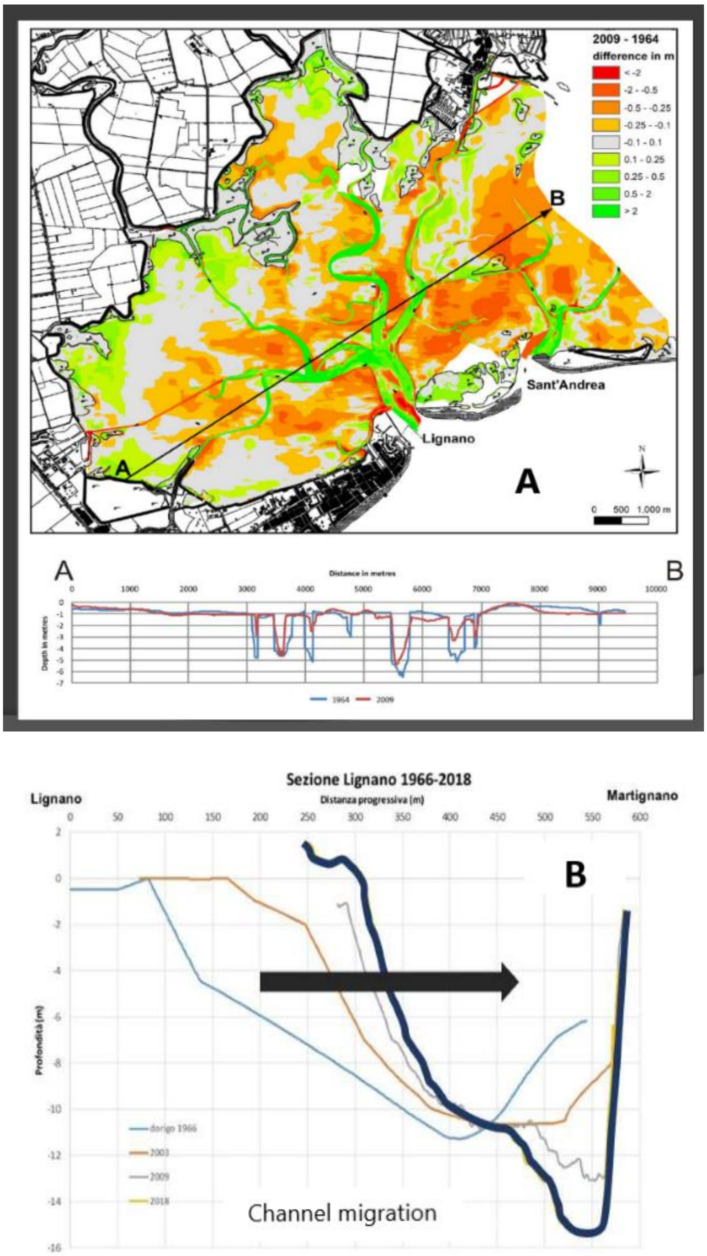


__Figure 34 A-B__. The evolutionary asymmetry of the Lignano inlet and channel due to relative sea level rise (courtesy of Coastal Group). (A) The A-B black arrow represents the transect to assess the evolution of channel bathymetry comparing 1964 (blue line) with 2009 (red line) in the line chart. (B) The Lignano channel migration in the time period 1966-2018.

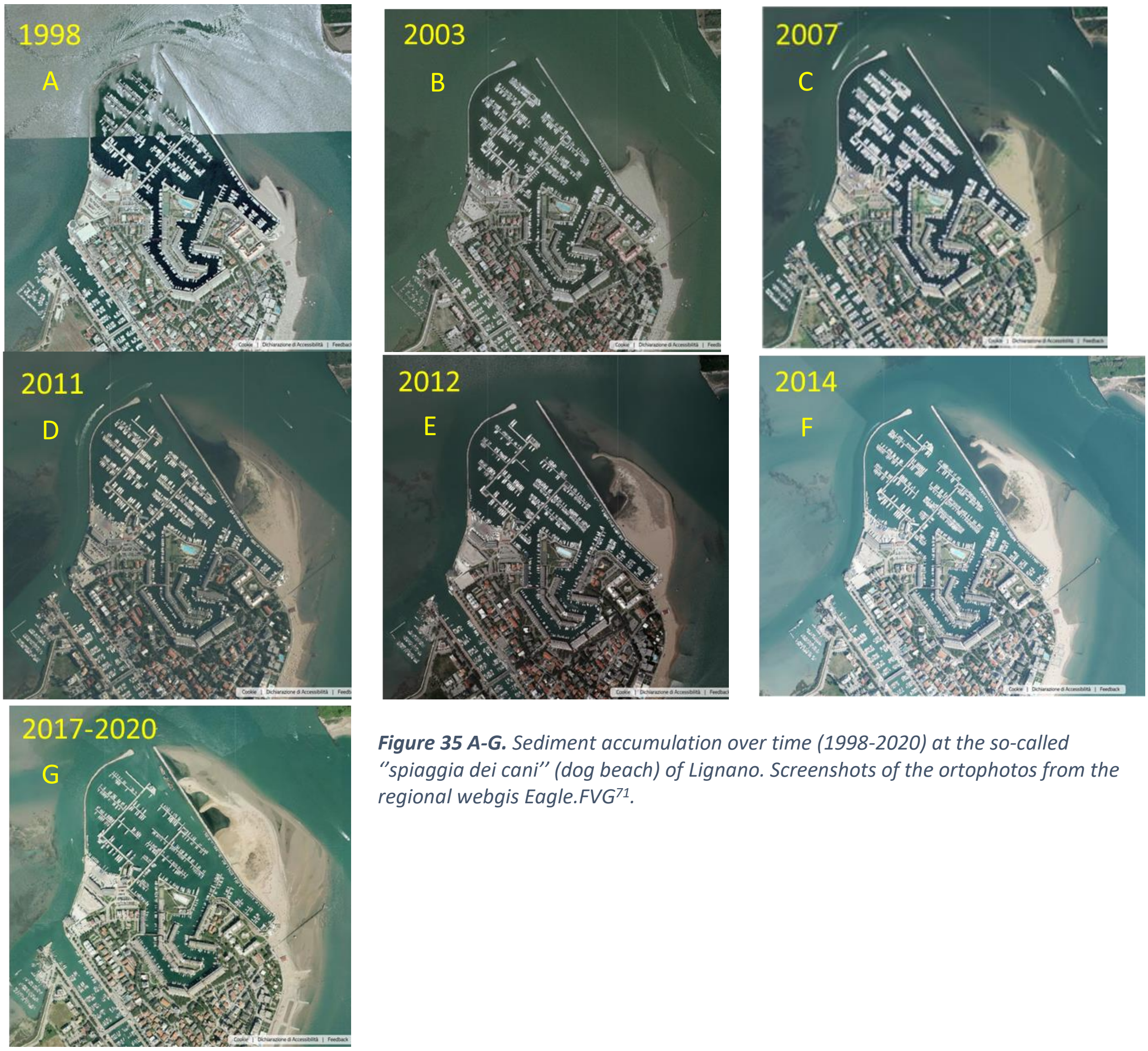


Figure 35 A-G. *Sediment accumulation over time (1998-2020) at the so-called ''spiaggia dei cani'' (dog beach) of Lignano. Screenshots of the ortophotos from the regional webgis Eagle.FVG[71].*

[71] https://eaglefvg.regione.fvg.it/eagle/main.aspx?configuration=guest

It is important to remember that the sediment resource is not limited. Circular thinking offers benefits, but if the beach has been raised so high to counterbalance the SLR, the sediment will eventually run out.

At present, the SLR is imperceptible on a human scale, but the trend observed in the FVG coastal area is consistent with the global trend. During the 20th century, the global mean sea level rose at a rate of 1.5-2.0 mm/year, but in the last 30 years the rise has reached about 3 mm/year (ARPA FVG 2023).

Furthermore, Marcos & Tsimplis (2008)[72] found a sea level rise rate of 4.4 mm/year from 1992 to 2016 in Trieste. At this rate, the mean sea level will be about 10 cm higher in 2050 and about 34 cm higher in 2100. In this case, slope plays a crucial role, as beaches with gentle slopes are more vulnerable to flooding due to sea level rise (**Figure 36**). Consequently, beach retreat will be more pronounced.

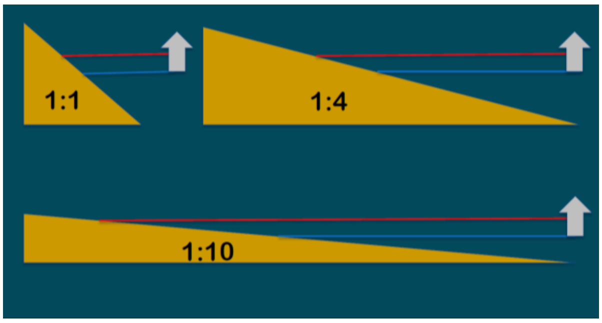


Figure 36. *How SLR (the difference between the blue and the red line) affects beaches with different slope. Top left: beach with a 100% slope (45°); top right: beach with a 25% slope (14°); bottom: beach with a 10% slope (5.7°) (courtesy of Coastal Group).*

In **Figure 37** (A-C), Picture B shows the beach of Lignano Sabbiadoro (recognisable by its "Terrazza a mare" beach resort) characterised by a slope of 1% and the response in case of an SLR of 20 cm. In this case, the sea/land boundary could shift, causing the beach to retreat by 20 m.

Finally, we must not forget the phenomenon of subsidence. Compared with gently sloping beaches, subsidence not only causes the coastline to recede (several metres compared with a fall of a few centimetres), but also increases the slope of the seabed and thus reduces the amount of sand on the coast (RAFVG & UNITS 2022).

[72] Marcos M & Tsimplis MN (2008). *Coastal sea level trends in southern Europe*. Geophysical Journal International, Vol. 175, 70–82. DOI: https://doi.org/10.1111/j.1365-246X.2008.03892.x.

In addition, subsidence interacts with sea level rise and contributes to beach erosion. For a more in-depth look, please see the Deliverable 5.3.1-*General Knowledge framework for local adaptation plans*.

Hypoyhesis: SLR = +20 cm

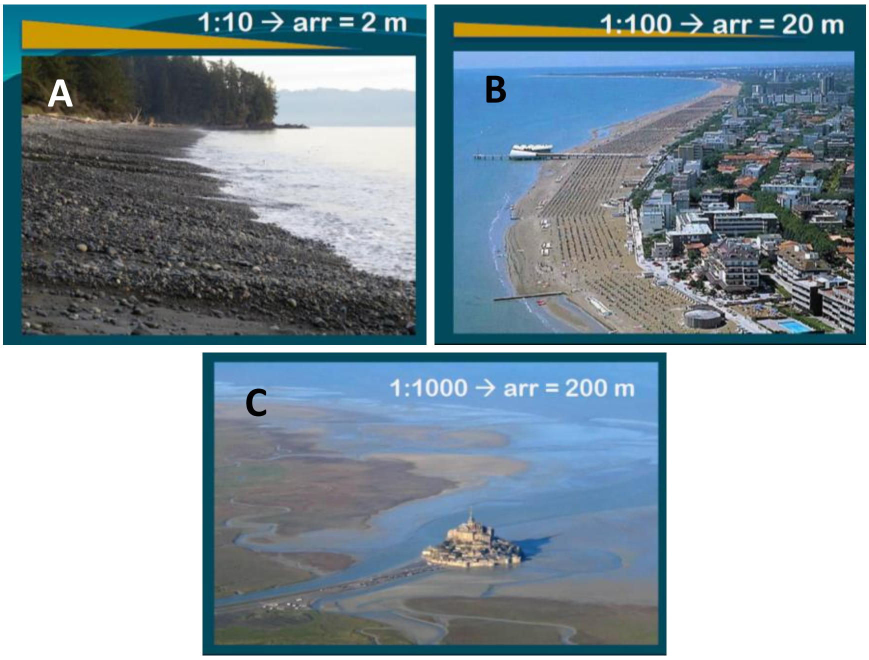


Figure 37 A-C. *Different beaches' response to a hypothetic SLR of 20 cm according to their slope. (A) Pebble beach: slope = 10%, beach retreat = 2 m. (B) Sandy beach: slope = 1%, beach retreat = 20 m. (C) Muddy tidal plain: slope = 0.1%, beach retreat = 200 m (courtesy of Coastal Group).*

Returning to the present, the management of beaches for tourist use requires the creation of a real system in which needs are identified and solutions are found from a broad perspective that thinks in the long term. The planning of non-structural measures is necessary, such as the identification of sediment reservoirs, the study of lost/accumulated volumes of beach sand and the location where the sediment can be reused. Monitoring becomes a fundamental element to assess the evolution of the beach and the coastline in general, and has insignificant costs compared to interventions after extreme events.

Finally, as a **working scheme** on beach management in the perspective of climate change, we have resumed in the following workflow the information and steps shown in the previous paragraphs, result of expert and stakeholder interaction.

What is the area vocation?

- Tourism

SHs needs – Lignano beach managers

- Maintaining an adequate beach width for tourist use
- Be certain that there are sufficient resources to deal with the damage caused by extreme events
- Obtain funding for the beach nourishment project from the FVG Region
- Resolving the problem of erosion through a Plan to manage the consequences of phenomena that compromise the integrity of the beach (extreme events)

SHs needs – Lignano Municipality

- Improving the impact-related knowledge
- Involving and raising awareness in stakeholders and local community
- Improving the impact-related knowledge
- Overcoming fragmented approaches and limited interaction between stakeholders

SHs needs – FVG Region

- Preserving natural resources and local economy

What information is needed/missing? – Carrying out systematic information gathering

- Obtaining volumetric data to understand how the erosion phenomenon evolves increasingly linked to the submergence of geomorphologies due to the effects of climate change
- Identifying possible sediment reservoirs, i.e. areas where large natural accumulations of sand occur
- Estimating subsidence

What actions/interventions are needed? – Establishing priorities according to area vocation and evolutionary trend

- Establishing a monitoring plan that allows for periodic topographic transects along the submerged and emerged beach on a regional scale, both to evaluate eventually beach retreat (erosion) or progression (accumulation)
- Drafting up a shared Management Plan among several SHs, managing sediment reservoirs, beach nourishments, extreme What actions are needed?

Rationale of the action/interventctions

- Rational use of sediment from an area to another (based on the previous point)
- Be aware that the situation is progressively going to beach drowning and sooner or later the reallocation of sediments will not be sufficient to counteract rising sea levels

Chapter 4 - Communicating climate change impacts

4.1 - Impacts' summary cards

As a simple information tool for interacting with stakeholders, we develop 6 "Impact Summary Cards". Here is the list of the effects on ecosystems that we took into account. (**Figure 38 A-F**):

- 2 summary cards for the subsector Marine Ecosystems, summarising the following: (1) Mass Mortality Events (MME) in the Mediterranean Sea; and (2) Ocean Acidification;
- 2 summary cards for the sub-sector Freshwater and transitional ecosystems, summarising (3) the "marinization" of the lagoon from a physical point of view and (4) the disappearing of salt marshes;
- 1 summary card for the sub-sector Terrestrial ecosystems, summarising (5) the dynamics of alien plants invasion;
- 1 summary card for the sub-sector Forests, summarising (6) the rise in wildfires.

Cards are arranged so that the first section gives a brief summary of the impact under consideration. The impact's cause is described in the following section. Then, where it is practicable, details about current studies are given in order to point out also researches, knowledge, and future views.

Information and data are taken from the recent article "Segnali dal Clima in FVG" (ARPA FVG 2023), published by ARPA FVG on behalf of the technical-scientific working group "Clima FVG", a group of experts from the Universities of Udine and Trieste, the International Centre for Theoretic Physics (ICTP), the National Institute of Oceanography and Applied Geophysics (OGS), the Marine Sciences Institution and the Polar Sciences Institution (CNR-ISMAR and CNR-ISP, respectively) from the National Research Council, the Friuli Venezia Giulia Region and ARPA FVG.

The Summary Cards in pdf format are digitally attached to the present document as annexes (see Annex 3). The language in which the Cards are written is Italian, as this is a product intended for and aimed at local policy makers.

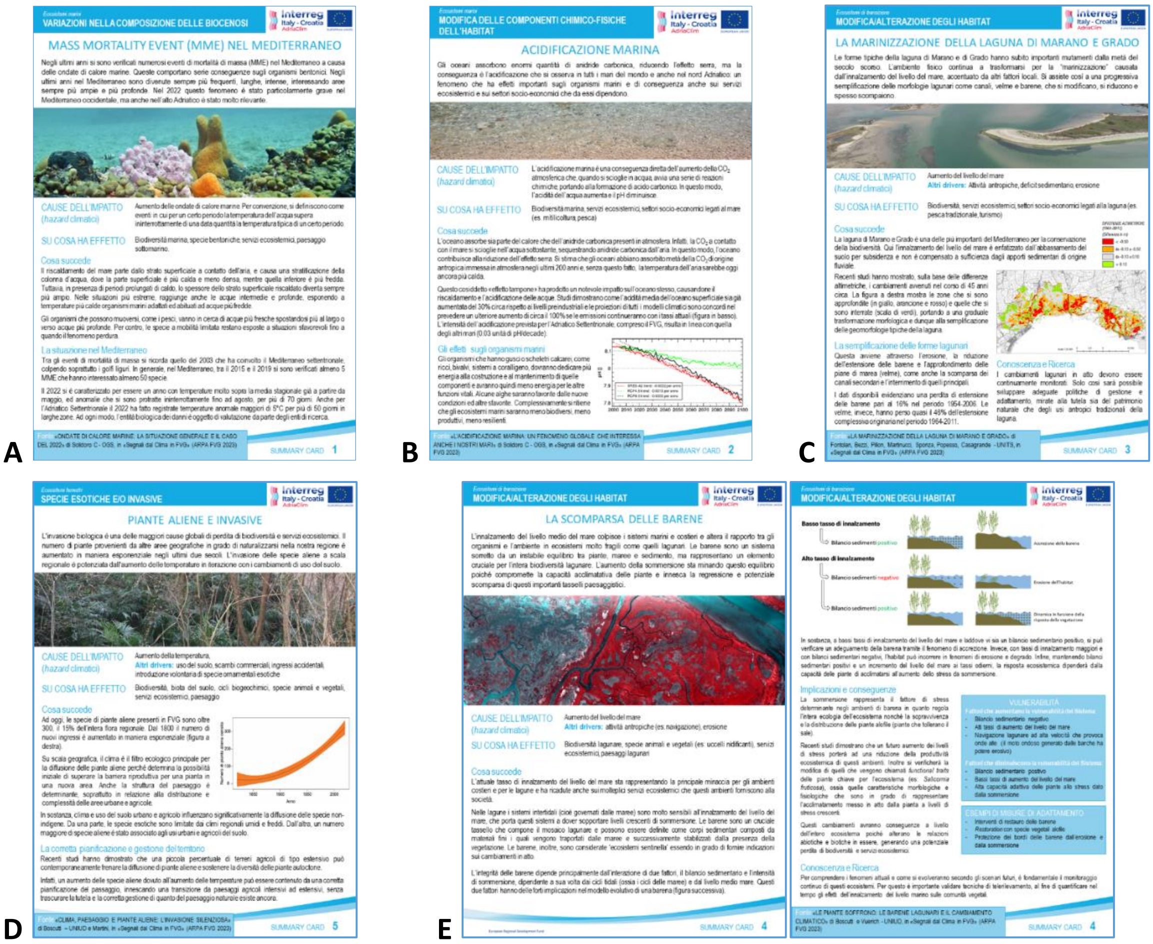


***Figure 38**. Impacts Summary Cards. (A) Mass Mortality Events (MME) in the Mediterranean Sea; (B) ocean acidification; (C) "marinization" of the lagoon from a physical point of view; (D) disappearing of salt marshes; (E) dynamics of alien plants invasion; (F) rise in wildfires.*

References

Sitography

Aquileia UNESCO site management Plan - https://www.fondazioneaquileia.it/files/documenti/pdg_aquileia.pdf

Aquileia UNESCO site - Geological Report, Fondo Cossar - https://www.fondazioneaquileia.it/files/documenti/04_relazione_geologica.pdf

Bologna Charter – Bologna Charter, Join Action Plan.

Climate ADAPT, adaptation measures - https://climate-adapt.eea.europa.eu/en/knowledge/adaptation-information/adaptation-measures

Climate Menu - https://www.climatemenu.eu/en/climate-actions/

CORINE Biotopes list for italy - *https://www.isprambiente.gov.it/it/attivita/biodiversita/ispra-e-la-biodiversita/attivita-e-progetti/elenchi-degli-habitat-italiani*

Eagle.FVG, Webgis of the Friuli Venezia Giulia Region - https://eaglefvg.regione.fvg.it/eagle/main.aspx?configuration=guest

EUROSION - http://www.eurosion.org/

Emilia Romagna GIDAC - https://ambiente.regione.emilia-romagna.it/it/suolo-bacino/argomenti/difesa-della-costa/gidac/gidac-dicembre-2022/

IPCC focal point for Italy, Nature Based Solutions - https://ipccitalia.cmcc.it/nature-based-solutions/

ISPRA (Italian Institute for the Environmental Protection) - Istituto Superiore per la Protezione dell'Ambiente

ISPRA guidelines for drawing the Nature Map- https://www.isprambiente.gov.it/files/pubblicazioni/manuali-lineeguida/cartanatura_manuale_2009_48_50mila.pdf

IUCN, Nature Based Solutions - https://www.iucn.org/our-work/nature-based-solutions

MOSE, mobile barriers for the protection of Venice from high tides - https://www.mosevenezia.eu/project/?lang=en

NATURA 2000 sites in FVG - https://www.regione.fvg.it/rafvg/cms/RAFVG/ambiente-territorio/tutela-ambiente-gestione-risorse-naturali/FOGLIA203/FOGLIA1/, visited on 22/06/2023.

OGS - National Institute of Oceanography and Applied Geophysics

Ramsar Convention - https://www.ramsar.org

Bibliography

Acquavita A, Aleffi IF, Benci C, Bettoso N, Crevatin E, Milani L, Tamberlich F, Toniatti L, Barbieri P, Licen S & Mattassi G (2015). *Annual characterization of the nutrients and trophic state in a Mediterranean coastal lagoon: The Marano and Grado Lagoon (northern Adriatic Sea).* Reg. Stud. Mar. Sci. 2, 132–144. DOI: https://doi.org/10.1016/j.rsma.2015.08.017.

Alberti A & Tomao A (2023). *L'equilibrio perduto tra foreste e incendi alla luce della crisi climatica*, in: ARPA FVG. *Segnali dal Clima in FVG – Cambiamenti, impatti azioni*. Edited by ARPA FVG on behalf of Gruppo di Lavoro tecnico-scientifico Clima FVG, May 2023, pp. 70-73.

ARPA FVG (2018). *Studio Conoscitivo dei cambiamenti climatici e di alcuni loro impatti in Friuli Venezia Giulia. Primo Report – Marzo 2018*. In collaboration with RAFVG, ICTP, CNR-ISMAR, OGS, UNITS, UNIUD, 348 pp.

ARPA FVG (2023). *Segnali dal clima in FVG – Cambiamenti, impatti, azioni*. Edited by ARPA FVG on behalf of Gruppo di Lavoro tecnico-scientifico C-lima FVG, May 2023, 116 pp.

Barnes RSK (1980). *Coastal lagoons*. 1st ed.; Cambridge Univ. Press, New York, USA, 1980; pp. 106.

Bezzi A, Martinucci D, Pillon S, Sponza S, Petti M, Bosa S, Pascolo S, Triches A, Cosolo M & Fontolan G (2019). *Sediment budget analysis, critical issues and perspectives for a morphological restoration in a deficit lagoon*. Conferance paper of the 34th IAS-International Meeting of Sedimentology (Rome, Italy, 10-13 September 2019).

Bezzi A, Pillon S, Popesso C, Casagrande G, Da Lio C, Martinucci D, Tosi L & Fontolan G (2021). *From rapid coastal collapse to slow sedimentary recovery: The morphological ups and downs of the modern Po Delta*. Estuarine, Coastal and Shelf Science, 260, 107499. DOI: https://doi.org/10.1016/j.ecss.2021.107499.

Borja A, Franco J, Pérez V (2000). *A marine biotic index to establish the ecological quality of soft-bottom benthos within European estuarine and coastal environments*. Mar. Pollut. Bull. 40, 1100–1114. DOI: https://doi.org/10.1016/S0025-326X(00)00061-8.

Boscutti F & Vuerich M (2023). *L'acqua sale, le piante soffrono: le barene lagunari e il cambiamento climatico*, in: ARPA FVG. *Segnali dal Clima in FVG – Cambiamenti, impatti azioni*. Edited by ARPA FVG on behalf of Gruppo di Lavoro tecnico-scientifico Clima FVG, May 2023, pp. 54-57.

Boscutti F, Trevisan F, Scagnetto I (2023). *Le fanerogame sommerse viste da vicino*, in: ARPA FVG. *Segnali dal Clima in FVG – Cambiamenti, impatti azioni*. Edited by ARPA FVG on behalf of Gruppo di Lavoro tecnico-scientifico Clima FVG, May 2023, pp. 58-59.

Brambati A (1985). *Studio sedimentologico marittimo costiero dei litorali del Friuli-Venezia Giulia, Regione Autonoma Friuli-Venezia Giulia*. 665 pp.

Brambati A, Fontolan G, Pillon S, Schiozzi L, Gonella M, Atzeni P, Soldati M (2004). *Il litorale prospicente il lungomare Adriatico a Lignano: analisi dei processi di dissesto e proposte di intervento contro l'erosione marina*. 65pp.

Casagrande G (2022). *Shoreline: is the IGM42 Italian datum still an updated reference to account for the Sea Level Rise?* Knowledge hub, 1st Sea Level Rise Conference (Venice, 17-18 October 2022), poster.

Castello M & Bacaro G (2023). *Il Carso, un paesaggio vulnerabile agli incendi*, in: ARPA FVG. *Segnali dal Clima in FVG – Cambiamenti, impatti azioni*. Edited by ARPA FVG on behalf of Gruppo di Lavoro tecnico-scientifico Clima FVG, May 2023, pp. 64-69.

Chelleri A (2020). *Assetto ed erosione del litorale di Lignano: analisi e proposta di ripascimento* [Unpublished master degree thesis]. Università degli Studi di Udine and Università degli Studi di Trieste, 103 pp.

Comune di Lignano Sabbiadoro (2022). *Piano d'Azione per l'Energia Sostenibile e il Clima*. Edited by Agenzia Per l'Energia del Friuli Venezia Giulia, 194 pp.

Crespi A, Terzi S, Cocuccioni S, Zebisch M, Berckmans J, Füssel H-M (2020). *Climate-related hazard indices for Europe*. European Topic Centre on Climate Change impacts, Vulnerability and Adaptation (ETC/CCA) - Technical Paper 2020/1. DOI: 10.25424/cmcc/climate_related_hazard_indices_europe_2020.

Donnelly C, Kraus N & Larson M (2006). *State of Knowledge on Measurement and Modeling of Coastal Overwash*. Journal of Coastal Research, 224, 965-991. DOI: https://doi.org/10.2112/04-0431.1.

Doody P, Ferreira M, Lombardo S, Lucius I, Misdrop R, Niesing H, Salman A, Smallengange M, Cipriani LE, Lanza S, Pranzini E & Randazzo G (2007). *Vivere con l'erosione costiera in Europa – Sedimenti e spazio per la sostenibilità. Risultati dello studio Eurosion.* Edited by the European Commission, 21 pp.

Ferrarin C, Umgiesser G, Bajo M, Bellafiore D, De Pascalis, F, Ghezzo M, Mattassi G & Scroccaro, I (2010). *Hydraulic zonation of the lagoons of Marano and Grado, Italy*. A modeling approach. Estuar. Coast. Shelf Sci. 87, 561–572. DOI: https://doi.org/10.1016/j.ecss.2010.02.012.

Fontolan G (2006). *Il nastro litoraneo tra banchi di sabbia e moto ondoso*, in: Bianco F, Bondesan A, Paronuzzi P, Zanetti M & Zanferrari A. *Il Tagliamento.* Università di Udine, Circolo Menocchio - Cierre edizioni, Sommacampagna (VR), pp. 152-159.

Fontolan G, Pillon S, Delli Quadri F, Bezzi A (2007). *Sediment storage at tidal inlets in northern Adriatic lagoons: ebb-tidal delta morphodynamics, conservation and sand use strategies.* Estuarine Coastal and Shelf Sciences, 75 (1-2): 261-277. DOI: https://doi.org/10.1016/j.ecss.2007.02.029.

Fontolan G, Bezzi A, Martinucci D, Pillon S, Popesso C, & Rizzetto F (2015). *Sediment budget and management of the Veneto beaches, Italy: An application of the modified Littoral Cells Management System (SICELL)*. Proceedings of the 3rd Coastal and Maritime Mediterranean Conference CM2, (Ferrara, Italy, November 2015), pp. 25-27.

Fontolan G, Bezzi A, Pillon S (2011). *Rischio da mareggiata*, in: Vitturi A. *Atlante Geologico della Provincia di Venezia. Cartografie e Note illustrative*. Provincia di Venezia, ISBN 978-88-907207- 0-3, pp. 581–600.

Fontolan G, Bezzi A, Pillon S, Martinucci D, Sponza S, Popesso C, Casagrande G (2023). *La marinizzazione della laguna di Marano e Grado*, in: ARPA FVG. *Segnali dal Clima in FVG – Cambiamenti, impatti azioni*. Edited by ARPA FVG on behalf of Gruppo di Lavoro tecnico-scientifico Clima FVG, May 2023, pp. 43-46.

Fontolan G, Brambati A, Bezzi A, Delli Quadri F, Pillon S (2005). *Studio preliminare per la riqualificazione del litorale di Lignano Sabbiadoro*. Committed by the Lignano Municipality, 131 pp.

Gordini E, Marocco R, Ramella R (2006). *Dinamica morfologica del litorale del delta del Fiume Tagliamento (Adriatico Settentrionale) in relazione ai possibili interventi di ripascimento*. Il Quaternario, 19, 45-65 pp.

Grall J & Glémarec M (1997). *Bioévaluation des structures benthiques en rade de Brest*, in: Annales de l'Institut océanographique (Monaco). Vol. 73, No. 1, pp. 7-16.

Marcos M & Tsimplis MN (2008). *Coastal sea level trends in southern Europe*. Geophysical Journal International, Vol. 175, 70–82. DOI: https://doi.org/10.1111/j.1365-246X.2008.03892.x.

MATTM-Regioni (2018). *Linee Guida per la difesa della costa dai fenomeni di erosione e dagli effetti dei cambiamenti climatici. Versione 2018*. Edited by the National Table on Coastal Erosion MATTM-Regioni with the technical coordination by ISPRA, 305 pp.

McLusky DS & Elliott M (2007). *Transitional waters: a new approach, semantics or just muddying the waters?* Estuarine, Coastal and Shelf Science, 71(3-4), 359-363. DOI: https://doi.org/10.1016/j.ecss.2006.08.025.

Ministero dell'Ambiente e della Tutela del Territorio e del Mare (2015). *Strategia Nazionale di Adattamento ai Cambiamenti Climatici*.

Muxika I, Borj A, Bonne W (2005). *The suitability of the marine biotic index (AMBI) to new impact sources along European coasts*. Ecol. Ind. 5, 19-31. DOI: https://doi.org/10.1016/j.ecolind.2004.08.004.

Muxika I, Borja A, Bald J (2007). *Using historical data, exert judgment and multivariate analysis in assessing reference conditions and benthic ecological status, according to the European Water Framework Directive*. Mar. Pollut. Bull. 55, 16–29. DOI: https://doi.org/10.1016/j.marpolbul.2006.05.025.

Newton A, Icely J, Cristina S, Brito A, Cardoso AC, Colijn F ... & Zaldívar JM (2014). *An overview of ecological status, vulnerability and future perspectives of European large shallow, semi-enclosed coastal systems, lagoons and transitional waters*. Estuarine, Coastal and Shelf Science, 140, 95-122. DOI: https://doi.org/10.1016/j.ecss.2013.05.023.

Nielsen A & Williams B (2018). *Configuration dredging for beach stabilisation*. Conference paper. NSW Coastal Conference 2018.

Orel G, Zamboni R, Grimm F, Zentilin A (2001). *Evoluzione dei popolamenti bentonici della Laguna di Marano e Grado (Adriatico Settentrionale) in un triennio di ricerche*. Biol. Mar. Medit. 8(1), 424-431.

Pearson TH & Rosenberg R (1978). *Macrobenthic succession in relation to organic enrichmentand pollutionof the marine environment*. Oceanogr. Mar. Biol. A.Rev. 16, 229-331

Pérès J, Picard J (1964). *Nouveau Manuel de Bionomie Benthique de la Mer Méditerranée*. Réc. Trav. Stat. Mar. Endoume 31, 5–137.

Pérez-Ruzafa A, Marcos C, Pérez-Ruzafa IM & Pérez-Marcos M (2011). *Coastal lagoons:"transitional ecosystems" between transitional and coastal waters*. Journal of Coastal Conservation, 15, 369-392. DOI: https://doi.org/10.1007/s11852-010-0095-2.

Pranzini E (2004). *La forma delle coste, geomorfologia costiera impatto antropico e difesa dei litorali.* Zanichelli, 245 pp.

Provincia di Venezia - Assessore all'Ambiente Servizio Geologico, Difesa del Suolo e Tutela del Territorio (2011). *Atlante Geologico della Provincia di Venezia - Note Illustrative*. Edited by Andrea Vitturi. Arti Grafiche Venete srl – Quarto d'Altino (VE), 874 pp.

RAFVG-Dir. Centrale Ambiente ed Energia & UNITS-Dip.to Matematica e Geoscienze (2022). *Accordo attuativo di collaborazione per lo studio e monitoraggio morfo-sedimentologico dello stato dei litorali della Regione Friuli Venezia Giulia finalizzato alla gestione integrata della zona costiera in applicazione alla Convenzione Quadro tra la Regione Autonoma Friuli Venezia Giulia e l'Università degli Studi di Trieste (DGR 264/2014). Relazione delle Attività - Giugno 2022*. Responsabili scientifici: Bratus A & Fontolan G. Gruppo di lavoro: Bieker F, Colombetta L, Gallitelli D, Lipizer M, Sgambati F, Bezzi A, Bussi M, Casagrande G, Fernetti M, Furlani S, Martinucci D, Pillon S, Sponza S; courtesy of Coastal Group.

Regione Autonoma Friuli Venezia Giulia (2020). Aree naturali protette del Friuli Venezia Giulia. Edited by Direzione Centrale Risorse Agroalimentari, Forestali e Ittiche – Servizio Biodiversità, 25 pp.

Regione Autonoma Friuli Venezia Giulia (2021). Carta della natura del FVG. Edited by Direzione Centrale Difesa dell'ambiente, Sviluppo Sostenibile e Energia - Servizio Valutazioni Ambientali.

Simboura N & Zenetos A (2002). *Benthic indicators to use in ecological quality classification of Mediterranean soft bottom marine ecosystems, including a new biotic index*. Mediterranean Marine Science, 3(2), 77-111. DOI: https://doi.org/10.12681/mms.249.

SNPA (2021). *Rapporto sugli indicatori d'impatto dei cambiamenti climatici – Edizione 2021*. Report SNPA 21/2021.

Solidoro C (2023). *Ondate di calore marine: la situazione generale e il caso del 2022*, in: ARPA FVG. *Segnali dal Clima in FVG – Cambiamenti, impatti azioni*. Edited by ARPA FVG on behalf of Gruppo di Lavoro tecnico-scientifico Clima FVG, May 2023, pp. 33-34.

Appendixes

Appendix 1

FVG Nature Map legenda according to Corine Biotopes classification (cf. **Figure 4**)

CARTA NATURA FVG

- Abetine acidofile
- Abetine calcicole endalpiche
- Abetine neutrofile
- Acque ferme prive di vegetazione
- Acque lagunari con vegetazione a fanerogame marine
- Acque lagunari con vegetazione a ruppie
- Acque lagunari prive di vegetazione
- Amorfeti
- Arbusteti succulenti dei suoli fini salati ad Arthrocnemum fruticosum e/o Atriplex portulacoides
- Aree agricole con elementi naturali residui
- Aree denudate soggette ad erosione accelerata
- Arenile con vegetazione annuale pioniera
- Arenile privo di vegetazione
- Bacini e canali artificiali delle acque dolci
- Banchi di fango fluviali con vegetazione a carattere eurosiberiano
- Betuleti montani e subalpini
- Bordi dei corsi d'acqua
- Bordure forestali termofile
- Boscaglie ripariali a galleria di pioppo italico
- Boschi di carpino bianco e querce a gravitazione illirica
- Boschi di farnia e carpino bianco subigrofili illirici della pianura
- Boschi di Ostrya carpinifolia
- Boschi di pendio alpini e perialpini a frassino
- Brughiere acidofile montane e subalpine a Rhododendron e Vaccinium
- Brughiere calcifile montane e alpine ad Ericacee
- Canneti a Phragmites australis
- Canneti e cariceti interdunali
- Carpineti di Carpinus orientalis
- Castagneti
- Cave abbandonate
- Cespuglieti a Corylus avellana
- Cespuglieti a Juniperus communis
- Cespuglieti a Spartium junceum
- Cespuglieti e boscaglie igrofile con Salix cinerea
- Cespuglieti e siepi submediterranei sudorientali
- Cespuglieti ripariali con salici e Hippopha fluviatilis
- Cespuglieti termofili a rovi
- Cladieti palustri
- Colture di tipo estensivo e sistemi agricoli complessi
- Comunit- mediterranee dei fanghi salati a Salicornia
- Comunit- spondicole anfibie dei fanghi lacustri ad Eleocharis sp.
- Corsi d'acqua: fascia del temolo
- Corsi d'acqua: fascia della carpa
- Corsi d'acqua: fascia della trota
- Dune bianche con vegetazione ad Ammophila arenaria
- Dune brune con ginepreti e altri cespuglieti
- Dune brune con vegetazione arborea
- Dune grigie con vegetazione erbacea annuale o perenne
- Dune mobili con vegetazione ad Elytrigia juncea
- Estuari
- Faggete acidofile collinari a Luzula
- Faggete acidofile montane a Luzula
- Faggete calcifile illiriche montane
- Faggete calcifile illiriche subalpine
- Faggete calcifile lliriche submontane
- Faggete neutrofile collinari a Melica
- Faggete neutrofile montane a Cardamine
- Foreste acidofile di querce dell'Italia orientale
- Foreste di pino silvestre su greto
- Foreste illiriche allagate di frassini, querce e ontani
- Foreste padane dei terrazzi fluviali a farnia, frassino ed ontano
- Formazioni a grandi carici
- Formazioni alpine di salici prostrati (Salix alpina, S. waldsteiniana)
- Formazioni dominate da Carex davalliana
- Formazioni postcolturali a frassino maggiore e nocciolo
- Formazioni ruderali con specie autoctone
- Formazioni ruderali con specie esotiche
- Formazioni secondarie di larice
- Formazioni subalofile a Bolboschoenus maritimus (=Scirpus maritimus)
- Frutteti
- Gallerie ripariali e boschi palustri a Salix alba
- Ghiacciai e superfici costantemente innevate
- Ghiaioni basici alpini del piano alpino e nivale
- Ghiaioni basici del piano montano

- Ghiaioni calcarei illirici
- Ghiaioni silicei alpini
- Ghiaioni termofili perialpini calcarei
- Grandi Parchi
- Greti privi di vegetazione
- Impianti di latifoglie
- Lagune e canali artificiali delle acque salate e salmastre
- Lariceti primari pionieri su calcare
- Leccete illiriche dei substrati compatti
- Leccete illiriche dei substrati sabbiosi
- Linee di deposito costiere degli ambienti alo-nitrofili
- Mantelli dei suoli igrofili a salici e Viburnum opulus
- Megaforbieti alpini
- Megaforbieti nitrofili a Rumex alpinus
- Mughete carbonatiche delle Alpi centro-orientali
- Nardeti collinari e montani infranemorali
- Nardeti subalpini ed alpini Pirenaico-Alpini
- Oliveti
- Ontanete ad Alnus viridis delle Alpi
- Ontanete meso-eutrofiche a Alnus glutinosa
- Ontanete ripariali montane a Alnus incana
- Paludi acide
- Paludi salmastre e mediterranee a Juncus maritimus e/o Juncus acutus
- Pascoli montani delle Alpi orientali a Carex austroalpina
- Pascoli subalpini ed alpini delle Alpi orientali a Carex austroalpina
- Pavimenti calcarei
- Peccete a megaforbie
- Peccete acidofile subalpine delle Alpi
- Peccete calcifile subalpine delle Alpi
- Peccete montane acidofile
- Peccete montane calcifile
- Piane fangose e sabbiose sommerse parzialmente dalle maree
- Piantagioni di conifere esotiche
- Piantagioni di pioppo canadese
- Pinete pioniere delle Alpi orientali di pino nero e pino silvestre
- Praterie a Festuca paniculata
- Praterie a zolle discontinue a Carex firma
- Praterie igrofile con Molinia caerulea
- Praterie salmastre a Puccinellia Festuciformis e Limonium serotinum
- Praterie salmastre perennemente inondate a Spartina maritima
- Praterie subalpine a Calamagrostis arundinacea
- Praterie umide interdunali
- Prati aridi submediterranei xero-mesofili carsici
- Prati aridi submediterranei xero-mesofili planiziali e prealpini
- Prati aridi submediterranei xerofili carsici
- Prati aridi submediterranei xerofili planiziali e prealpini
- Prati da sfalcio montani alpici
- Prati da sfalcio planiziali e collinari
- Prati permanenti
- Prati pingui e degradati delle alte quote
- Querceto a roverella dell'Italia settentrionale e dell'Appennino centro-settentrionale
- Riforestazioni di peccio
- Rimboschimenti a Pinus nigra
- Robinieti
- Rupi acide alpine
- Rupi calcaree alpine
- Rupi calcaree montane
- Rupi costiere del carso triestino
- Saliceti ripariali planiziali con Salix triandra
- Spalliere alpine a Loiseleuria e Vaccinium
- Sponde lacustri non vegetate
- Sponde sabbiose dei fiumi con vegetazione scarsa
- Torbiere alte prossimo naturali
- Torbiere di transizione
- Torbiere montane a Schoenus ferrugineus
- Torbiere planiziali a Schoenus nigricans
- Vegetazione dei fondi lacustri a Chara sp. pl
- Vegetazione erbacea delle ghiaie del basso corso dei fiumi con numerose specie ruderali
- Vegetazione erbacea delle ghiaie del medio corso dei fiumi
- Vegetazione erbacea delle ghiaie e dei ciottoli dell'alto corso dei fiumi
- Vegetazione erbacea ed arbustiva delle radure
- Vegetazione radicante natante
- Vegetazione radicante sommersa
- Vegetazione sommersa delle acque correnti
- Vigneti

Appendix 2

Natura 2000 habitats legenda (cf. **Figure 6**)

NATURA 2000 HABITAT

- Acque oligomesotrofe calcaree con vegetazione bentica di Chara spp.
- Acque stagnanti, da oligotrofe a mesotrofe, con vegetazione dei Littorelletea uniflorae e/o degli Isoeto-Nanojuncetea
- Banchi di sabbia a debole copertura permanente di acqua marina
- Bordure planiziali, montane e alpine di megaforbie idrofile
- Distese fangose o sabbiose emergenti durante la bassa marea
- Distese sabbiose o fangose emergenti durante la bassa marea
- Dune con foreste di Pinus pinea e/o Pinus pinaster
- Dune costiere con Juniperus spp.
- Dune costiere fisse a vegetazione erbacea (dune grigie)
- Dune embrionali mobili
- Dune mobili del cordone litorale con presenza di Ammophila arenaria (dune bianche)
- Estuari
- Fiumi alpini con vegetazione riparia legnosa a Salix eleagnos
- Fiumi delle pianure e montani con vegetazione del Ranunculion fluitantis e Callitricho- Batrachion
- Foreste a galleria di Salix alba e Populus alba
- Foreste alluvionali di Alnus glutinosa e Fraxinus excelsior (Alno-Padion, Alnion incanae, Salicion albae)
- Foreste di Quercus ilex e Quercus rotundifolia
- Foreste miste riparie di grandi fiumi a Quercus robur, Ulmus laevis e Ulmus minor, Fraxinus excelsior o Fraxinus angustifolia (Ulmenion minoris)
- Formazioni a Juniperus communis su lande o prati calcicoli
- Formazioni erbose rupicole calcicole o basofile dell'Alysso-Sedion albi

- Formazioni erbose secche della regione submediterranea orientale (Scorzoneratalia villosae)
- Ghiaioni del Mediterraneo occidentale e termofili
- Habitat non di interesse comunitario
- Laghi eutrofici naturali con vegetazione del Magnopotamion o Hydrocharition
- Lagune costiere
- Lande secche europee
- Paludi calcaree con Cladium mariscus e specie del Caricion davallianae
- Pareti rocciose calcaree con vegetazione casmofitica
- Pascoli inondati mediterranei (Juncetalia maritimi)
- Pavimenti calcarei
- Praterie con Molinia su terreni calcarei, torbosi o argilloso-limosi (Molinion caeruleae)
- Praterie di Posidonia (Posidonion oceanicae)
- Praterie e fruticeti alofili mediterranei e termo-atlantici (Sarcocornietea fruticosi)
- Praterie magre da fieno a bassa altitudine (Alopecurus pratensis, Sanguisorba officinalis)
- Praterie umide mediterranee con piante erbacee alte del Molinio-Holoschoenion
- Prati di Spartina (Spartinion maritimae)
- Querceti di rovere illirici (Erythronio-Carpinion)
- rForeste alluvionali di Alnus glutinosa e Fraxinus excelsior (Alno-Padion, Alnion incanae, Salicion albae)
- Scogliere
- Torbiere basse alcaline
- Vegetazione annua delle linee di deposito marine
- Vegetazione annua pioniera a Salicornia e altre specie delle zone fangose e sabbiose

Annexes

1. Cultural heritage impacts-hazards matrix
2. Ecosystems impacts-hazards matrix
3. Impacts summary cards

   3.1 Impacts on ecosystems and biodiversity - changes in the composition of biocenosis: *Mass Mortality Events (MME) in the Mediterranean Sea* ("Mass Mortality Event (MME) nel Mediterraneo)

   3.2 Impacts on ecosystems – alteration of the habitat's chemistry and physical structure: *Ocean acidification* ("Acidificazione marina")

   3.3 Impacts on the physical environment: *A changing lagoon* ("La marinizzazione della laguna di Marano e Grado")

   3.4 Impacts on ecosystems and biodiversity - habitats' loss or reduction/decline: *Disappearing saltmarshes* ("La scomparsa delle barene")

   3.5 Impacts on ecosystems and biodiversity: *Alien and invasive plants* ("Piante aliene e invasive")

   3.6 Impacts on forests - habitats' loss or reduction/decline & changes in the composition of ecological communities: *Wildfires* ("Incendi boschivi")