Project ID: 10252001

AdriaClim

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

D5.3.1

General knowledge framework for local adaptation plans

Pilot Area: Friuli Venezia Giulia coast and lagoon area

PP 11 – ARPA FVG

Final version

30th June 2023

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About this Deliverable

AdriaClim's Deliverable 5.3.1 aims at providing a general knowledge framework for local adaptation plans in Friuli Venezia Giulia pilot area. Therefore, it includes an overview of existing spatial and sectoral plans, of available information about climate change and related impacts, as well as available references and tools for adaptation.

Chapter 1 - Outline of the jurisdictional framework

1.1 – Main national and regional policy references for climate change adaptation

In Italy, the foundations for the definition of climate change adaptation actions and policies were laid with the *National Strategy for Adaptation to Climate Change* (SNAC, MATTM 2015)[1] and the related technical-scientific supporting documents.

The National Strategy:

- identified the main impacts of climate change on environmental resources and on a set of relevant socio-economic sectors at national level;
- indicated for each of them initial proposals for actions to adapt to these impacts.

The Strategy will be implemented through the National Plan for Adaptation to Climate Change (PNACC), which was subjected to public consultation in 2017, then to further revision by the Regions in 2018 and subsequently to the VAS/SEA process (Strategic Environmental Assessment). Pending the Final approval of the PNACC, the Plan and its annexes are available in the version published in February 2023 as part of the VAS/SEA procedure[2].

The main objective of the PNACC is to update the complex national knowledge reference framework on adaptation so that it can be functional for planning adaptation actions at the various levels of government and in the various sectors of intervention. In this way, Italy will be able to contribute to the achievement of the global climate change adaptation goal set out in the 2015 Paris Agreement, consisting of: enhancing adaptive capacity, building resilience and reducing vulnerability to climate change as part of the sustainable development and containment goal of the rise in the global average temperature.

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

[2] https://va.mite.gov.it/it-IT/Oggetti/Documentazione/7726/11206

In Friuli Venezia Giulia, the drawing up of a Regional Strategy for Adaptation to Climate Change has not yet been formally launched. However, a first step was taken to support this process with the realization of the first *Study of climate change and some of its impacts in Friuli Venezia Giulia* (March 2018)[3]. The Study was coordinated by ARPA FVG on a regional mandate (DGR n. 1890-2016) and it was carried out in collaboration with the Universities of Udine and Trieste, ICTP, OGS, CNR-ISMAR and the regional administration itself.

The drafting of this first fact-finding study was an opportunity to set up a regional technical table on climate change and its impacts in FVG, which was coordinated by ARPA and involved the experts from the Universities of Udine and Trieste and from the research institutions (OGS, ICTP, CNR-ISMAR and CNR-ISP) who contributed to the study. In May 2022 the Region formally established[4] the "Technical-scientific working group Climate FVG" (Gruppo di lavoro tecnico-scientifico Clima FVG) made up of the same institutions. The working group Climate FVG therefore brings together the technical and scientific excellence present in FVG, able to provide the regional administration and the other entities and subjects of the FVG with the most up-to-date knowledge to deal with climate change in FVG area.

In 2023, the Regional Law of 17 February 2023, n. 4 *"FVGreen - Provisions for the sustainable development and ecological transition of Friuli Venezia Giulia"* was approved. The FVGreen law provides for and regulates:

- the Regional strategy for sustainable development (approved in February 2023);
- the Regional strategy for mitigation and adaptation to climate change (yet to be drafted);
- the Regional plan for mitigation and adaptation to climate change (yet to be drafted).

The Region also recognizes the fundamental role of the Municipalities in the identification and implementation of actions to mitigate and adapt to climate change on the regional territory through adhesion to the initiative "EU Covenant of Mayors for Climate & Energy" and the preparation of the Sustainable Energy and Climate Action Plan (SECAP), as territorial coordinator of the initiative.

1.2 – Regional plans mapping

A survey of existing regional plans is desirable in the context of a general knowledge framework for planning adaptation measures and actions to address climate change impacts. These plans

[3] 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.

[4] Decree No. 2137 of 04/05/2022 of the Central Directorate for the Defence of the Environment, Energy and Sustainable Development.

represent the planning instruments that public bodies, such as regional administrations or managing bodies of a certain area, adopt to govern the territory or to regulate specific sectors.

By CReIAMO PA[5], the Italian Ministry of the Environment's project for the improvement of public administrations' skills in addressing environmental policies, we provided a survey of the planning instruments available on a regional scale, considering both general and sectoral plans. In fact, as specified in the 5th line (L5)[6] of the CReIAMO PA project (*L5-Reinforcement of administrative capacity for adaptation to climate change*), effective adaptation planning starts from preliminarily defining potential institutional stakeholders competent in the field of adaptation and existing planning tools suitable for adaptation mainstreaming.

This survey is part of the steps guiding a public body in designing an adaptation plan, as outlined in the CReIAMO PA document "Methodologies for defining regional climate change adaptation strategies and plans", a guideline for regional administrations. As explained in section A.2.2, a survey of the organisational structure and distribution of competencies is recommended. As adaptation to climate change has a strong cross-cutting connotation, adaptation measures should be taken by different sectors, from agriculture to infrastructure, from water management to cultural heritage, involving a large number of stakeholders in different contexts. Efficient coordination among the stakeholders of the public body, lays the foundation for successful cooperation and leads to effective adaptation.

With regard to the survey on regional plans carried out for the AdriaClim project in the FVG pilot area, we started to map the regional regulatory and planning framework, considering relevant plans, programmes and projects from an adaptation perspective. Once significant planning instruments were identified, we looked into them for the themes of climate, climate change, adaptation and mitigation, each time highlighting whether these themes were present and in what terms. To quantify the presence of climate change issues in planning instruments, we assigned them a kind of score called "mainstream adaptation": the higher it is, the more climate change issues are present in the plan/programme.

In addition, we examined the planning instruments in terms of content, checking whether there were specific targets or objectives, actions or measures, whether the plan/programme contained implementation rules and economic evaluations. This in the perspective of making available these results to other Public Bodies involved in adaptation planning processes, providing a preliminary analysis on existing planning instruments.

[5] CReIAMO PA – Competenze e reti per l'integrazione ambientale e per il miglioramento delle organizzazioni della Pubbliche Amministrazioni

[6] L5 – Rafforzamento della capacità amministrativa per l'adattamento ai cambiamenti climatici

Finally, we assigned one or more specific *impact sectors* to each planning instrument, referring to the categories that define climate change impacts in the National Strategy for Adaptation to Climate Change (SNAC) (**Table 1**).

The purpose of mapping the regional plans/programmes is to understand whether some of them can already be a tool for action or are already an action in themselves, in the perspective of climate change adaptation.

***Table 1**. Impact sectors from the Italian National Strategy for Adaptation to Climate Change (SNAC).*

ITALIAN NATIONAL STRATEGY FOR ADAPTATION TO CLIMATE CHANGE (SNAC) - IMPACT SECTORS				
Original categories (IT)		*Symbol*	*Modified categories (ENG)*	
RISORSE IDRICHE		RI	WATER RESOURCES	
DESERTIFICAZIONE, DEGRADO DEL TERRITORIO E SICCITÀ		DE	DESERTIFICATION, LAND DEGRADATION AND DROUGHTS	
DISSESTO IDROGEOLOGICO		DI	HYDROGEOLOGICAL RISK	
BIODIVERSITÀ ED ECOSISTEMI	Ecosistemi terrestri	ET	BIODIVERSITY AND ECOSYSTEMS	Terrestrial ecosystems
	Ecosistemi marini	EM		Marine ecosystems
	Ecosistemi di acque interne e di transizione	EA		Freshwater and transitional ecosystems
FORESTE		FO	FORESTS	
AGRICOLTURA, ACQUACOLTURA E PESCA	Agricoltura e produzione alimentare	AG	AGRICULTURE, AQUACULTURE AND FISHING	Agriculture and food production
	Pesca marittima	PM		Sea fishing
	Acquacoltura	AC		Aquaculture
ZONE COSTIERE		ZC	COASTAL AREAS	
TURISMO		TU	TOURISM	
SALUTE		SA	HEALTH	
INSEDIAMENTI URBANI		IU	URBAN SETTLEMENTS	
INFRASTRUTTURA CRITICA	Patrimonio culturale	PC	CRITICAL INFRASTRUCTURE	Cultural Heritage
	Trasporti e infrastrutture	TI		Transportation and infrastructure
	Industrie e infrastrutture pericolose	IP		Industry and dangerous infrastructure
ENERGIA		EN	ENERGY	

Regarding the result of this effort, we found a total of 25 planning instruments, mostly concerning the regional territory (**Figure 1**, **Table 1**). In some cases, plans were at a district scale (i.e. at a basin scale), namely the geographical unit identified for the governance of water resources. The FVG pilot area is located in the Eastern Alps district and the responsible public authority is the Eastern Alps District Basin Authority which draw up the Basin Plan. This Basin Plan is composed by several Plans, as the Water Management Plan (PGA), the Flood Risk Management Plan (PGRA) and the Hydro-geological Structure Plans (PAI and PAIR), all at the Eastern Alps district scale. These are Plans that regard specific impact sectors, at first Water resources-**RI** and Hydrogeological risk-**DI**, secondly Desertification, land degradation and droughts-**DE**.

On the other hand, plans/programmes of a general nature are drawn up by the Autonomous Region of Friuli Venezia Giulia (RAFVG) and its Directorates and Offices, such as the Regional Landscape Plan (PPR) and the Territorial Government Plan (PGT), which are managed by the Regional Landscape, Territorial and Strategic Planning Service. To these are added the Smart Specialisation Strategy (S3), the Strategic Plan (PS), the Administrative Improvement Plan (PRA) and the Regional Action Plan on Green Public Procurement (PAR GPP), drawn up by the Regional Central Directorate. Altogether, 6 out of 25 planning instruments are characterised by a general value and do not address any specific area of impact.

The plans/programmes/strategies that refer to well-defined impact sectors on a regional scale, are the Regional Water Protection Plan (PRTA), which mainly falls under Water resources-**RI** impact sector; the Integrated Urban Waste Management Plan (PRGRU) (Urban settlements-**IU**); the Regional Health Prevention Plan (PRP) (Health-**SA**); the Regional Energy Plan (PER) (Energy-**EN**); the Regional Plan for Transport Infrastructure, Freight Mobility and Logistics (PT) (Transportation and infrastructure-**TI**); the Rural Development Programme (PSR) (Agriculture-**AG**); the Tourism Plan (PDT) (Tourism-**TU**); the Regional Wildlife Plan (PFR) and the Regional Strategy for Invasive Alien Species (IAS) (both Terrestrial-**ET** and Freshwater and transitional ecosystems-**EA**).

Also, some plans regulate a smaller area than the regional one and are drawn up on a local scale. This is the case of the Adaptation Plan of the *Banco della Mula di Muggia* Pilot Site, within the Interreg Italy-Croatia Change We Care[7] project (2019-2021), which falls under two impact sectors, namely Freshwater and transitional ecosystems-**EA** and Coastal areas-**ZC**, as well as the Wetland Contract of the Marano Lagoon, which comes from CREW[8], another Interreg Italy-Croatia project (2018-2021). Other two plans considered are due to the UNESCO programme, as they concern a World Heritage Site and a Man and Biosphere (MAB) Reserve. These are the Archaeological Area and the Patriarchal Basilica of Aquileia and the Miramare Biosphere Reserve, regulated by a Management Plan (Cultural heritage-**PC**) and an Action Plan (Marine ecosystems-**EM)** respectively. At the end, regarding the local area of the Marano and Grado lagoon, the Plan for the Sustainable

[7] Climate cHallenges on coAstal and traNsitional chanGing arEas: WEaving a Cross-Adriatic REsponse
[8] Coordinated Wetland management in Italy-Croatia cross border region

Tourism (PTS) concerns mainly the Tourism-**TU** sector, while the Plan on the Small-scale Fishing (PP) considers primarily the Sea-fishing-**PM** impact sector.

Table 2*. Plans/programmes/strategies considered for the FVG pilot area. In yellow (ID=0) the plans excluded from the further considerations (see the text below).*

ID	PLAN/PROGRAMME/STRATEGY		ACRONYM	SPATIAL SCALE	YEAR OF APPROVAL / LAST UPDATE
	ENG	ITA			
1	Regional Landscape Plan	Piano Paesaggistico Regionale del Friuli Venezia Giulia	PPR	FVG	2018
2	Territorial Government Plan	Piano del Governo del Territorio	PGT	FVG	2013
3	Water Management Plan	Piano di Gestione delle Acque	PGA	River basin	2021
4	Flood Risk Management Plan	Piano di Gestione del Rischio Alluvioni	PGRA	River basin	2021
5	Hydro-geological Structure sub-Plan	Piano stralcio per l'assetto idrogeologico dei bacini dei fiumi Isonzo, Tagliamento, Piave, Brenta-Bacchiglione	PAI	River basin	2013
6	Hydro-geological Structure Regional Plan	Piano stralcio per l'assetto Idrogeologico dei bacini di interesse Regionale	PAIR	River basin	2017
7	Regional Water Protection Plan	Piano Regionale di Tutela delle Acque	PRTA	FVG	2018
8	Integrated Urban Waste Management Plan	Piano d'ambito di gestione integrata dei rifiuti urbani	PRGRU	FVG	2022
9	Smart Specialisation Strategy	Strategia per la specializzazione intelligente	S3	FVG	2021
10	Strategic Plan	Piano Strategico	PS	FVG	2019
11	Regional Health Prevention Plan	Piano Regionale di Prevenzione del Friuli Venezia Giulia	PRP	FVG	2021
12	Administrative Improvement Plan	Piano di Rafforzamento Amministrativo	PRA	FVG	2018
13	Regional Energy Plan	Piano Energetico Regionale	PER	FVG	2015

ID	PLAN/PROGRAMME/STRATEGY		ACRONYM	SPATIAL SCALE	YEAR OF APPROVAL / LAST UPDATE
	ENG	ITA			
14	Regional Plan for Transport Infrastructure, Freight Mobility and Logistics	Piano Regionale delle infrastrutture di trasporto, della mobilità delle merci e della logistica	PT	FVG	2011
15	Rural Development Programme	Programma di Sviluppo Rurale	PSR	FVG	2015
16	Tourism Plan	Piano del Turismo	PDT	FVG	2014
17	Regional Wildlife Plan	Piano Faunistico Regionale	PFR	FVG	2015
18	the Regional Strategy for Invasive Alien Species	Strategia Regionale per le specie esotiche invasive	IAS	FVG	2020
19	Regional Action Plan on Green Public Procurement	Piano d'azione della Regione Friuli Venezia Giulia per gli acquisti verdi	PAR GPP	FVG	2022
20	Adaptation Plan of the Banco della Mula di Muggia Pilot Site	Piano di adattamento per il sito pilota Banco della Mula di Muggia	CHANGE WE CARE	Local area	2022
21	Wetland Contract of the Marano Lagoon	Contratto di Area Umida della Laguna di Marano - Dichiarazione d'intenti	CREW	Local area	2021
22	Plan for the Sustainable Tourism	Piano del Turismo Sostenibile	PTS	Local area	2018
23	Plan on the Small-scale Fishing	I mestieri della pesca nella Laguna di Marano e Grado: criteri e modalità di esercizio dell'attività di pesca professionale	PP	Local area	2018
24	Archaeological Area and the Patriarchal Management Plan	Piano di Gestione Area archeologica di Aquileia e Basilica Patriarcale	PDG UNESCO	Local area	2017
25	Miramare Biosphere Reserve Action Plan	Piano di Azione della Riserva di Biosfera di Miramare	PA MAB	Local area	2022
0	Basin Plan	Piano di Bacino	/	River basin	/
0	Integrated Water Service Management Scope Plan	Piano d’ambito di gestione del servizio idrico integrato	/	FVG	/
0	Regional Strategy for the Sustainable Development	Strategia Regionale per lo Sviluppo Sostenibile	/	FVG	/

ID	PLAN/PROGRAMME/STRATEGY		ACRONYM	SPATIAL SCALE	YEAR OF APPROVAL / LAST UPDATE
	ENG	ITA			
0	Regional Plan for the Coastal Management	Piano Regionale di Gestione Costiera	/	FVG	/
0	Regional General Urban Plan	Piano Urbanistico Regionale Generale	PURG	FVG	1978

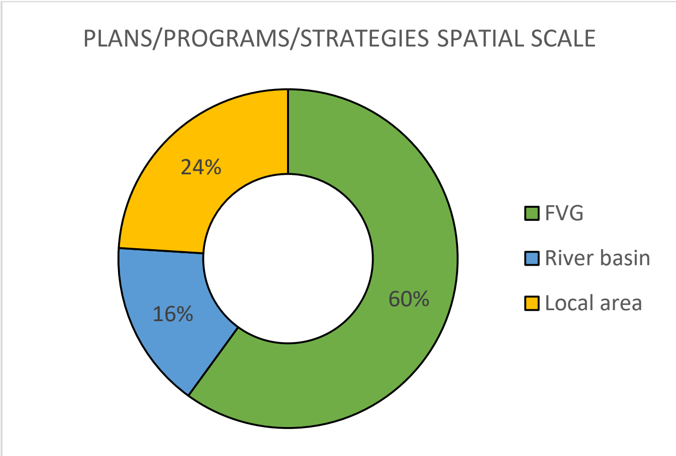

***Figure 1**. Spatial scale of the 25 considered planning instruments.*

It is important to note that some plans have been tracked but excluded from the further considerations because they have not yet been drafted or are outdated. The first case is that of the Integrated Water Service Management Scope Plan, the Regional Strategy for the Sustainable Development as well as the Regional Plan for the Coastal Management. To the second case belongs the Regional General Urban Plan (PURG) which has been published in 1978 and it has been updated by the Territorial Government Plan. Lastly, the Basin Plan consists of several sub-plans and we considered only that ones in our further analysis.

Finally, we also considered marine-coastal protected areas within the FVG pilot area, both Regional Nature Reserves and Natura 2000 sites. We found a total of 17 documents which mainly fall under the Biodiversity and ecosystems impact sector. These documents consist of the Regulation and/or the Conservation and Development Plan (PCS) for almost all 5 Regional Nature Reserves (RNR) and 1 Marine Protected Area (MPA) in the FVG pilot area. On the other hand, as far as the European ecological network is concerned, the 10 Natura 2000 sites (both SACs and SPAs) are governed by a Management Plan (PDG) or by both general and Site-Specific Conservation Measures (MCS). In some cases, Regional Nature Reserves overlap partially or totally the with Natura 2000 sites (**Table 3**). Anyway, PCSs, Regulations, PDGs and MCSs are real planning and management instruments, so they have been included in our further analysis.

Table 3. Marine-Coastal protected areas that overlook the sea/lagoon within the FVG pilot areas and the planning/management instruments considered. RNR=Regional Nature Reserves; MPA=Marine Protected Area; REG=Regulation; PDG=Management Plan; PCS=Conservation and Development Plan; N2K=Natura 2000; SAC=Special Area of Conservation; SPA=Special Protected Area; MSC= Site-Specific Conservation Measures.

PROTECTED AREA		OVERLAPPING	PLANNING/MANAGEMENT INSTRUMENT		
NAME	TYPE		TYPE	ID	ACRONYM
Foce dell'Isonzo	RNR	Partially with N2K site IT3330005 Foce dell'Isonzo-Isola della Cona	Regulation	1	REG_Foce-Isonzo_RNR
			PCS	2	PCS_Foce-Isonzo_RNR
Foci dello Stella	RNR	None	Regulation (joined with Valle Canal Novo)	3	REG_Valle-Canal-Novo_Foci-Stella_RNR
Valle Canal Novo	RNR	None	Regulation (joined with Foci dello Stella)		
			PCS	4	PCS_Valle-Canal-Novo_RNR
Valle Cavanata	RNR	Partially with N2K site IT3330006 Valle Cavanata e Banco Mula di Muggia	Regulation	5	REG_Valle-Cavanata_RNR
Falesie di Duino	RNR	Partially with N2K sites IT3340006 Carso Triestino e Goriziano and IT3341002 Aree Carsiche della Venezia Giulia	Regulation	6	REG_Falesie-Duino_RNR
			PCS	7	PCS_Falesie-Duino_RNR
Miramare	MPA	Totally with IT3340007 Area Marina di Miramare	Regulation	8	REG_Miramare_MPA
IT3320037 Laguna di Marano e Grado	SAC/SPA	None	PDG	9	PDG_Laguna_N2K
IT3320038 Pineta di Lignano	SAC	None	MCS	10	MCS_Pineta_N2K
IT3330005 Foce dell'Isonzo-Isola della Cona	SAC/SPA	Partially with RNR Foce dell'Isonzo	PDG	11	PDG_Foce-Isonzo_N2K
IT3330006 Valle Cavanata e Banco Mula di Muggia	SAC/SPA	Partially with RNR Valle Cavanata	PDG	12	PDG_Valle-Cavanata_N2K

PROTECTED AREA		OVERLAPPING	PLANNING/MANAGEMENT INSTRUMENT		
NAME	TYPE		TYPE	ID	ACRONYM
IT3330007 Cavana di Monfalcone	SAC	None	MSC	13	MSC_Cavana_N2K
IT3330008 Relitti di Posidonia presso Grado	SAC/SPA	None	MSC	14	MSC_Relitti_N2K
IT3330009 Trezze di San Pietro e Bardelli	SAC/SPA	None	MSC	15	MSC_Trezze_N2K
IT3340007 Area Marina di Miramare	SAC/SPA	Totally with MPA Miramare	MSC	16	MSC_Miramare_N2K
IT3340006 Carso Triestino e Goriziano	SAC	Partially with RNR Falesie di Duino and N2K site IT3340006 Carso Triestino e Goriziano	MSC (joined with IT3341002 Aree Carsiche della Venezia Giulia)	17	MSC_Carso_N2K
IT3341002 Aree Carsiche della Venezia Giulia	SPA	Partially with RNR Falesie di Duino and N2K site IT3341002 Aree Carsiche della Venezia Giulia	MSC (joined with IT3340006 Carso Triestino e Goriziano)		

With regard to impact sectors, in addition to the main sector in which the considered planning/management instruments fall, we have also identified secondary or tertiary impact sectors that could affect the plan. This allowed us to estimate which areas of impact are most represented and which areas are least considered in regional and local planning.

The planning/management instruments of RNRs, MPA and N2K sites have been excluded from this analysis because of their specificity (i.e., very sectorial instruments) and their affinity to the "Ecosystem and biodiversity" sector.

So, we assigned an alphabet letter to characterize the main impact sector under which the planning instrument falls (only the plans/programmes/strategies in **Table 2**). Where an *A* is present, it means that the plan/programme falls mainly in the area of that impact sector. Where there is a *B*, the impact sector is of secondary interest in respect of the plan/programme. Where the plan/programme presents a *C*, the impact sector is marginally involved in that plan/programme. If the plan/programme expressed a territorial governance value on a larger scale, we assigned a "general" value (marked by the *G* letter).

Later, we assigned a score to each letter to highlight which impact sectors were the most represented in the plans/programmes (*A* = 3; *B* = 2; *C* = 1; *G* = 0.5). For each impact sector, we checked which and how many letters appeared. The final score each impact sector had, is the result of the interaction of the letters:

$(A * 3) + (B * 2) + (C * 1) + (G * 0.5)$.

For example, the impact sector "Forests" received a final score of 9. This means that in 6 plans/programs, the "Forests" sector had a "general" value (*G*, N=6) while in 3 plans/programs "Forests" had a different weight for each. In one it represented the main impact sector under which that plan fell (*A*, N=1); in another, it was the secondary impact sector (*B*, N=1); and in the last plan/program, it was the marginal one (*C*, N=1).

So, the final score is:

$9 = (1_A * 3) + (1_B * 2) + (1_C * 1) + (6_G * 0.5)$.

Considering both the main sector and the other ones, we found that Freshwater and transitional-**EA** and Terrestrial ecosystems- **ET** are the most represented, followed by Tourism-**TU** and Coastal areas-**ZC**. Then, there are Marine ecosystems-**EM**, Sea fishing-**PM**, Aquaculture-**AC**, Cultural heritage-**PC**, Urban settlements-**IU**, Hydrogeological risk-**DI**, Agriculture-**AG** and Water resources-**RI.** In the last places are Forests-**FO**, Transportation and Infrastructure-**TI**, Health-**SA**, Energy-**EN**, Industry and dangerous infrastructure-**IP** and, finally, Desertification, land degradation and droughts-**DE** (**Figure 2**).

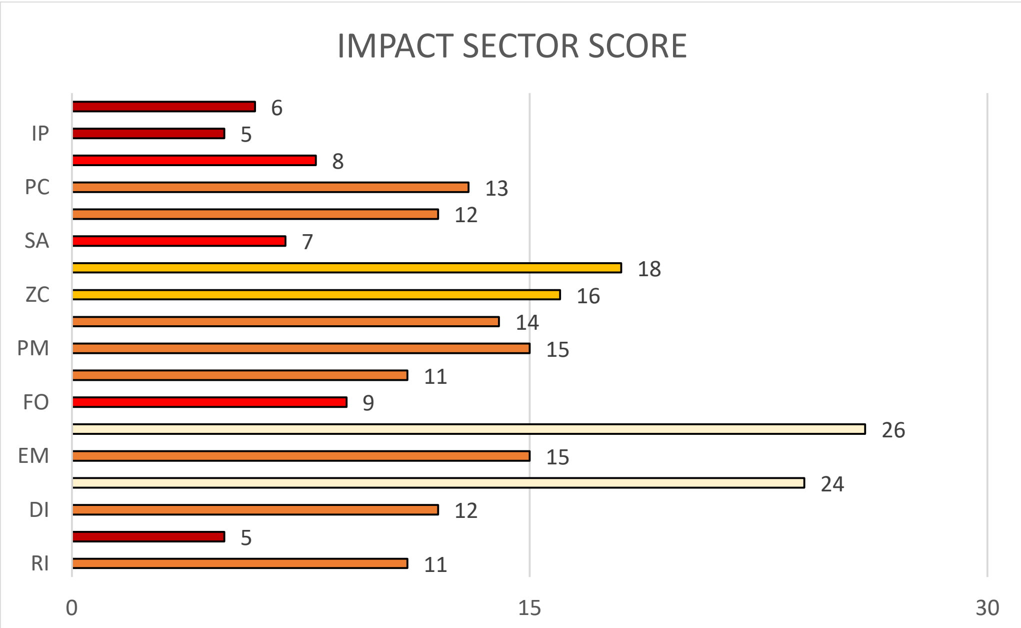

Figure 2*. Impact sector score considering 25 planning instruments (see* ***Table 2****). Dark red=last 3 positions; Red= score lower than 10; Orange=score between 10 and 15; Yellow=score between 16 and 20; Light yellow=score higher than 20.*

As mentioned above, we also assigned to the planning instruments a kind of score called "mainstream adaptation". This time, we considered both plans/programmes/strategies in **Table 2** and those in **Table 3** (protected areas). Considering the content of each plan/programme, we checked if climate change issues appeared in it. We assigned a score of 1 for the presence of a climate framework, 2 for mentioning climate change (CC), 3 if the plan/programme considered the impacts of climate change, and 4 for the presence of the adaptation topic:

(1 * climate) + (2 * CC) + (3 * CC impacts) + (4 * CC adaptation).

As regards of the first pool of 25 planning instruments (**Table 2**), the plans with the highest score are the PGT, PGA, PGRA, PRTA, the S3 and the Adaptation Plan of the *Banco della Mula di Muggia* (**Figure 3**). It is interesting to note that out of these 6 plans, 3 (PGA, PGRA, PRTA) fall in the area of Water resources-RI and Hydrogeological risk-DI, two areas that are closely linked to each other and to climate change issues. The PRGRU, Strategic Plan, PRP and PER also score high overall, demonstrating that waste, public health and energy are subject areas to be dealt with in a cross-cutting approach. It is unexpected that the PPR is placed at the bottom of this particular ranking, as it is considered a kind of Master Plan to which other regional plans should refer.

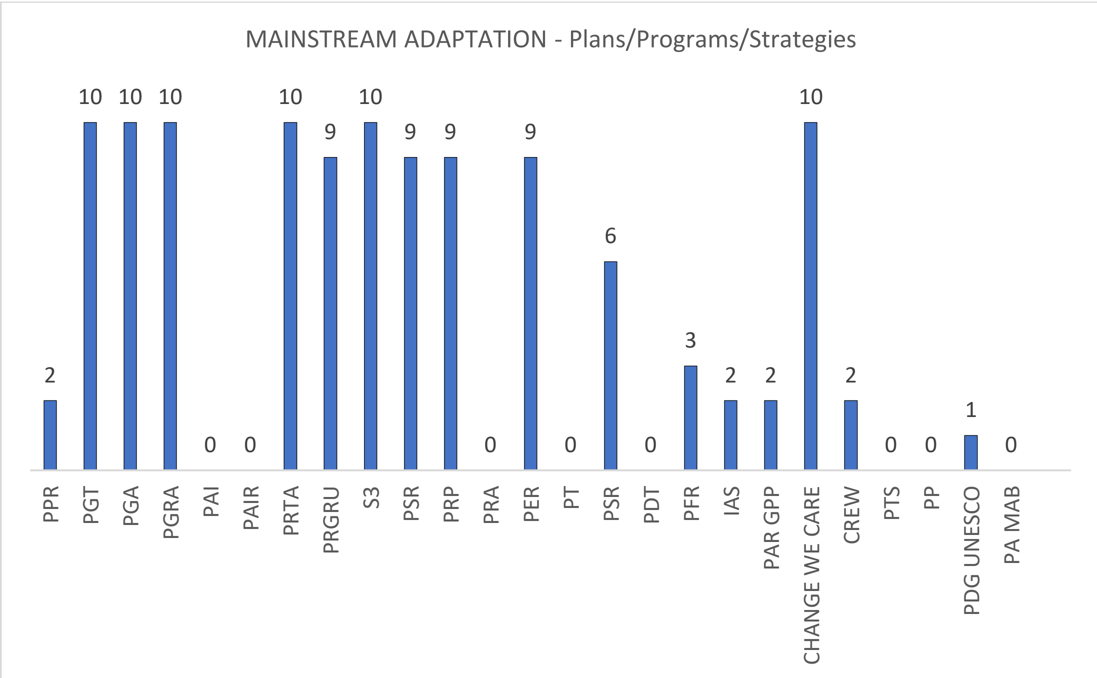

Figure 3*. Mainstream adaptation score in the considered plans/programmes/strategies.*

Also regarding protected areas, among the 17 planning/management instruments considered, almost all have a very low score, or even 0 (**Figure 4**). As mentioned above, these are very sectorial instruments drawn up in the management of protected areas or natural resources. Clearly, by their nature, this sectoral and pragmatic approach does not leave much room for adaptation planning, for now. The only exception is the Management Plan of the Marano and Grado Lagoon, it is a Plan that has undergone a long process of updating and approval and which, not coincidentally, concerns one of the most fragile coastal areas in the Region.

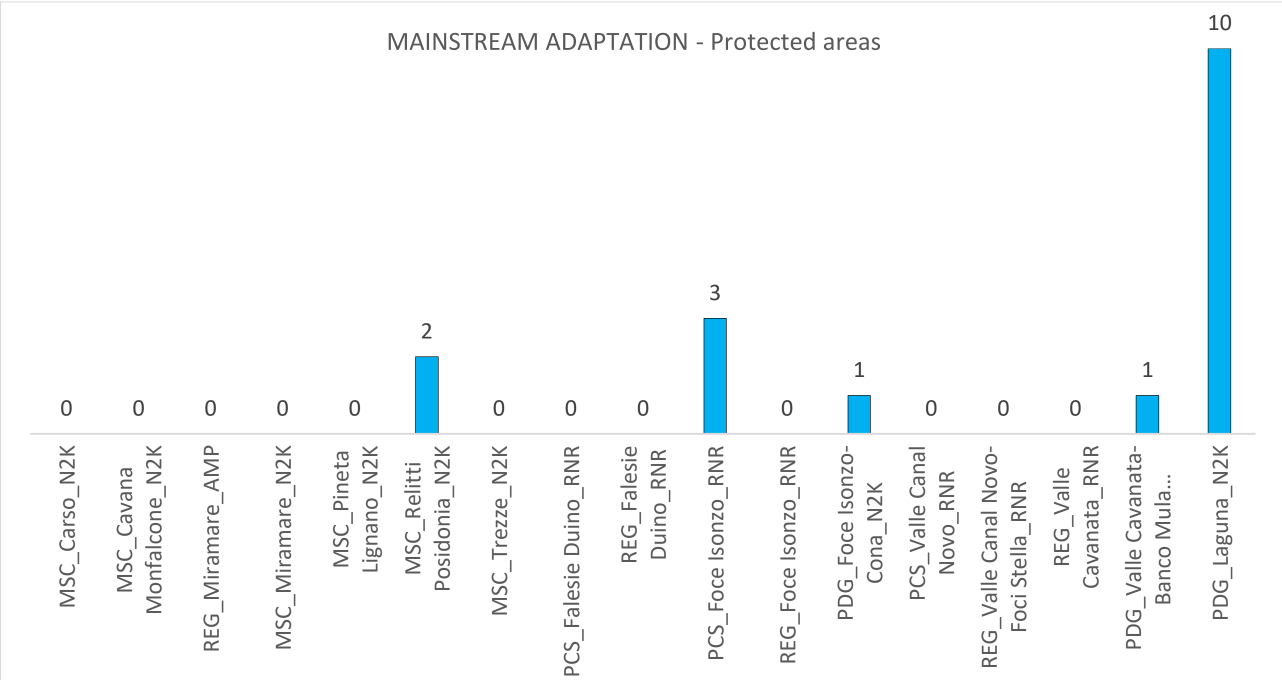

Figure 4. *Mainstream adaptation score in the planning/management instruments of the considered protected areas.*

Finally, from this simple but effective analysis, it emerges that climate change and adaptation are not systematically addressed in planning instruments and that there is a considerable difference depending on the area of impact in which the plan/programme/strategy falls. This means that there are some areas where climate change risks are considered significant and others where they are overlooked. This allows us to reason that adaptation to climate change impacts cannot remain an issue confined to a few areas, but must permeate all levels and sectors of planning.

The complete survey in excel format (**Figure 5 A-B**) is digitally attached to this document as an annexe. The language in which the survey is written is Italian, as this is a product intended for and aimed at local policy makers.

In fact, this survey and analysis of existing planning tools already proved useful for the regional administration: in November 2022 the *Regione Autonoma Friuli Venezia Giulia* officially requested the mapping synoptic table, that will be used in the revision process of the Regional Master Plan (*Piano di Governo del Territorio*), according to the adaptation mainstreaming approach. The official request will be attached to D5.3.1 as an annex or as a complementary document in the project G-drive.

A

Denominazione	Obiettivi/target specifici (Y/N)	Se sì, quali? (ref.)	Azioni/misure (Y/N)	Se sì, quali? (ref.)	Norme attuazione (Y/N)	Se sì, quali? (ref.)	Valutazione economica (Y/N)	Se sì, quale? (ref.)	Ref. clima (Y/N)	Se sì: fonte, pp., accenno/paragrafo	Ref. CC (Y/N)	Se sì: fonte, pp., accenno/paragrafo	Ref. impatti CC (Y/N)	Se sì: fonte, pp., accenno/paragrafo	Ref. ACC (Y/N)	Se sì: fonte, pp., accenno/paragrafo	Ref. MCC (Y/N)	Se sì: fonte, pp., accenno/paragrafo	mainstreaming adattamento (teorico)
	INFO CONTENUTO								INFO CLIMA/CC										
Piano Paesaggistico Regionale del Friuli	Y	Obiettivi generali:	N	ND	Y	All. 3 Norme	N	ND	N	ND	Y	Accenno nella	N	ND	N	ND	N	ND	2
Piano del Governo del Territorio (PGT)	Y	Obiettivi per (1)	Y	(1) Politiche	Y	All. 4 Norme	N	ND	Y	Cenni [All. 1 Relazione	Y	Cenni [All. 1 Relazione	Y	Accenno indiretto	Y	Obiettivo 2.4, cap.	Y	Art. 19, comma 1,	10
Piano Urbanistico Regionale Generale																			0
Piano di Bacino																			0
Piano di Gestione delle Acque (PGA) 2021-2027	Y	Obiettivi della	Y	(1) Vol. 6 Programm	Y	Vengono stabilite	Y	Vol. 5 Analisi	Y	Accenno [Vol. 1	Y	Tutti i Volumi	Y	Tutti Volumi	Y	Appendice B – Analisi	Y	10.4,10.6- Vol. 5	10
Piano di Gestione del Rischio Alluvioni 2021-	Y	(OS1) Riduzione	Y	(M2) Prevenzion	Y	Vengono stabilite	N	ND	Y	2.1.1- Caratterist	Y	2.2- Cambiame	Y	Cenni in 5.2-Principi	Y	Cenni in 2.2-	N	ND	10
Piano per l'Assetto Idrogeologico (PAI)																			0
Piano stralcio per l'assetto idrogeologico dei bacini	N	Mancano degli	Y	Interventi strutturali	Y	Allegato alla	Y	3.7-Costo complessiv	N	ND	N	ND	N	ND	N	ND	N	ND	0
Piano stralcio per l'assetto Idrogeologico dei bacini	N	Mancano degli	Y	Interventi strutturali	Y	7-Norme di attuazione	Y	4.8.5- Metodologi	N	ND	N	ND	N	ND	N	ND	N	ND	0
Piano Regionale di Tutela delle Acque (PRTA)	Y	Cap. 1- Obiettivi di	Y	Capp. 2-5 degli	Y	4-Norme di attuazione	Y	5-Sintesi dell'analisi	Y	3.1- Caratterist	Y	3.1.2- Cambiame	Y	L'argomento CC, ACC e	Y	L'argomento CC, ACC e	Y	L'argomento CC, ACC e	10
Piano d'ambito di gestione integrata dei	Y	4.4- Obiettivi di	Y	4.5-Azioni di piano	Y	Cap. 6- Norme di	Y	3.6.7-Costi di	N	ND	Y	Argomento trasversale	Y	Cenni nel cap. 3-	Y	Argomento trasversale	N	ND	9
Piano d'ambito di gestione del servizio																			0
Strategia per la specializzazione	Y	4.1-Bisogni e	Y	4.3-Azioni a supporto	N	ND	N	ND	Y	1.1.1- Ambiente e	Y	1.1.1- Ambiente e	Y	1.8.4- Minacce	Y	1.8.3- Opportunit	Y	1.8.3- Opportunit	10
Piano Strategico 2018-2023	Y	8 linee strategich	N	ND	N	ND	N	ND	N	ND	Y	Strategia 6- Mondo	Y	Strategia 6- Mondo	Y	Strategia 6- Mondo	N	ND	9
Piano Regionale di Prevenzione del Friuli	Y	6 Macro Obiettivi	Y	9 Programmi	N	ND	N	ND	N	ND	Y	3.9-PP09 Ambiente,	Y	Argomento trasversale	Y	Adattamen to ai CC (da	Y	Cenno in 3.9.3.1-	9
Strategia Regionale per lo Sviluppo Sostenibile																			0
Piano di Rafforzamento Amministrativo (PRA)	Y	5-Obiettivi di	Y	6- Interventi	N	ND	N	ND	N	ND	N	ND	N	ND	N	ND	N	ND	0
Piano Energetico Regionale (PER)	Y	4.4-Dalla Vision alla	Y	4.5-Le Misure del	Y	Norme tecniche di	Y	6-La potenzialit	N	ND	Y	1.1-Quadro normativo	Y	Argomento trasversale	Y	1.1.7-La Strategia	Y	Schede 22-27 in 4.7-	9
Piano Regionale delle infrastrutture di	Y	Obiettivi generale e	Y	All. 2, suddivise	Y	All. 3 Norme di	N	ND	N	ND	N	ND	N	ND	N	ND	N	ND	0
Programma di Sviluppo Rurale (PSR) 2014-2020	Y	Obiettivi generali:	Y	8- Descrizion	N	15- Modalità	Y	10-Piano di finanziame	N	ND	Y	Tutela dell'ambie	N	Generale riferimento	Y	Mitigazion e dei	Y	Mitigazion e dei	6
Piano del turismo (PDT) 2014-2018	Y	5 linee strategich	Y	5 misure per	N	ND	N	ND	N	ND	N	ND	N	ND	N	ND	N	ND	0
Piano Faunistico Regionale (PFR)	Y	All. 3 del PFR -	Y	Per alcune delle	N	ND	N	ND	Y	Cenni in 2- Inquadram	Y	Per alcune specie si fa	N	ND	N	ND	N	ND	3
Strategia Regionale per le specie esotiche invasive	Y	5- Obiettivi,	Y	6-Tabelle di sintesi	N	ND	N	ND	N	ND	Y	Argomento trasversale	N	ND	N	ND	N	ND	2

B

Denominazione	Link	Autorità di riferimento	Anno approvazione / ultimo aggiornamento	Ref. Normativo	Pianificazione territoriale generale (=esprimono governo del territorio) (Y/N)	Pianificazione regionale di settore (=si occupano di uno o più settori)	Scala territoriale
	INFO GENERALI						
Piano Paesaggistico Regionale del Friuli	https:// www.re	Servizio pianificazione paesaggistica,	2018	Approvato con Decreto del	Y	N	FVG
Piano del Governo del Territorio (PGT)	https:// www.re	Servizio pianificazione paesaggistica,	2013 (in aggiornament	Approvato con Decreto del	Y	N	FVG
Piano Urbanistico Regionale Generale	https:// www.re	Servizio geologico - DC difesa dell'ambiente,	1978		Y	N	FVG
Piano di Bacino	https:// www.re	Servizio gestione risorse idriche - DC	Vari		N	Y	FVG
Piano di Gestione delle Acque (PGA) 2021-2027	http://w ww.alpi	Autorità di bacino distrettuale delle Alpi	2021	Seduta 2/2021 del 20/12/2021	N	Y	Distretto delle Alpi Orientali (bacini
Piano di Gestione del Rischio Alluvioni 2021-	http://w ww.alpi	Autorità di bacino distrettuale delle Alpi	2021	Il aggiornamento del PGRA previsto ai sensi	N	Y	Distretto delle Alpi Orientali (bacini
Piano per l'Assetto Idrogeologico (PAI)	http://w ww.alpi	Autorità di bacino distrettuale delle Alpi	2021	Ultimo aggiornamento	N	Y	Distretto delle Alpi Orientali (bacini
Piano stralcio per l'assetto idrogeologico dei bacini	http://p ai.adbv	Servizio geologico - DC difesa dell'ambiente,	2013	Decreto del Presidente del	N	Y	Bacini dei fiumi Isonzo, Tagliamento,
Piano stralcio per l'assetto Idrogeologico dei bacini	https:// www.re	Servizio geologico - DC difesa dell'ambiente,	2017	Approvato con DPReg. n. 28 del	N	Y	Bacini idrografici dei tributari della Laguna
Piano Regionale di Tutela delle Acque (PRTA)	https:// www.re	Servizio gestione risorse idriche - DC	2018	Approvato con Decreto del	N	Y	FVG
Piano d'ambito di gestione integrata dei	https:// www.re	AUSIR-Autorità Unica per i Servizi Idrici	2022	Approvazione di cui al D.P.Reg. 31 dicembre	N	Y	FVG
Piano d'ambito di gestione del servizio	ND	AUSIR-Autorità Unica per i Servizi Idrici	ND	Redatto ai sensi dell'art. 13 LR 5/2016	N	Y	FVG
Strategia per la specializzazione	http:// mtom.r	Direzione generale - RAFVG	2021	Attualmente in fase di negoziato.	Y	N	FVG
Piano Strategico 2018-2023	https:// www.re	Servizio programmazione,	2019	Approvato con Delibera della Giunta	Y	N	FVG
Piano Regionale di Prevenzione del Friuli	https:// www.sa	DC salute, politiche sociali e disabilità	2021	Approvazione preliminare con	N	Y	FVG
Strategia Regionale per lo Sviluppo Sostenibile	ND	DC difesa dell'ambiente,			N	N	FVG
Piano di Rafforzamento Amministrativo (PRA)	http:// mtom.r	Direzione generale - RAFVG	2018	Avvio alla Seconda fase del PRA con	Y	N	FVG
Piano Energetico Regionale (PER)	https:// www.re	DC difesa dell'ambiente,	2015	Approvazione della Giunta regionale n.	N	Y	FVG
Piano Regionale delle infrastrutture di	https:// www.re	Servizio relazioni internazionali e	2011	Approvato con DPReg n. 300 del 16	N	Y	FVG
Programma di Sviluppo Rurale (PSR) 2014-2020	https:// www.re	Servizio politiche rurali e sistemi	2015	Ultima modifica approvata dalla CE	N	Y	FVG
Piano del turismo (PDT) 2014-2018	http://w ww.pro	Servizio turismo e commercio - DC	2014	Allegato alla Delibero n. 993 del 30.05.2014	N	Y	FVG
Piano Faunistico Regionale (PFR)	https:// www.re	Servizio caccia e risorse ittiche - DC	2015	Il 10.07.2015 è stato approvato il Piano	N	Y	FVG
Strategia Regionale per le specie esotiche invasive	https:// www.re	Servizio biodiversità - DC Risorse	2020	Approvato con DGR n. 1257 del 07.08.2020	N	Y	FVG

Denominazione	RISORSE IDRICHE	DESERTIFICAZIONE, DEGRADO	DISSESTO IDROGEOLOGIC	BIODIVERSITÀ ED ECOSISTEMI	BIODIVERSITÀ ED ECOSISTEMI	BIODIVERSITÀ ED ECOSISTEMI	FORESTE	AGRICOLTURA, ACQUACOLTU	AGRICOLTURA, ACQUACOLTU	AAGRICOLTURA,	ZONE COSTIERE	TURISMO	SALUTE (rischi e impatti dei	INSEDIAMENTI URBANI	INFRASTRUTTURA CRITICA -	INFRASTRUTTURA CRITICA -	INFRASTRUTTURA CRITICA -	ENERGIA (produzione e
	SETTORI SNAC																	
Piano Paesaggistico Regionale del Friuli	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G
Piano del Governo del Territorio (PGT)	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G
Piano Urbanistico Regionale Generale																		
Piano di Bacino	A		A															
Piano di Gestione delle Acque (PGA) 2021-2027	A	B		C		C	C						C					
Piano di Gestione del Rischio Alluvioni 2021-	B		A	C	C	C								C	C	C	C	
Piano per l'Assetto Idrogeologico (PAI)			A											C				
Piano stralcio per l'assetto idrogeologico dei bacini			A											C				
Piano stralcio per l'assetto Idrogeologico dei bacini			A											C				
Piano Regionale di Tutela delle Acque (PRTA)	A			B		B	B											
Piano d'ambito di gestione integrata dei														C				
Piano d'ambito di gestione del servizio	A																	
Strategia per la specializzazione	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G
Piano Strategico 2018-2023	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G
Piano Regionale di Prevenzione del Friuli													A					
Strategia Regionale per lo Sviluppo Sostenibile																		
Piano di Rafforzamento Amministrativo (PRA)	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G
Piano Energetico Regionale (PER)																		A
Piano Regionale delle infrastrutture di																A		
Programma di Sviluppo Rurale (PSR) 2014-2020								A	A	A								
Piano del turismo (PDT) 2014-2018												A						
Piano Faunistico Regionale (PFR)				A		A	A	B										
Strategia Regionale per le specie esotiche invasive				A		A												

***Figure 5 A-B**. Screenshots (A and B) of the Regional Plans survey and analysis in excel format.*

1.3 – Local adaptation to climate change in the pilot area: state of the art

In Friuli Venezia Giulia, more than 70 local authorities (as single or aggregated Municipalities) have joined the *EU Covenant of Mayors for Climate & Energy* and are at different stages in the process of drafting, implementing and monitoring their local plans (either SEAP - Sustainable Energy Action Plan or SECAP - Sustainable Energy and Climate Action Plan) (**Table 4**).

***Table 4**. Number of SEAP/SECAP plans in Friuli Venezia Giulia (September 2022)[9].*

PROVINCE	COMMITMENTS
Gorizia	9
Pordenone	26
Trieste	6
Udine	33
Total local authorities	**74**

In the following table (**Table 5**), Municipalities belonging to AdriaClim's Friuli Venezia Giulia pilot area that are signatories of the EU Covenant of Mayors are highlighted (10 Municipalities out of 39).

***Table 5**. Local authorities that signed the UE Covenant of Mayors and their commitments in Friuli Venezia Giulia (September 2022)[10].*

SIGNATORY	POPULATION	COMMITMENTS	ADHESION DATE	APPROVAL DATE
Province of GORIZIA				
Capriva del Friuli	1746		2014	2015
Doberdò del Lago	1455		2013	2014
Farra d'Isonzo	1749		2014	2015
Mossa	1619		2014	2015
Romans d'Isonzo	3732		2014	2015
San Lorenzo Isontino	1558		2014	2015

[9] https://eu-mayors.ec.europa.eu/en/action_plan_list
[10] Idem

SIGNATORY	POPULATION	COMMITMENTS	ADHESION DATE	APPROVAL DATE
Savogna d'Isonzo - Sovodnje ob Soči	1722		2015	2020
Staranzano	7309		2019	
Turriaco	2811		2020	
Province of PORDENONE				
Associazione Intercomunale Val Cosa e Val D'Arzino	4533		2016	2018
AVIANO	9142		2013	2014
Azzano Decimo	15775		2017	2020
BRUGNERA	9387		2016	2018
Budoia	0		2016	2018
Caneva-Budoia-Polcenigo	12163		2016	2018
Casarsa della Delizia	8608		2016	2018
CHIONS	5192		2016	2018
Fanna	1609		2015	2017
Fiume Veneto	11645		2015	2017
Fontanafredda	12205		2016	2018
Frisanco	618		2015	2017
Maniago	11885		2015	2017
MONTEREALE VALCELLINA	4500		2013	2015
PASIANO DI PORDENONE	7749		2016	2018

SIGNATORY	POPULATION	COMMITMENTS	ADHESION DATE	APPROVAL DATE
PORCIA	15280		2016	2018
PRATA DI PORDENONE	8467		2016	2018
ROVEREDO IN PIANO	5967		2016	2020
Sacile	19837		2016	2017
Sacile, Brugnera			2016	
San Giorgio della Richinvelda	4646		2016	2018
San Martino al Tagliamento	1468		2016	2018
Tramonti di Sopra	348		2015	2017
Tramonti di Sotto	410		2015	2017
Travesio.	1790		2016	2018
Valvasone Arzene	3988		2016	2018
Province of TRIESTE				
Duino-Aurisina / Devin Nabrežina	8700		2012	2014
Monrupino-Repentabor	868		2016	2018
MUGGIA	12899		2021	
Sgonico-Zgonik	2090		2016	2018
Sgonico-Zgonik, Monrupino-Repentabor	0		2016	
Trieste	208136		2012	2014
Province of UDINE				

SIGNATORY	POPULATION	COMMITMENTS	ADHESION DATE	APPROVAL DATE
Artegna	2884		2015	2018
Associazione Intercomunale Conca Tolmezzina	13510		2013	2014
Attimis	1808		2016	2017
Bordano	786		2009	
BUTTRIO	4074		2015	2018
Cavazzo Carnico	0		2013	2014
Cervignano del Friuli	13844		2016	2018
Congiunto Comuni di Mereto di Tomba, Basiliano, Flaibano e Sedegliano	13081		2016	2018
Faedis	2941		2016	2017
Forgaria nel Friuli	0		2016	2018
Forgaria nel Friuli-Vito d'Asio	2572		2016	2018
Forni di sotto	600		2015	
Latisana	13600		2016	2018
Lignano Sabbiadoro	6837		2020	2022
Mereto di Tomba	0		2016	2018
Moruzzo	2391		2015	2018
Pagnacco	5117		2013	
Palazzolo dello Stella	3001		2016	2017

SIGNATORY	POPULATION	COMMITMENTS	ADHESION DATE	APPROVAL DATE
Pasian di Prato	9454	Mitigation	2016	2018
Pocenia	2570	Mitigation	2016	2017
Pradamano	3600	Mitigation, Adaptation, Energy poverty	2020	
Remanzacco	6200	Mitigation, Adaptation, Energy poverty	2021	
Resiutta	284	Mitigation, Adaptation, Energy poverty	2021	
Ronchis	2048	Mitigation, Adaptation, Energy poverty	2016	2018
San Giorgio di Nogaro	7607	Mitigation	2015	2018
San Pietro al Natisone	2213	Mitigation, Adaptation, Energy poverty	2016	
Savogna	360	Mitigation, Adaptation, Energy poverty	2021	
Socchieve	930	Mitigation	2015	2019
Stregna	330	Mitigation, Adaptation, Energy poverty	2019	
Tavagnacco	14446	Mitigation	2010	2012
Udine	99071	Mitigation, Adaptation, Energy poverty	2009	2022
Varmo	2853	Mitigation	2016	2018
Verzegnis	0	Mitigation	2013	2014

Mitigation Adaptation Energy poverty

Chapter 2 – Available knowledge, tools and methodologies for adaptation

2.1 – Existing knowledge resources about climate change and related impacts

The main source of information on climate change in Friuli Venezia Giulia is the *First Study of climate change and some of its impacts in FVG* (ARPA FVG 2018).

As regards the evidence of climate change in FVG, ARPA FVG annually updates the elaborations and makes them available, for example, through the 13th number (annual summary) of the "meteo.fvg" bulletin and through the yearly updated slide version of the above mentioned fact-finding study.

As regards the climate projections for the FVG, from June 2023 the results of the bias-correction carried out on the data of the projections already used for the 2018 fact-finding study will be available. They will also be made accessible to non-expert users via the *Climate Projection Platform for the North-East*[11], thanks to the collaboration between ARPA FVG and ARPA Veneto.

As regards climate impacts, the *National System for Environmental Protection* (SNPA) has been working on climate change impacts indicators since 2016: the dedicated working group published two reports, although there is still a long way to go in order to develop a reliable set of impact indicators both on a national and on a regional scale.

- *First Study of climate change and some of its impacts in Friuli Venezia Giulia* (2018)

In 2018 ARPA FVG published the first fact-finding *Study of climate change and some of their impacts in FVG*. The study was promoted and financed by the Autonomous Region of Friuli Venezia Giulia (DGR n. 1890 of 10.7.2016) and was carried out with the scientific collaboration of the Region itself, the Universities of Udine and Trieste and public research bodies based in FVG: the International Center for Theoretical Physics (ICTP) - International Center for Theoretical Physics, the National Institute of Oceanography and Experimental Geophysics (OGS) and the National Research Council - Institute of Marine Sciences (CNR-ISMAR) U.O.S. of Trieste.

The report was published and presented in March 2018, consists of approximately 340 pages (pdf - 26 MB) and is divided into three parts:

- Part 1 - Current and future climate change in FVG;
- Part 2 - Survey of the impacts of climate change: from national documents to the first considerations for FVG;

[11] https://clima.arpa.veneto.it/

– Part 3 - Case study on the impacts of climate change in FVG.

The Study is available in two versions:

– Full REPORT of the fact-finding study of climate change and its most significant impacts for the FVG (340 pages, 26 MB)[12];
– Summary SLIDES: summary presentation of the fact-finding study, with updates on past and present climate variability in FVG and some references also to climate change on a global scale[13].

- *The Future Climate Platform for the North East* (2023)

The *North-East Climate Projection Platform* (PPCNE) is an interactive tool that allows different types of users, even non-experts, to analyze and visualize the possible changes in temperatures and rainfall from today until 2100 in the “Triveneto”[14] area and even in specific localities of the territory. It was developed as part of a collaboration between the ARPAs of Friuli Venezia Giulia and Veneto: publication is scheduled for June 2023[15].

The platform offers climate projections for the territory of North-East Italy through eleven indicators calculated for possible future climate scenarios and adapted to the data collected by regional meteorological stations. These projections are provided in terms of maps and time series, for various time scales and various scenarios, with the possibility of extracting and downloading data for specific points of interest.

In this platform the data of the regional modelling simulations of the EURO-CORDEX project[16] have been corrected through bias-correction with the data of the stations of the regional meteorological networks and the information is therefore accessible on a municipal basis.

- *Climate change impact indicators* (continually updated)

Climate change impact indicators are used to quantify and monitor the impacts that climate change produces on the various natural systems and socio-economic sectors. In Italy they are the subject of the activities of the SNPA working group dedicated to *Impacts, vulnerability and adaptation to*

[12] https://www.arpa.fvg.it/temi/temi/meteo-e-clima/pubblicazioni/studio-conoscitivo-dei-cambiamenti-climatici-e-di-alcuni-loro-impatti-in-friuli -venezia-giulia/
[13] https://www.arpa.fvg.it/documents/2821/CambiaClimaFVG_sintesiStudio.pdf
[14] Commonly, the Italian north-east macro-region including FVG, Veneto and Trentino Alto Adige.
[15] https://clima.arpa.veneto.it/
[16] See Chapter 4 for explanations.

climate change (born in 2016 and currently called Rete RR TEM 27 -2021- 2023) in which ARPA FVG also participates.

The working group has produced some contributions and two reports on the subject and feeds the section on climate change impact indicators in the *Italian Platform on Adaptation to Climate Change*[17].

With regard to the impact indicators, the following publications can provide useful information:

- *Impact indicators of climate change in the urban environment in the XIII Urban Environment Quality Report* (ISPRA/SNPA 2017)[18];
- *Introduction to climate change impact indicators: key concepts, candidate indicators and criteria for defining priority indicators - Manuals and Guidelines* - SNPA 178/2018 (SNPA 2018)[19];
- *Report on climate change impact indicators - 2021 Edition*. Report SNPA 21/2021 (SNPA 2021)[20].

2.2 – Existing tools about adaptation measures suitable

A local government or a private management entity, i.e. any entity responsible for the management of resources or territory, could have open access to several tools showing existing adaptation measures, often already classified by impact sector.

The following section lists a pool of platforms to search and find the measures to be applied eventually.

- Adriadapt - https://adriadapt.eu/

As part of the Italian-Croatian Interreg project Adriadapt (2019-2021), a "Resilience Information Platform for Adriatic Cities and Towns" has been developed to share knowledge on adaptation options and planning for the Adriatic region. It provides an overview of possible adaptation measures, divided into societal, green and grey options, as well as case studies, guidelines, legal frameworks and other useful information on climate change and adaptation, such as on climate models and scenarios.

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

The Climate Menu for Adriatic regions was developed within the framework of the RESPONSe project (2019-2022) funded by the Interreg Italy-Croatia Programme. The platform consists of a set

17 http://climadat.isprambiente.it/
18 https://www.isprambiente.gov.it/files2017/pubblicazioni/stato-ambiente/rau-2017
19 https://www.snpambiente.it/wp-content/uploads/2018/12/linee_guida_snpa_12_2018.pdf
20 https://www.snpambiente.it/wp-content/uploads/2021/06/Rapporto-SNPA-21_2021.pdf

of actions that can be taken by local decision-makers in different fields to adapt to climate change or mitigate its effects at local, regional and national levels. The glossary and the pre-search menu allow the user to define search criteria such as the impact sector, the type of action (grey, green, soft) or the level of implementation (commune or association of communes, provincial, regional, etc.).

- Climate-ADAPT - https://climate-adapt.eea.europa.eu/

It's the European Adaptation Platform, a partnership between the European Commission and the European Environment Agency (EEA) that aims to help countries and managers adapt to climate change. Much information is provided, such as the expected climate in Europe and the current and future vulnerability of regions. With regard to adaptation, various adaptation strategies and options at European, national and trans-national levels are presented, as well as adaptation case studies and potential options and tools to support adaptation planning.

- MASTER ADAPT - https://masteradapt.eu/?lang=en

The LIFE project MASTER ADAPT (2016-2020) aimed to identify, test and disseminate multi-level governance tools to support regional and local authorities in integrating adaptation into sectoral policies, in order to meet the needs of local authorities affected by the adverse effects of climate change. The tools section provides guidance on both adaptation and mainstreaming (the process of integrating adaptation into 'mainstream' planning and programming), as well as documents on adaptation policies across the EU. Finally, a guide to methods of climate analysis and vulnerability assessment at regional and local level is provided. This will help local decision-makers to identify the needs of their territory and the specific adaptation measures best suited to it.

2.3 – Conceptual framework, methodologies and guidelines for adaptation planning

Within the *National Operational Programme on Governance and Institutional Capacity 2014-2020*, funded by the EU, the Italian MASE-Ministry of the Environment and Energy Security (at the time the MATTM-Ministry of the Environment and the Protection of the Territory and the Sea) has been developing an institutional process aimed at spreading the culture of adaptation to climate change at a regional and local level and overcoming the territorial disparities in this matter , in line with the contents of the National Strategy for Adaptation to Climate Change (SNAC) and the National Adaptation Plan (PNACC), currently being approved.

This path is the basis of the activities of the Line of Intervention 5 "*Strengthening of administrative capacity for adaptation to climate change*" of the CReIAMO PA project, aimed at developing skills, defining and disseminating methodologies for adapting to climate change. The Project action envisaged, among other things, the preparation in 2020 of some methodological documents aimed at national, regional and local public decision-makers. Two of these documents have now been officially attached to the PNACC in its most recent version:

- Methodologies for the definition of regional strategies and plans for adaptation to climate change;
- Methodologies for the definition of local strategies and plans for adaptation to climate change.

In 2021 the Autonomous Region Friuli Venezia Giulia, through its Central Directorate for Environment, Energy and Sustainable Development, joined the CReIAMO PA – L5 project. ARPA FVG, which supports the Regional Administration in its planning activities, has been repeatedly invited to bring its technical-scientific contribution within the activities of CReIAMO PA L5[21].

Therefore, all ARPA FVG's activities supporting adaptation are meant to be consistent with the national methodologies outlined by CReIAMO PA L5, which, in turn, refer to guidelines and methodologies already developed in other contexts and projects related to adaptation (e.g. MasterAdapt Life project)[22].

The adaptation planning "road-map" according to the Italian national guidelines

The Methodologies attached to the PNACC propose a road-map for adaptation planning which is made up of three segments and divided into different implementation steps (illustrated in the following diagram, **Figure 6**). Each step represents a fundamental element in the process of planning and implementing interventions, starting from the efforts necessary to build consensus around the issue and to set up the coordination structures of the adaptation process. The following steps include the analysis of climate risks in order to identify the actions needed to address them. Finally, the roadmap ends with the monitoring and review process that is necessary to analyse the successes and review the adaptive challenges that had been set.

In planning adaptation at a regional scale, the first segment "A. Building the foundations for adaptation" is necessarily the responsibility of the Regional Administration: it includes the steps relating to the definition of the legal framework of adaptation, its governance, the relationship between the adaptation Strategy and Plan and the launch of cooperation and participation processes.

The second segment "B. Identifying risks and finding solutions" consists of a series of steps that require specific technical-scientific skills in order to collect, interpret and disseminate climate information and to identify the current and future effects of climate change. These steps – which are typically carried out by environmental agencies, universities and research centres - provide the

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[21] PNACC, Annex 1 - "Metodologie per la definizione di strategie e piani regionali di adattamento ai cambiamenti climatici".
[22] https://masteradapt.eu/?lang=en

knowledge basis for defining the adaptation objectives and the actions to be implemented in relation to the identified risks. However, most of these steps involve close interaction between technical-scientific experts and the regional administration, as well as the involvement of actors from different sectors on the territory.

The third segment "C. Implement and monitor actions" is aimed at moving from adaptation planning to concrete action, through the implementation process and the setting up of a permanent monitoring, evaluation and support system. It is by its nature in the hands of the Regional Administration.

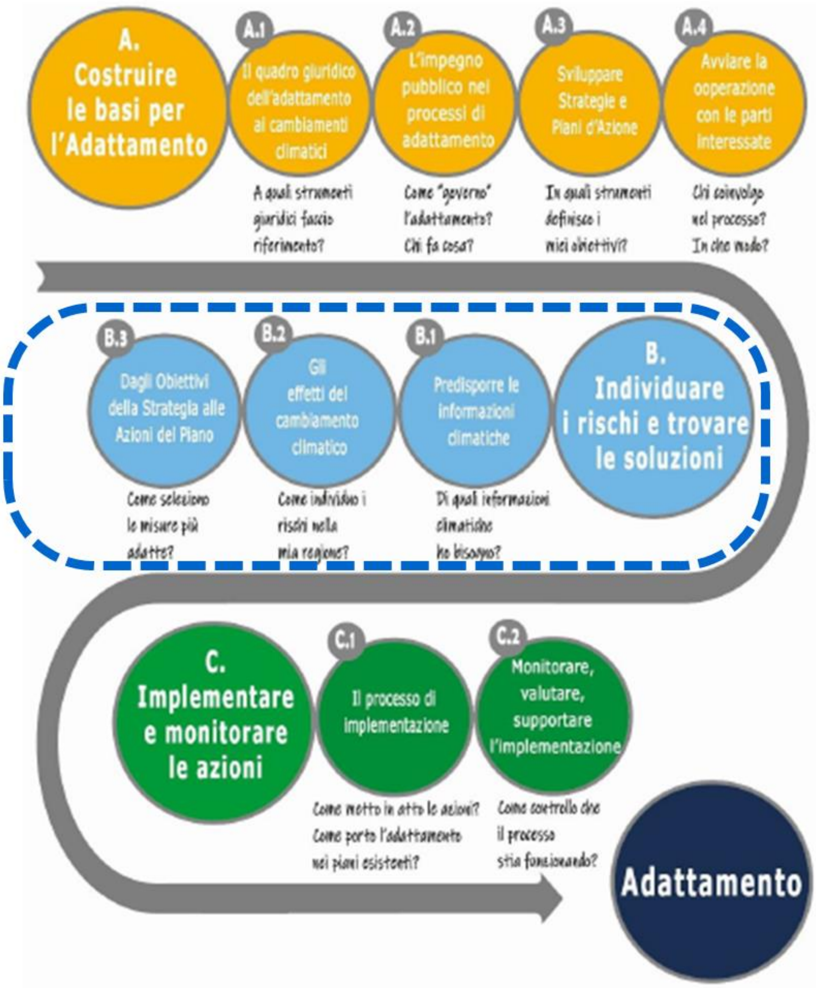

***Figure 6**. The road map for adaptation planning at a regional or local level, according to the methodologies developed by CReIAMO PA – L5 project, now officially part of the Italian National Plan for Adaptation to Climate Change (PNACC)- https://va.mite.gov.it/File/Documento/771083. ARPA FVG's skills and activities are mainly related to the central segment, focusing on climate change and its impacts on the regional territory.*

In supporting the adaptation planning process, the skills that ARPA FVG can provide are mainly concentrated in the technical-scientific steps of the central segment, in particular those relating to climate change and its effects on the territory, on which therefore also the contents of activity 5.3 of the AdriaClim project mainly focus.

Impact chains

In this work segment, the methodology involves the development of impact chains: a very widespread analytical tool that allows for a better understanding, arrangement and relevance of the various components and factors that determine risk in a system (**Figure 7**).

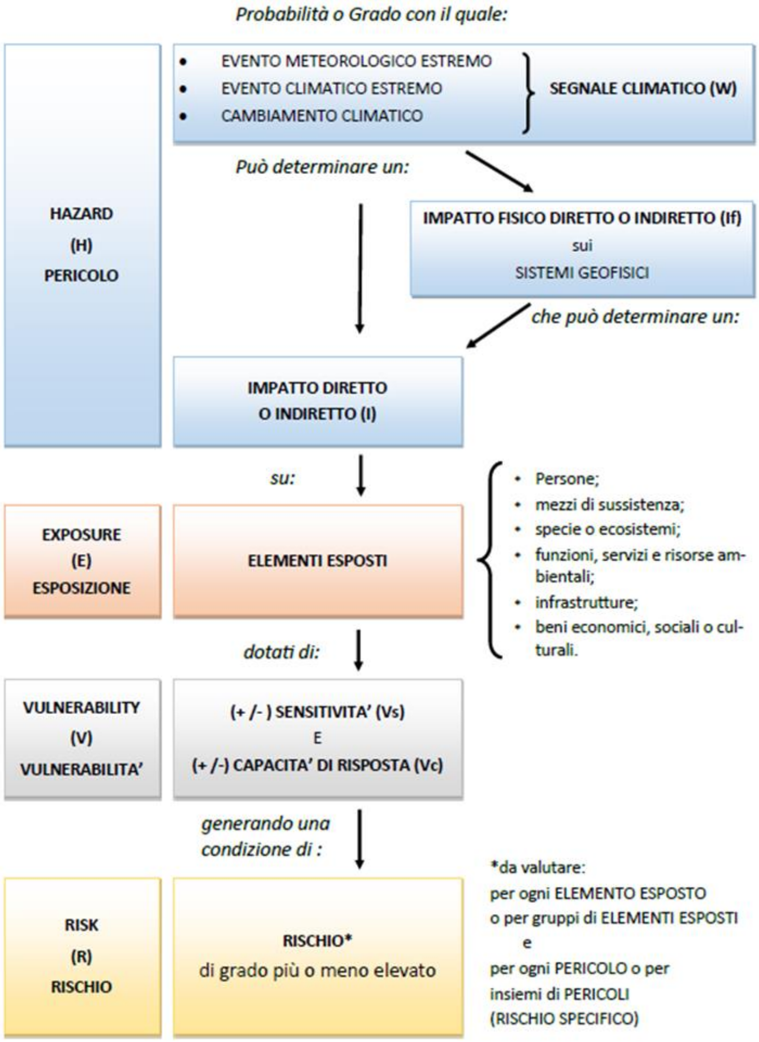

Figure 7. *Impact chain scheme, from PNACC - Annex 1 "Metodologie per la definizione di strategie e piani regionali di adattamento ai cambiamenti climatici".*

The sequence of work steps for the development of an impact chain includes:

1. Identify meteorological and climatic events and climatic changes expected in the reference period that may affect the study area.
2. Determine the hazard and intermediate impacts, by identifying which climate-related events or trends and their impacts (including physical ones) pose a hazard to exposed elements in the area of interest.
3. Determine exposure by locating and selecting exposed items.
4. Determine the vulnerability of the exposed elements by defining, for each one, the characteristics of sensitivity and ability to respond.
5. Estimate the climatic risks and related expected impacts in the study area.

The starting point, fundamental for the assessment of possible climate impact scenarios, is constituted by the knowledge of the current and past conditions of the planning area (region, province, urban area, catchment area, etc.) with regard to the following elements:

- current and past climatic conditions (see Chapter 4 – FVG Pilot Site climate analysis and hazards);
- socio-economic and environmental structure (see 5.1 – Context analysis);
- impacts that have already occurred deriving from extreme meteorological and climatic events and from climate change (see Chapter 6 – Climate change impacts).

The characterization of the current and previous climatic features of the planning area (climate normals) is then combined with the elaboration of observed trends and future climate scenarios on a regional scale (climate change evidence and climate change projections).

The socio-economic, environmental and territorial framework, together with the inventory of previous events (occurred impacts) which have had significant effects in the planning area, constitutes the output of this recognition phase, which represents the knowledge base on which one can then develop risk analyses, which in turn make it possible to identify the most effective adaptation actions for each specific territorial context and impact sector.

Chapter 3 – FVG Pilot Site identification

In general terms, the AdriaClim project (hereinafter "the Project") identified the FVG pilot area as the coastal and lagoon area of Friuli Venezia Giulia. In this case, we identified the pilot area as the one affected by the activities of WP5, i.e. those activities aimed at supporting adaptation planning with respect to the ongoing or expected consequences of the climate crisis, in the coastal and meteo-marine context. So, we understood the FVG pilot site as the municipalities that may be involved in adaptation planning in the face of one or more impacts on their territory.

In addition, the choice of the pilot area also considered the part of the sea where the Project's meteo-marine models were applied. Accordingly, the pilot area comprises a coastal and a marine part. The criteria adopted for the identification of the whole pilot area are detailed below.

3.1 – Identification of the FVG coastal pilot area

As for the coastal part of the FVG pilot area, this was defined on the basis of criteria referring to two different topics:

1) the adaptation governance;
2) the exposure to meteo-marine climate hazards.

Starting from the governance domain, we considered those parties that are responsible for planning and implementing adaptation actions and measures on their territory, primarily Municipalities. In addition, account was taken of planning instruments that could help us in delimiting and characterising the area of interest, providing a solid methodology in dividing the territory into homogeneous units, based on sound criteria (and of course, for adaptation planning). Among the planning instruments, the Regional Landscape Plan (PPR)[23] was chosen in the first place.

[23] *Piano Paesaggistico Regionale* of the Friuli Venezia Giulia Region, 2018

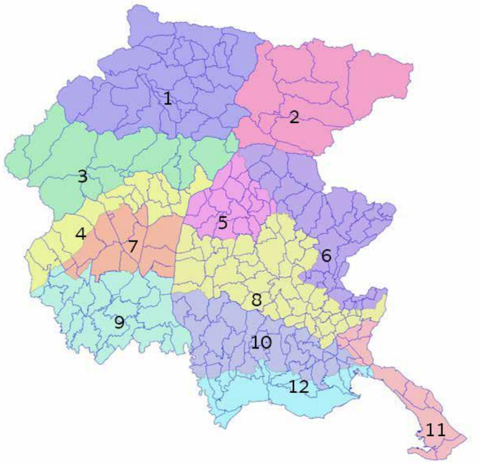

Figure 8*. The twelve landscape areas identified in the Regional Landscape Plan (from the PPR-FVG's General Report*[24]*). To note no. 11 "Karst and East Coast" (light red) and no. 12 "Lagoon and Coast" (light blue).*

The aim of the PPR is to integrate landscape protection and enhancement into the land transformation processes, also with a view to regional economic competitiveness. The Plan recognises the landscape components through the following fundamental levels of in-depth analysis: (*1*) on a general homogeneous scale referring to the "landscape areas"; (*2*) on a detailed scale aimed at recognising the "landscape assets".

In fact, 12 landscape areas are identified in the PPR according to the following delimitation criteria: (*a*) hydro-geomorphological characteristics, (*b*) ecosystem and environmental characteristics, (*c*) historical-cultural and community identity characteristics, (*d*) administrative and management characteristics, (*e*) presence of a historical territorial dimension and (*f*) consistency with urban and territorial settlements.

In particular, landscape areas no. 11 "Karst and East Coast" and no. 12 "Lagoon and Coast" were considered (**Figure 8**). Of the criteria mentioned above, the (*a*) hydro-geomorphological and (*b*) ecosystem and environmental characteristics were the most relevant for the identification of the landscape area no. 12 (**Table 7**).

For the identification of landscape area no. 11, on the other hand, the ecosystem-environmental criterion also had the highest relevance, but the hydro-geomorphological characteristics were of medium relevance (**Table 6**). In addition, it's important to note that the hydro-geomorphological and ecosystem-environmental systems are the most directly affected by climate change. On the basis of these considerations, it was decided to include in the FVG pilot area all the Municipalities whose territory, partially or totally, falls within landscape area no. 12. For landscape area no. 11, on the other hand, only the Municipalities close to the coast were initially included.

[24] PPR-Relazione Generale (ALL. 2), published on the Official Gazette of the FVG Region no. 19 on the 19th May 2018

***Table 6**. PPR-FVG delimitation criteria for the landscape area N0. 11 "KARST AND EAST COAST"; relevance L=low, M=medium, H=high (from the PPR-FVG's General Report, modified).*

PPR-FVG DELIMITATION CRITERIA FOR THE LANDSCAPE AREA NO. 11 "KARST AND EAST COAST"

Criteria (ENG/*ITA*)		Relevance L	M	H
A	Hydro-geomorphological characteristics *I caratteri dell'assetto idro-geomorfologico*	●	●	○
B	Ecosystem and environmental characteristics *I caratteri ambientali ed ecosistemici*	●	●	●
C	Historical-cultural and community identity characteristics *Gli aspetti identitari e storico-culturali*	●	●	○
D	Administrative and management characteristics *L'articolazione amministrativa del territorio e I relative aspetti gestionali*	●	●	○
E	Historical phenomena of territorialisation of which the signs are still visible *I fenomeni di territorializzazione affermati nella storia di cui permangono i segni*	●	●	●
F	Consistency with urban and territorial settlements *Le figure territoriali di aggregazione dei morfotipi*	●	●	○

***Table 7**. PPR-FVG delimitation criteria for the landscape area no. 12 "LAGOON AND COAST"; relevance L=low, M=medium, H=high (from the PPR-FVG's General Report, modified).*

PPR-FVG DELIMITATION CRITERIA FOR THE LANDSCAPE AREA NO. 12 "LAGOON AND COAST"

Criteria (ENG/*ITA*)		Relevance L	M	H
A	Hydro-geomorphological characteristics *I caratteri dell'assetto idro-geomorfologico*	●	●	●
B	Ecosystem and environmental characteristics *I caratteri ambientali ed ecosistemici*	●	●	●
C	Historical-cultural and community identity characteristics *Gli aspetti identitari e storico-culturali*	●	○	○
D	Administrative and management characteristics *L'articolazione amministrativa del territorio e I relative aspetti gestionali*	●	○	○
E	Historical phenomena of territorialisation of which the signs are still visible *I fenomeni di territorializzazione affermati nella storia di cui permangono i segni*	●	○	○
F	Consistency with urban and territorial settlements *Le figure territoriali di aggregazione dei morfotipi*	●	●	●

After this first selection based on criteria related to the territory's administration and planning, the second step was to verify which municipalities might be interested in the Project's topics, in relation to their potential exposure to climate risks (i.e., hazards). In this context, we understand hazards as the result from the variation in the meteo-marine factors that regulate sea conditions. In particular, we assessed the territory's exposure to a factor that could affect a large area behind the lagoon and coastal strip, this is the sea level rise.

IPCC Sea Level Projections	Baseline	Scenario	Scenario
	1985–2006	RCP2.6	RCP8.5
Global (AR5, 2013)	2100	0.44 (0.28–0.61)	0.74 (0.52–0.98)
Global (SROCC, 2019)	2100	0.43 (0.29–0.59)	0.84 (0.61–1.10)
	1995–2014	SSP1-2.6 (m)	SSP5-8.5 (m)
Global (AR6, 2021)	2050	0.19 (0.16–0.25)	0.23 (0.20–0.29)
Global (AR6, 2021)	2100	0.44 (0.32–0.61)	0.77 (0.63–1.01)
	1995–2014	SSP1-2.6 (m)	SSP5-8.5 (m)
Local (AR6, 2021)	2050	0.19 (0.11–0.28)	0.23 (0.14–0.33)
Local (AR6, 2021)	2100	0.40 (0.22–0.62)	0.73 (0.52–1.03)

***Figure 9**. Local sea level values from Rizzo et al. (2022) used in the definition of the FVG pilot area in the AdriaClim project (red arrow).*

To evaluate the exposure to meteo-marine climate hazards, we developed a series of digital exposure maps in a GIS environment (qGIS software version 3.22). We considered the territory that could be below mean sea level at the end of the century (2081-2100) in the RCP 8.5 scenario, the worst in terms of emissions, according to the IPCC climate projections provided for the Mediterranean area in its latest report (AR6-Sixth Assessment Report published in 2021[25]). The IPCC projections, in fact, outline an average rise of 0.73 m (0.52-1.03 m) above mean sea level over the period 1995-2014 (Rizzo et al. 2022[26]), considering the local projections available for different Mediterranean coastal sites (**Figure 9**). With respect to these values, the territory potentially affected by the sea level rise, i.e. the areas that could potentially be submerged in a situation with no embankments and coastal defences, corresponds to that one previously identified, with the addition of the municipalities of Cervignano del Friuli and Fiumicello Villa Vicentina (**Figure 10**).

[25] Intergovernmental Panel on Climate Change – AR6 2021

[26] Rizzo A, Vandelli V, Gauci C, Buhagiar G, Micallef A S & Soldati M (2022). *Potential sea level rise inundation in the Mediterranean: from susceptibility assessment to risk scenarios for policy action*. Water, 14(3), 416. DOI: https://doi.org/10.3390/w14030416.

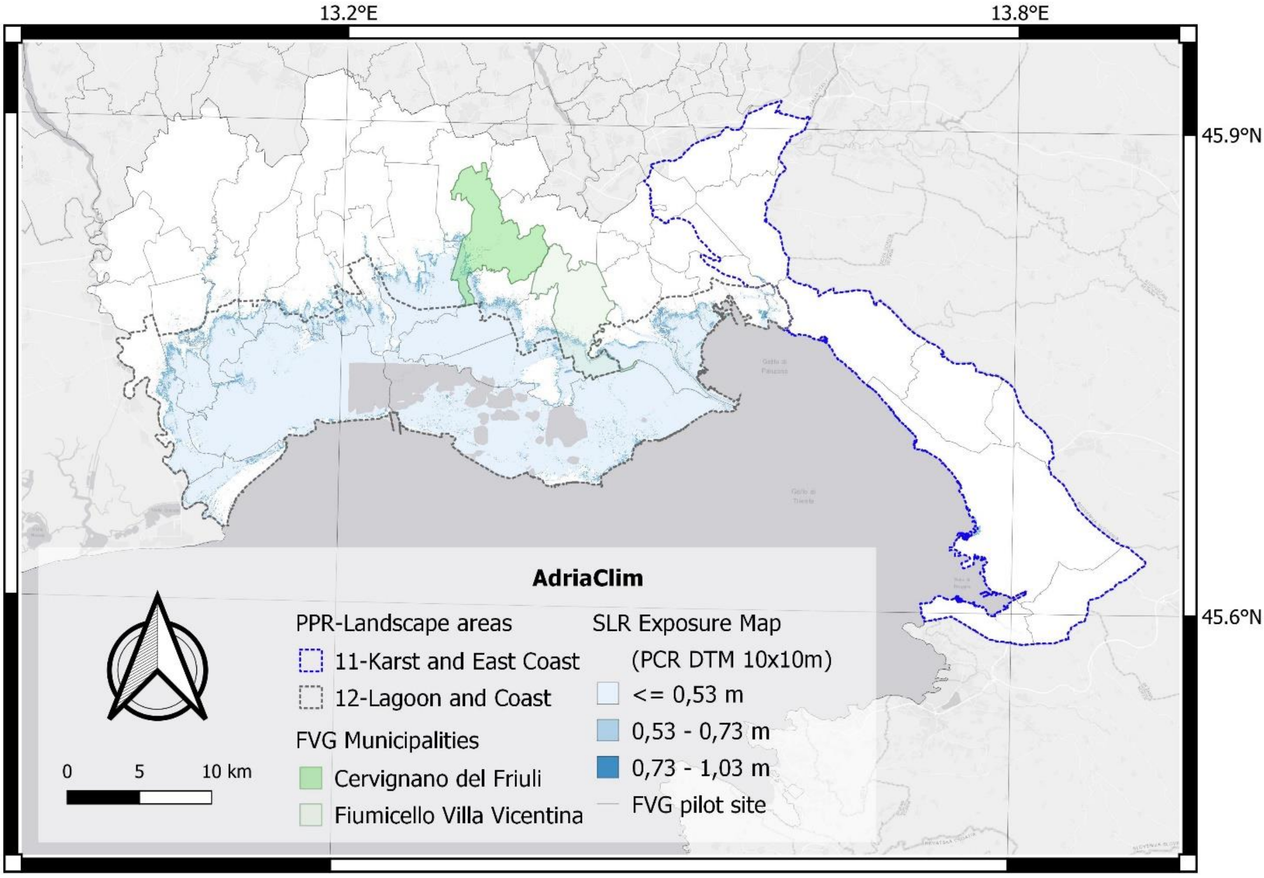

***Figure 10**. Risk exposure map relative to SLR hazard, according to IPCC level projections (local, AR6, 2021) reported in Rizzo et al. (2022) for RCP8.5-2100 (0.73, 0.52-1.03 m) (base map ESRI Grey).*

As regards the base map used for our digital elaborations, we used the DTMs-Digital Terrain Models produced by the Regional Civil Protection (PCR) with a resolution of 10x10m, CRS-Coordinate Reference System RDN2008/TM33, available on the official website[27] of the Friuli Venezia Giulia Region.

In a second moment, we compared the AR6 values chosen by Rizzo et al. for their study with those one provided by the NASA Sea Level Projection Tool[28], mentioned by Rizzo et al. themselves in their paper. The NASA tool, in fact, provides calibrated SLR values for different coastal locations. Consequently, the SLR values for the Venice area are different from those for Trieste, despite the fact that they share the same basin, the Northern Adriatic Sea.

[27] https://www.regione.fvg.it/rafvg/cms/RAFVG/ambiente-territorio/conoscere-ambiente-territorio/
[28] https://sealevel.nasa.gov/ipcc-ar6-sea-level-projection-tool

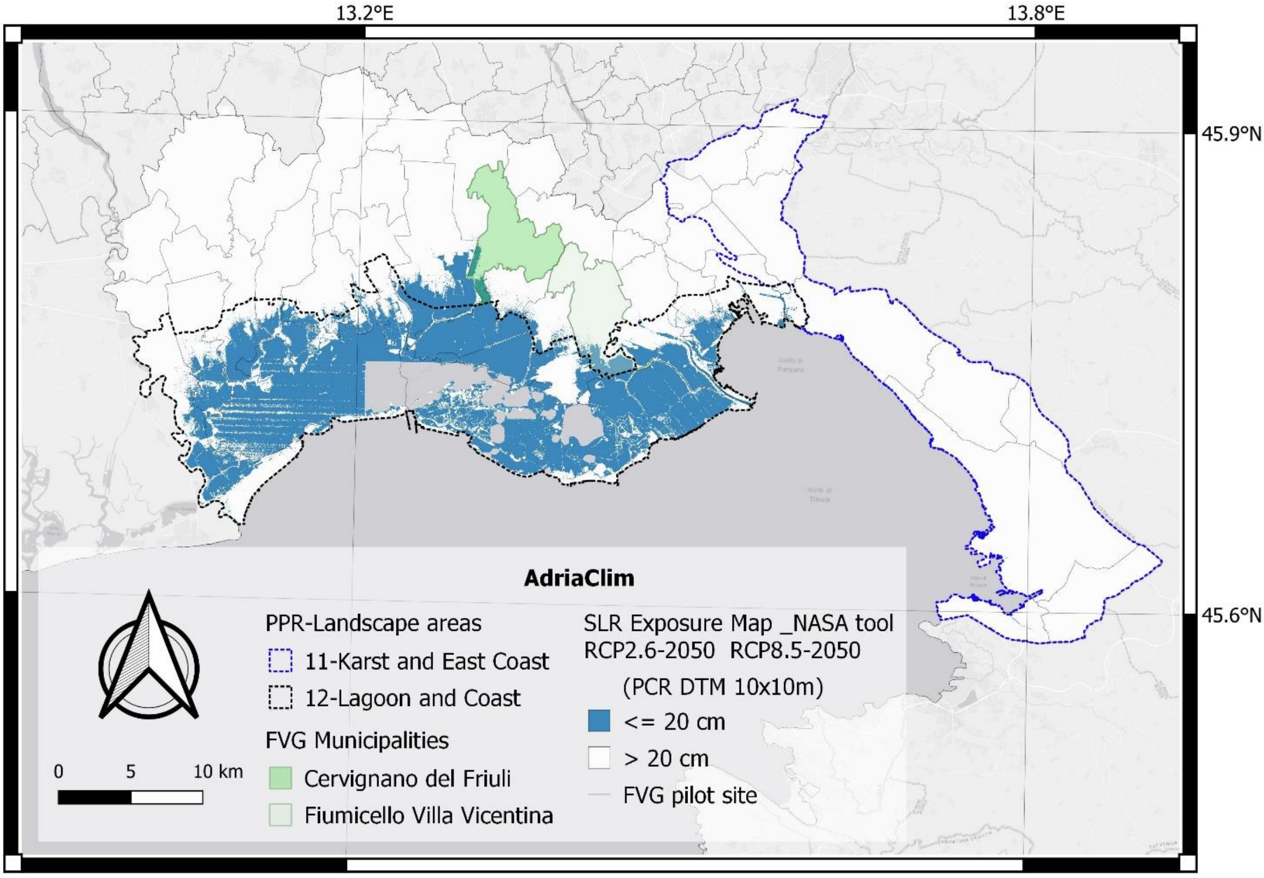

Figure 11. *Risk exposure map relative to SLR hazard, according to IPCC level projections reported in the NASA tool for Trieste, RCP2.6-2050 (0.17±0.090 m) and RCP8.5-2050 (0.21±0.090 m) (base map ESRI Grey). Values in the maps have been rounded up or down to 20 cm.*

The NASA tool is an innovative way to explore SLR on a local scale, as it integrates and makes visible information on the different components that determine the SLR. The user (also in terms of the general public and non-experts) is facilitated in gathering information on SLR and its contributions, compared to a literature search which is often the prerogative only of researchers and technicians.

The tool provides values on sea level change for 5 different SSPs-Shared Socioeconomic Pathways (SSP1-1.9, SSP1-2.6, SSP2-4.5, SSP3-7.0, SSP5-8.5, SSP1-2.6 Low Confidence, SSP5-8.5 Low Confidence) relative to a baseline of 1995-2014. SSPs are the scenarios of projected socioeconomic global changes up to 2100, used to derive greenhouse gas emissions scenarios with different climate policies. The climate projections are those from the IPCC AR6.

The new maps with the SLR values from the NASA tool are shown below (**Figure 11**, **Figure 12**). They do not show substantial differences compared to those processed using the values reported by Rizzo et al. In fact, the decision to include in the FVG pilot site the municipalities falling within the landscape areas of the PPR no. 11 and no. 12, together with Cervignano del Friuli and Fiumicello Villa Vicentina, is confirmed.

As can be seen, we have only considered scenarios SSP1-2.6 and SSP5-8.5 for 2050 and 2100 (**Table 8**), two very different scenarios, understood as the two extremes regarding the situation on future climate policies. Regarding the time period, we considered mid-century (2050) and end-of-century (2100) climate projections.

Furthermore, we have chosen to round the values up or down from those provided by the NASA tool. This is due to the inherent characteristics of climate projections. Indeed, as far as stakeholder interactions are concerned, providing an estimate of the SLR seemed more useful and understandable than providing a figure, accurate to the second decimal place, which in itself contains a certain amount of uncertainty.

With regard to the projected SLR, the tool shows several elements that individually contribute to increase or decrease the SLR. One of these is the Vertical Land Motion, which is important in our region, especially in the Marano and Grado Lagoon, due to subsidence (progressive lowering of the soil level caused by the compaction of materials). As far as the Marano and Grado area is concerned, many studies show different values of vertical movements depending on where and when the surveys were carried out (Marchesini 2006; ARPA FVG 2010; ARPA FVG 2018)[29, 30, 31].

However, the NASA tool shows the median value (17th, 83rd percentile) of the Vertical Land Motion contribution to SLR only for Trieste (5 SSP scenarios, relative to a baseline of 1995-2014). This value is -0.01 m (-0.03, 0.00 m) and corresponds to a prevalent ground uplift, in contrast to the well-known subsidence phenomenon in the lagoon basin. Therefore, taking the SLR projections provided by the NASA tool for Trieste and spreading them over the entire FVG pilot area of the Project, one must bear in mind that lagoon subsidence is not represented in these values.

It is important to note that, in this preliminary phase of WP5 (identification of the pilot area and interaction with stakeholders), we used the SLR values reported in Rizzo et al. first and those in the NASA tool later, since the downscaled local climate projections of WP3 were being implemented, including the SLR.

So, returning to the identification of the FVG pilot area, the municipalities in the Friuli Venezia Giulia coastal strip falling within the landscape areas no. 11 and no. 12 with the addition of Cervignano del Friuli and Fiumicello Villa Vicentina represent those that could primarily benefit from the activities

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[29] Marchesini C (2006). *Vertical movements in the Grado Lagoon (Italy) measured with various methods*. 12th FIG Symposium on Deformation Measurements (Baden, 22-24 may 2006), 5 pp.

[30] ARPA FVG (2010). *Le trasformazioni ambientali della laguna di Grado e Marano – RT1-ARPA 10*. Technical Report edited by Università di Trieste-Dip. Geoscienze. Committed by ARPA FVG. Scientific Director: Prof. G. Fontolan. Working Group: A. Bezzi, G. Fachin, S. Pillon. Trieste, febbraio 2010, 89 pp.

[31] 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.

and products of the Project. These municipalities are the first that could be affected by changing weather and sea conditions and, from the perspective of the climate crisis, represent the first area where some impacts might occur. In addition, it was decided to broaden the pilot area including municipalities behind the coastal strip, i.e. municipalities for which the project could be of interest and where impacts other than sea level rise may occur.

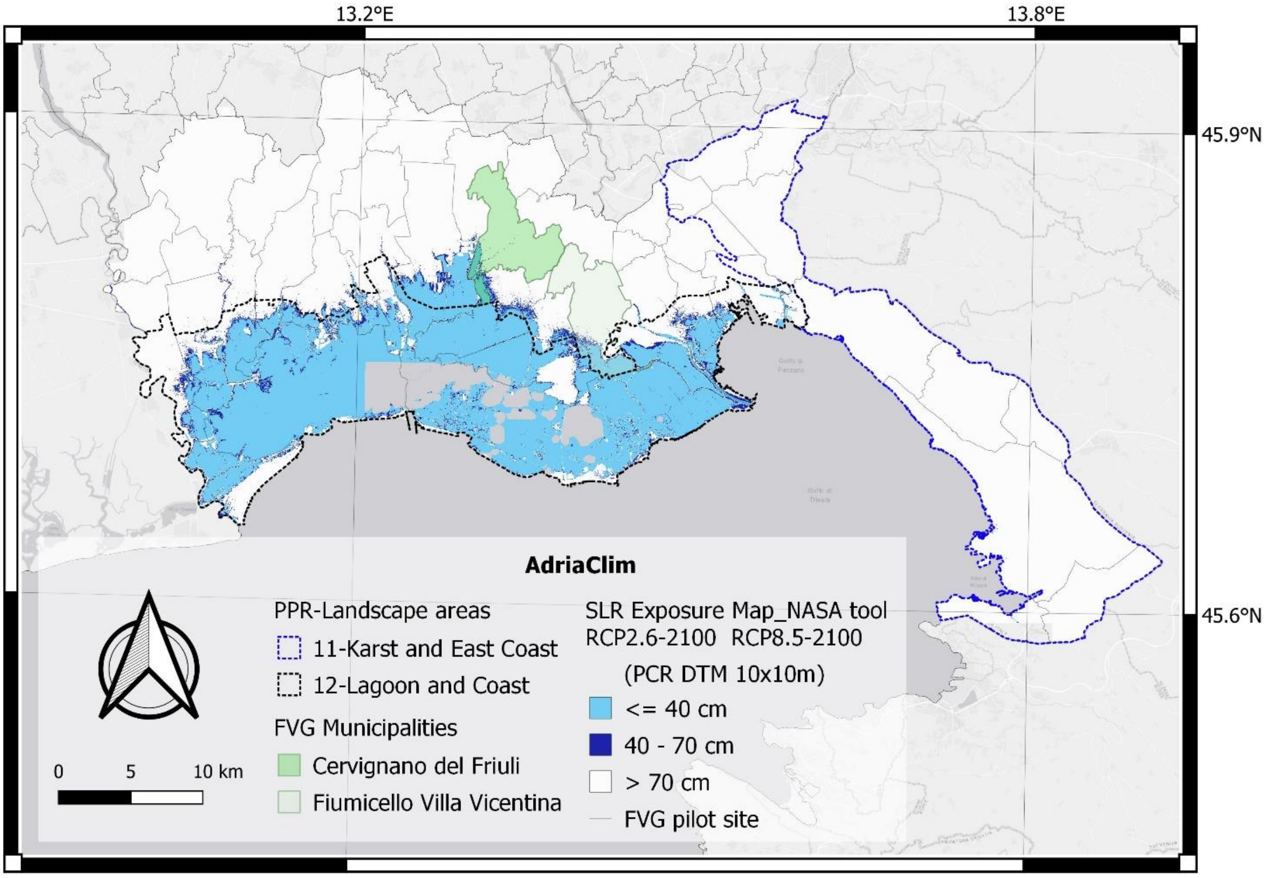

Figure 12*. Risk exposure map relative to SLR hazard, according to IPCC level projections reported in the NASA tool for Trieste, RCP2.6-2100 (0.39±0.210 m) and RCP8.5-2100 (0.67±0.280 m) (base map ESRI Grey). Values in the maps have been rounded up respectively to 40 and 70 cm.*

Table 8. SLR values (median) for RCP 2.6 and RCP 8.5 in 2050 and 2100 according to the NASA tool (screenshots from the Sea Level Projection NASA tool).

IPCC-NASA: Sea level projections – TRIESTE (visited December, 30, 2022)			
RCP	YEAR	SLR	
		Original value	Value rounded up or down
2.6	2050	0.17 ±0.09 m	20 cm
2.6	2100	0.39 ±0.21 m	40 cm
8.5	2050	0.21 ±0.09 m	20 cm
8.5	2100	0.67 ±0.28 m	70 cm

In order to organise the territories of the coastal strip, according to their exposure to impacts due to climate risks whose sources have to do with the marine environment, we have distinguished the municipalities according to a zoning that includes two areas (**Figure 13**). Zone A represents municipalities that directly face the sea or lagoon and could be directly affected by impacts due to changes in the marine environment as a result of climate change. Zone B, on the other hand, represents the municipalities that could be affected by other forms of impacts indirectly related to climate hazards linked to the sea, or direct impacts related to sources of hazards other than the sea.

Finally, with regard to the planning dimension, it is important to note that the entire identified pilot area includes all the municipalities of the *Comunità Riviera Friulana*[32], a local authority for the associated exercise of municipal and supra-municipal functions and services, to which the principles and the rules laid down for municipalities apply. The Community has participated in the Marano Lagoon Wetland Contract, a useful tool in the planning of mitigation and adaptation actions to address climate change.

The Wetland Contract is a voluntary instrument of strategic and negotiated planning on a participatory basis, which is a declination of the more widespread River Contract, in the territories affected by the presence of wetlands (lagoons, marshes, ponds etc.). The Contract's main aims are: (*i*) to guarantee a greater coordination among the different planning levels of wetlands, (*ii*) to raise awareness among local and territorial stakeholders about the importance of care in the multi-use management of lagoon ecosystems and (*iii*) to trigger good practices of environmental management and local development able to support local systems (tourism, production, leisure, etc.) by involving institutional and non-institutional subjects[33].

In **Table 9** we summarized the distribution of municipalities, landscape areas and other territorial units in the coastal part of the FVG pilot area. It covers a surface of 1166.0 km^2, overall (including

[32] Comunità Riviera Friulana
[33] CREW Interreg Italy-Croatia 2018-2021

the whole lagoon basin falling within the Marano and Grado municipalities). There are 39 municipalities, 20 for the A zone (788.9 km^2 in total) and 19 for the B zone (377.1 km^2 in total).

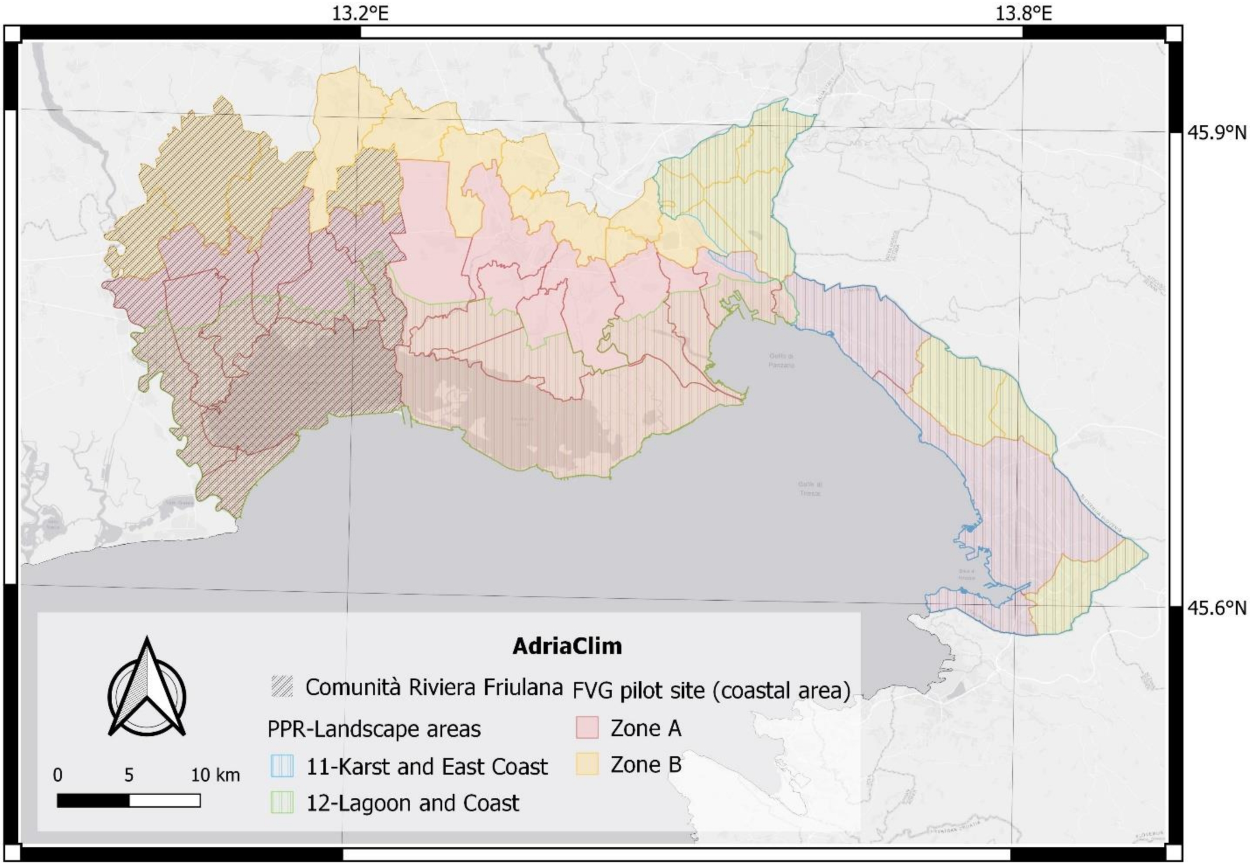

Figure 13. *FVG pilot site (coastal areas) with zones A and B.*

Table 9. *Municipalities, PPR-landscape areas (LA) and other territorial units in the coastal part of the FVG pilot area.*

MUNICIPALITY	PROVINCE	A / B ZONE	AREA (KM²)	OTHER TERRITORIAL UNITS
AQUILEIA	UD	A	37.0	• LA 12 partially
CARLINO	UD	A	30.4	• Comunità Riviera Friulana • LA 12 partially
CERVIGNANO DEL FRIULI	UD	A	29.1	
DUINO-AURISINA	TS	A	45.3	• LA 12 partially • LA 11 partially
FIUMICELLO VILLA VICENTINA	UD	A	28.8	
GRADO	GO	A	119.1	• LA 12 totally

MUNICIPALITY	PROVINCE	A / B ZONE	AREA (KM²)	OTHER TERRITORIAL UNITS
LATISANA	UD	A	37.9	• Comunità Riviera Friulana • LA 12 partially
LIGNANO SABBIADORO	UD	A	15.6	• Comunità Riviera Friulana • LA 12 totally
MARANO LAGUNARE	UD	A	85.6	• Comunità Riviera Friulana • LA 12 totally
MONFALCONE	GO	A	20.7	• LA 12 partially • LA 11 partially
MUGGIA	TS	A	13.9	• LA 11 totally
MUZZANA DEL TURGNANO	UD	A	24.3	• Comunità Riviera Friulana • LA 12 partially
PALAZZOLO DELLO STELLA	UD	A	34.4	• Comunità Riviera Friulana • LA 12 partially
PRECENICCO	UD	A	27.0	• Comunità Riviera Friulana • LA 12 partially
SAN CANZIAN D'ISONZO	GO	A	33.8	• LA 12 partially
SAN GIORGIO DI NOGARO	UD	A	25.9	• Comunità Riviera Friulana • LA 12 partially
STARANZANO	GO	A	18.5	• LA 12 partially
TERZO DI AQUILEIA	UD	A	28.6	• LA 12 partially
TORVISCOSA	UD	A	48.2	• LA 12 partially
TRIESTE	TS	A	84.9	• LA 11 totally
AIELLO DEL FRIULI	UD	B	13.4	
BAGNARIA ARSA	UD	B	19.0	
CASTIONS DI STRADA	UD	B	32.8	
DOBERDO' DEL LAGO	GO	B	27.0	• LA 11 totally
FOGLIANO REDIPUGLIA	GO	B	7.8	• LA 11 totally
GONARS	UD	B	19.9	
MONRUPINO	TS	B	12.8	• LA 11 totally
POCENIA	UD	B	23.9	• Comunità Riviera Friulana
PORPETTO	UD	B	18.1	• Comunità Riviera Friulana
RIVIGNANO TEOR	UD	B	47.6	• Comunità Riviera Friulana
RONCHI DEI LEGIONARI	GO	B	17.1	• LA 11 partially
RONCHIS	UD	B	18.4	• Comunità Riviera Friulana
RUDA	UD	B	19.2	
SAGRADO	GO	B	14.1	• LA 11 totally
SAN DORLIGO DELLA VALLE - DOLINA	TS	B	24.1	• LA 11 totally

MUNICIPALITY	PROVINCE	A / B ZONE	AREA (KM^2)	OTHER TERRITORIAL UNITS
SAN PIER D'ISONZO	GO	B	9.1	• LA 11 partially
SAVOGNA D'ISONZO	GO	B	16.3	• LA 11 totally
SGONICO	TS	B	31.3	• LA 11 totally
TURRIACO	GO	B	5.3	

With regard to stakeholder interactions, thanks to the SLR risk exposure maps, developed as mentioned above, we identified different receptors exposed to potential impacts due to SLR itself. In addition, further information layers can be overlay on the SLR exposure map, for example those representing cultural heritage or the network of protected areas, as well as the transport and infrastructure network (see Chapter 5 – Exposure and vulnerability context analysis). This set of digital maps contributes to the definition of public and private stakeholders that might be interested in the activities of WP 5, with a view to the participatory process.

3.2 – Identification of the FVG marine pilot area

The identification of the FVG marine pilot area was the responsibility of WP3, in order to determine the domain in which to run the climate models (**Figure 14**). It has been defined according to the environmental information and available experiences on the site features, which have been acquired by project partners so far, in particular by PP1 (CNR-ISMAR) and PP11 (ARPA FVG).

It is well known that the larger the computational domain, the more are the difficulties to be faced, especially concerning the northern Adriatic Sea, where lagoons are set and a large river (Po river) flows into it. Therefore, the marine area has been defined as the northernmost part of the Adriatic Sea, mainly focusing on the Gulf of Trieste and the Marano and Grado lagoon, and avoiding to consider the Venice lagoon and the Po river. This allows to get higher accuracy in the specific features of the region of interest, minimizing the issues to be faced dealing with a wider and interaction richer area.

However, the details of the simulations were defined in Activity 3.2-*Design and implementation of the integrated modelling systems* and well explained in the Deliverable 3.2.1-*Summary description of modeling systems and results*, from which the above text was extracted.

The total surface area of the marine part of the FVG pilot site is 3589.5 km^2, including the entire lagoon basin understood as a single surface area (thus not counting the presence of salt marshes, islands, barrier islands, fishing valleys and other lagoon morphologies). The marine area includes part of the Territorial Seas[34] (area enclosed within the maritime delimitations of a coastal state extending 12 Nautical Miles seawards from the baselines[35]) of 3 Countries: Croatia, Italy and Slovenia (**Figure 15**).

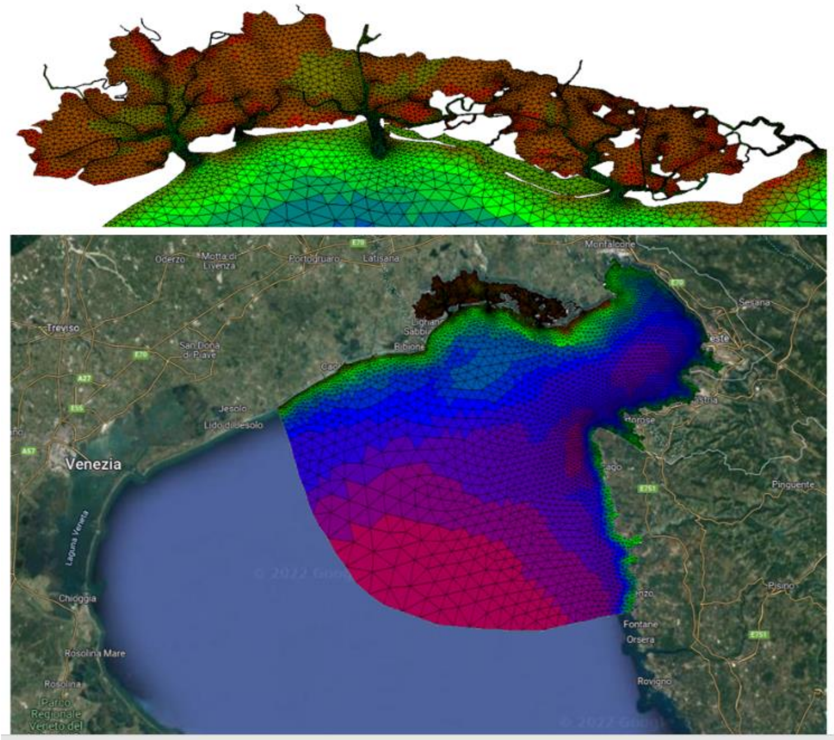

Figure 14*. ARPA FVG (PP11) pilot site (PS1) for the implementation of modelling systems.*

[34] Flanders Marine Institute (2019). *Maritime Boundaries Geodatabase: Territorial Seas (12NM), version 3*. Available online at https://www.marineregions.org/ https://doi.org/10.14284/387.

[35] "*The normal baseline for measuring the breadth of the territorial sea is the low-water line along the coast* […]" (Art. 5 UNCLOS). When the coast is deeply indented, has fringing islands or is highly unstable (presence of a delta), straight baselines may be used. The inner limit of the territorial sea corresponds to the outer limit of the internal waters.

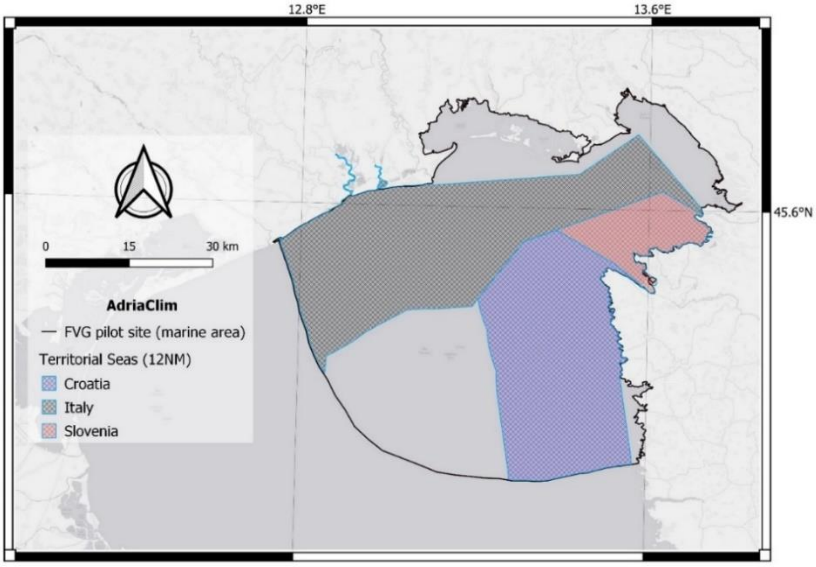

***Figure 15**. Territorial Seas (12 nautical miles from the baseline) of Croatia, Italy and Slovenia in the marine area of the FVG pilot site (base map ESRI Grey).*

3.3 – FVG pilot site

In summary, the identification of the FVG pilot site basically depended on the criteria showed in **Table 10**. The entire pilot site, with coastal and marine areas, has a surface of 4592.7 km^2 (**Figure 16**).

***Table 10**. Criteria for the FVG pilot site identification.*

WP of competence	Land / Sea	Criteria			Geographical / Administrative area
WP5	Coastal area	(1) The most relevant, cross-sector and updated existing territorial planning tool: PPR (Regional Landscape Plan)	(2) The exposure to the most invasive sea-weather climate hazard: SLR (Sea Level Rise)		Municipalities falling totally or partially within the PPR-landscape areas no. 11-"Karst and East Coast" and no.12-"Lagoon and Coast" + Cervignano and Fiumicello municipalities
WP3	Marine area	(1) Calculation time required to perform simulations within a reasonable timeframe	(2) Sufficient coverage compared to the models' points grid	(3) Distribution of competencies among partners to avoid overlapping with CNR-ISMAR area (Veneto)	The northernmost part of the Adriatic Sea, mainly focusing on the Gulf of Trieste and the Marano and Grado lagoon (avoiding to consider the Venice lagoon and the Po river)

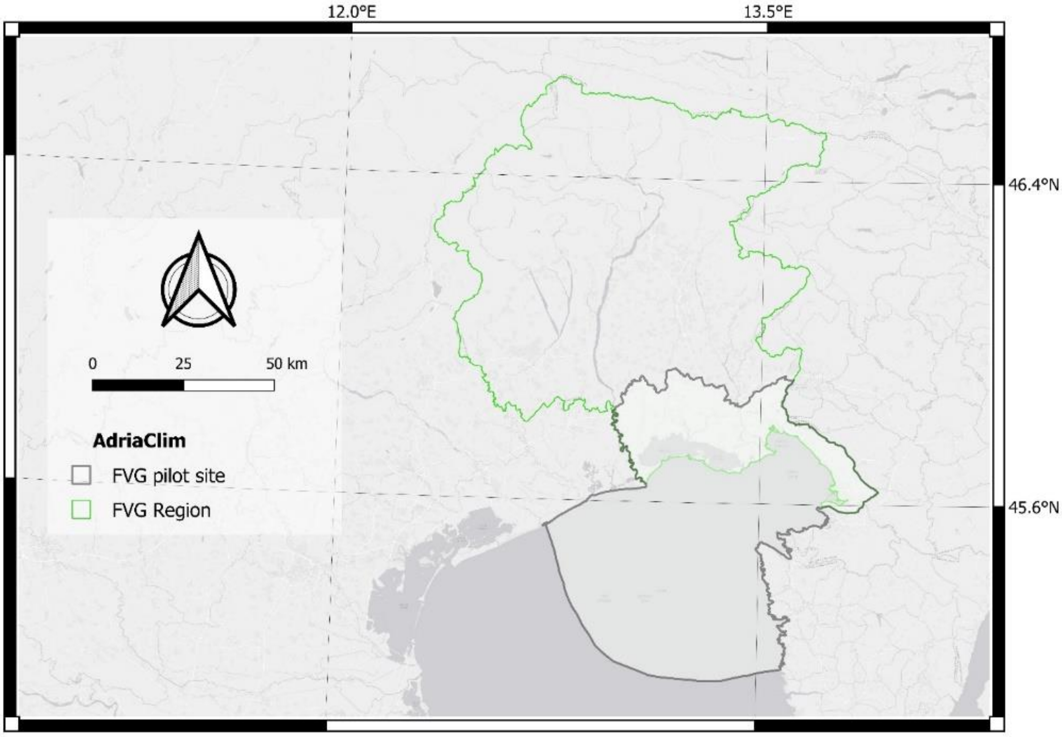

Figure 16. *Ensemble of the FVG pilot site (marine and coastal areas) in the context of the AdriaClim Project (basemap ESRI Grey).*

The digital maps presented in this section are the result of our own processing. The information layers showed in the maps come from the FVG Regional Infrastructure of Environmental and Territorial Data (*IRDAT)*[36] and its webgis application *Eagle.fvg*[37]. The "Ports and harbours" layer comes from the *Tools4MSP geographical platform*[38] (former ADRIPLAN portal). The "Territorial Seas (12NM)" layer comes from the *Maritime Boundaries Geodatabase*[39].

[36] Infrastruttura Regionale dei Dati Ambientali e Territoriali https://www.regione.fvg.it/rafvg/cms/RAFVG/ambiente-territorio/conoscere-ambiente-territorio/FOGLIA2/
[37] https://eaglefvg.regione.fvg.it/eagle/main.aspx?configuration=guest
[38] http://data.tools4msp.eu/layers/geonode%3Aports_harbor#more
[39] https://www.marineregions.org/sources.php

Chapter 4 – FVG Pilot Site climate analysis and hazards

Friuli Venezia Giulia is characterized by a geographical position and an orography which decisively condition its meteorology and therefore its climate.

The Alps strongly influence the processes of formation of perturbations and their evolution, with effects on both temperatures and rainfall.

The Adriatic Sea also influences the climate: it mitigates temperatures, so the coastal areas have higher average temperatures in winter and lower in summer than those of the inland plain; it is the cause of the increase in rainfall (summer storms and autumn and spring flows) as it transfers humidity to the air masses that pass through the Adriatic before hitting Friuli Venezia Giulia.

These are the key points of regional climatology:

- RAIN. The region is characterized overall by its high annual rainfall, by the frequency and intensity of the rains and by thunderstorms.
- TEMPERATURE. On the coastal strip the sea mitigates both summer and winter extremes, while in the rest of the region the temperature range becomes more important. The coast is the warmest area on average.
- GLOBAL SOLAR RADIATION and STATE OF THE SKY. Solar radiation is very heterogeneous, ranging from a minimum common to the whole Region of less than 5,000 kJ/m^2 on average per day in the month of December to almost 25,000 kJ/m^2 in the month of July in the plains.
  Over the course of the year, days with clear or partly cloudy skies range from about one third to about 70%, depending on the area; on average, the days when the sky is variable to overcast prevail – albeit slightly. Moving inland from the coastal strip, cloud cover gradually increases, especially in the spring and summer months, while the opposite often happens in the winter months.
- WIND. Overall, the region is quite sheltered from the winds, especially as regards the cold ones coming from the north, while it is subject on the eastern side, especially on the Carso and the city of Trieste, to the Bora, coming from the east-north-east. This dry and cold wind, of continental origin, occurs above all in winter, but is not uncommon in other seasons and can reach very high speeds with gusts. The breezes are present over a large part of the regional territory and alternate with the north-eastern winds, which bring good weather, and the southern ones which favour the rains.

4.1 – Climate normal

Athmosphere normal

1) ANNUAL MEAN TEMPERATURE

The average annual temperature varies in the different areas of the region (**Figure 17**). It records the maximum values (which are around 15°C) along the coastal strip, thanks to the mitigating action of the sea. The warmest area, in particular, is the Trieste coast below the karst edge, due to the favourable exposure to the sun.

2) MONTHLY TEMPERATURES

Considering the average monthly temperatures, the annual trend of temperatures generally records the maximum values in the months of July and August and the minimum values between December and February, with an average difference of about 11-12°C between the values of the hottest locations and those of colder sites (**Figure 18**).

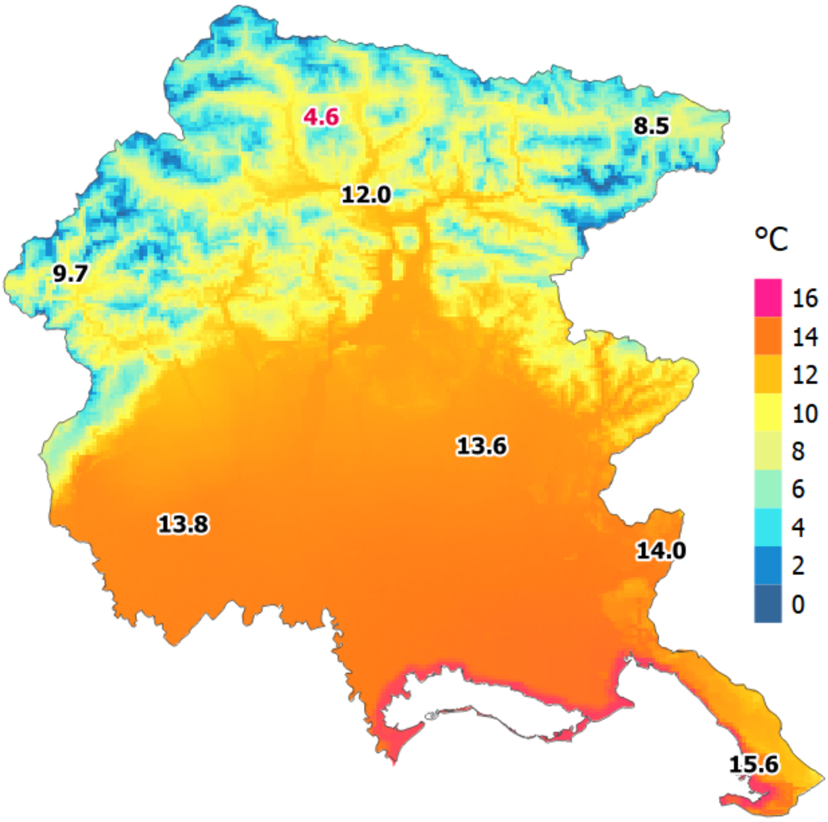

***Figure 17**. Friuli Venezia Giulia - Annual mean temperatures (regional meteorological network data 1991-2020). The figure in red corresponds to the altitude station at Monte Zoncolan; the figures in black refer to valley/plain/coastal stations.*

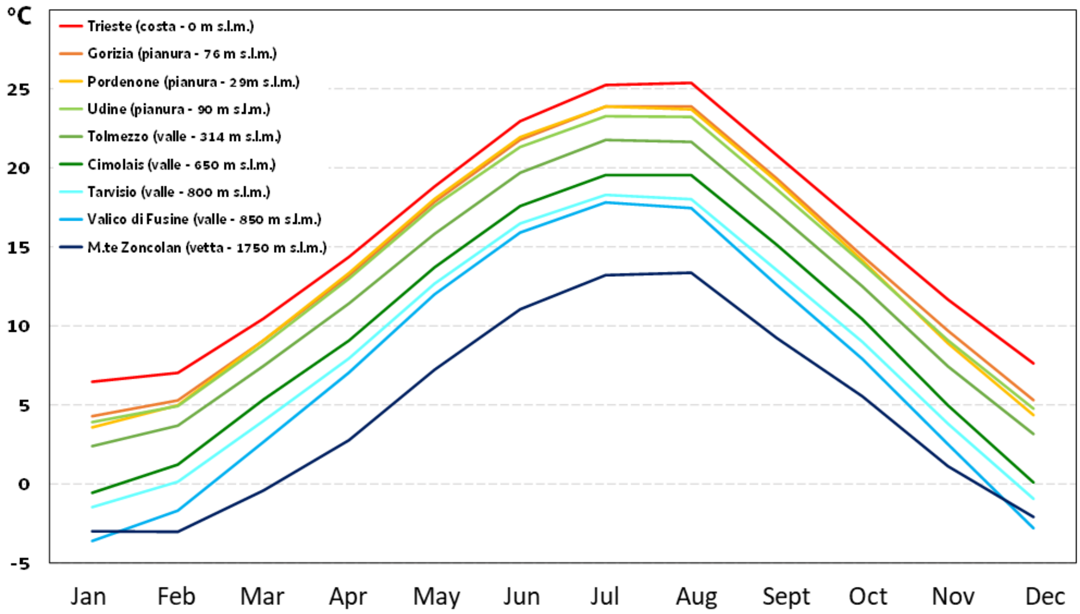

Figure 18. *Monthly mean temperature (1991-2022 average) in various locations in Friuli Venezia Giulia, from the Adriatic coast (Trieste) to the Alps (Tarvisio, Fusine, Zoncolan).*

3) YEAR MEAN RAINFALL

Precipitation in Friuli Venezia Giulia is a fairly complex phenomenon. The nature and origin of the rains vary throughout the year: during the late autumn, winter and spring months the rains are generally linked to the synoptic circulation and to the southern humid flows; during the summer months and in the first autumn months, the contribution to the total rainfall of rains of convective origin (showers and thunderstorms) or in any case linked to mesoscale dynamics becomes significant or even prevalent.

An examination of the maps of the average annual rainfall shows that the region can, to a large extent, be divided into 4 zones with distinct rainfall regimes (**Figure 19**):

i. Coastal strip: it is the least rainy area of the region; the annual totals reach an average of 900-1000 mm, with an increasing trend from the coast towards the interior;
ii. Plains and hills: getting closer to the mountains the rainfall increases; the average annual values vary from 1100 to 1800 mm;
iii. Prealpine belt: the average annual rainfall is between 2400 and 3400 mm (European record);
iv. Internal Alpine belt: north of the Carnic and Julian Pre-Alps the average annual rainfall decreases again to values of 1400 - 1600 mm, similar to those of the high plains.

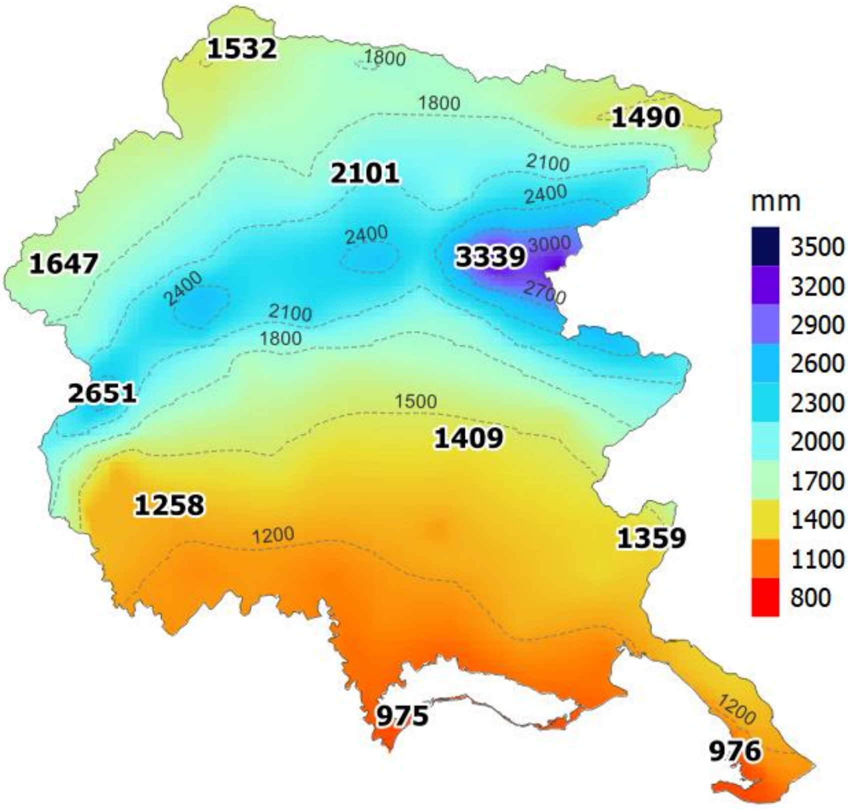

Figure 19. Average annual rainfall (data from the regional meteorological network).

4) MONTHLY MEAN RAINFALL

As regards the distribution of rainfall throughout the year, the least rainy month in the whole region is February, with values ranging from 60-90 mm of rain on the coast and in the plains, to 120-140 mm in the area prealpine.

During the spring, the rains gradually increase until reaching a first peak in May (80 mm on the coast and 280 mm on the Julian Pre-Alps). In July the rains decrease and then rise again starting from the third ten days of August. The autumn season is definitely the rainiest and the average monthly precipitation data in November varies from 100 mm on the coast to 450 mm in Musi (**Figure 20**).

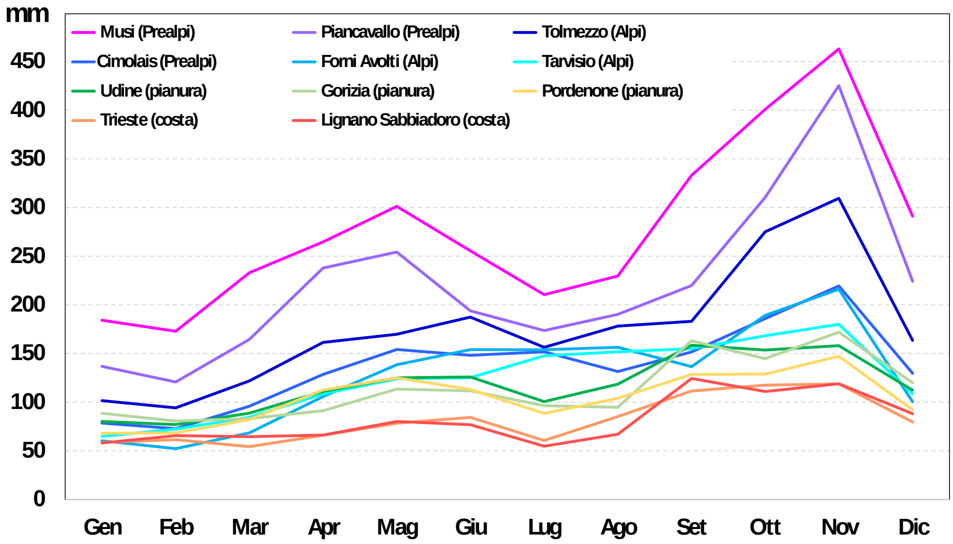

***Figure 20**. Development of average monthly rainfall at different locations over the year (regional meteorological network data 1991-2020).*

Sea normal

Since 2008, ARPA FVG has been conducted monthly monitoring of marine-coastal waters in the Gulf of Trieste (hereafter referred as GoT) under Italian jurisdiction. It is notable that, over the years, ARPA instruments have been gradually modified and upgraded with new and better performing ones. This is the case of the multi-parametric probe (CTD), which was employed to collect physico-chemical data along the water column. In 2014, ARPA's CTD probe was replaced with a new model (Idronaut mod. 316 *plus*) characterised by a sampling rate of 10Hz, which is higher than that of the probe previously used. This made it possible to obtain measurements at 0.25 dbar. Therefore, in the following paragraphs, the 2014-2022 dataset has been taken as a reference, as the measurements made in that period are more reliable due to the use of more precise instrumentation.

Temperature and salinity are the parameters took into consideration in the climatic context of the GoT. In the period 2014-2022 temperature and salinity showed an average ± standard deviation of 16.6°C±5.3°C (**Figure 21**) and of 36.9±1.9 PSU (**Figure 22**), respectively. It should be noted that measurements were conducted monthly for every year considered. Regarding depth, data were collected in the range 0-26 m (i.e., from the surface to the maximum depth recorded), which depends on the monitored stations. Overall, the entire dataset consists of 169782 measurements.

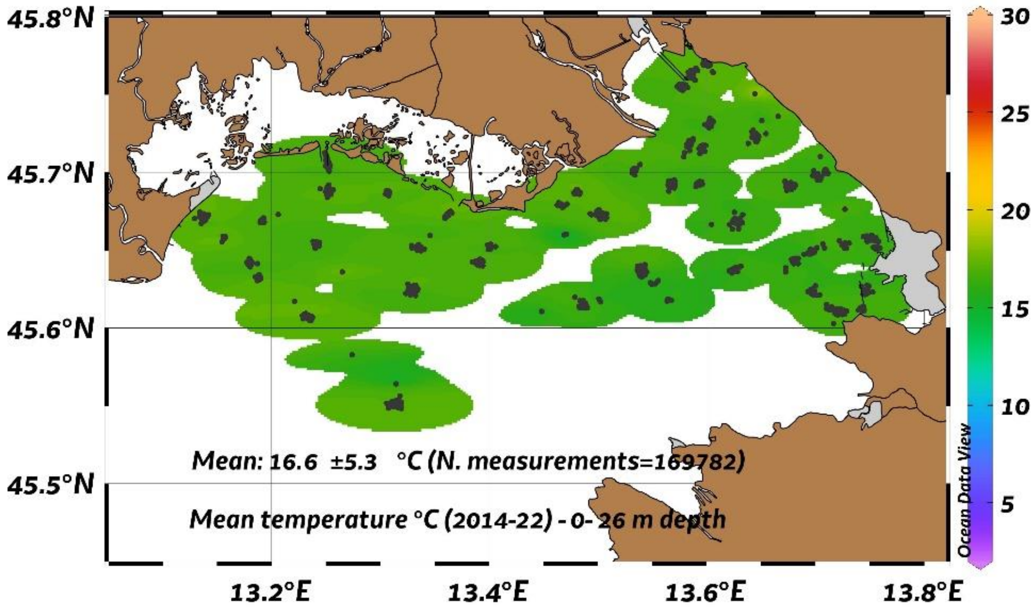

Figure 21. *Mean temperature (±SD) in the Gulf of Trieste during the period 2014-2022 (January-December) considering all the observations made by ARPA FVG (N=169782) in the water column (0-26 m). Black dots correspond to the georeferenced points where measurements were conducted. Map created with Ocean Data View software*[40].

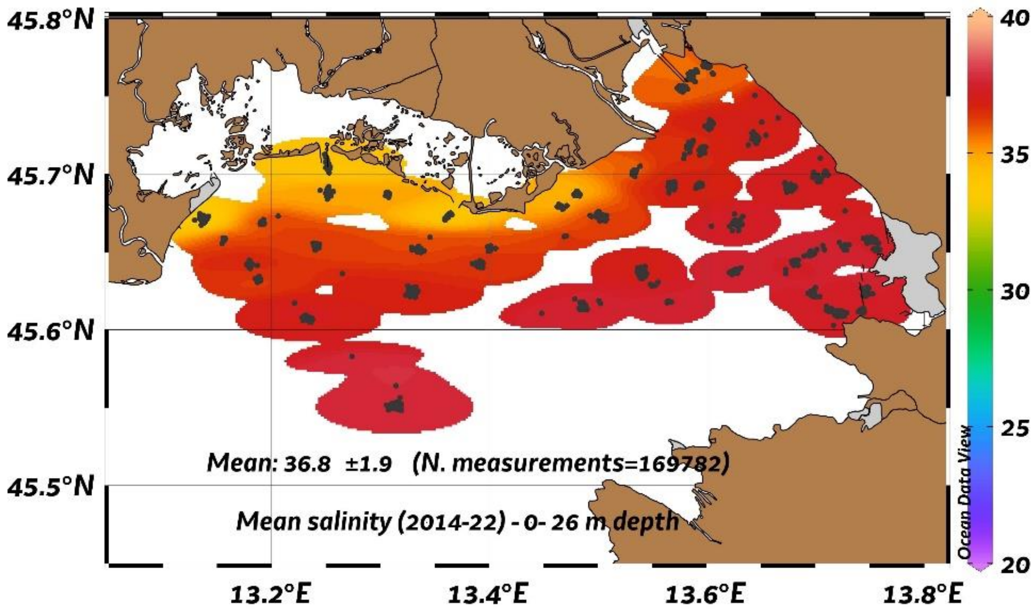

Figure 22. *Mean salinity (±SD) in the Gulf of Trieste during the period 2014-2022 (January-December) considering all the observations made by ARPA FVG (N=169782) in the water column (0-26 m). Black dots correspond to the georeferenced points where measurements were conducted. Map created with Ocean Data View software.*

In **Table 11** and **Table 12** are reported the results according to the selected different layers of the water column (surface, intermediate and bottom). For each layer, we provided different depths in order to consider layers with different thickness. The total number of measurements is different for each layer of the water column because of the depth range considered and the shore-offshore gradient, which implies more pronounced bathymetry as one moves away from the coast (**Figure 23**).

Table 11. *Temperature mean (±SD) in the Gulf of Trieste in the time period 2014-2022 (January-December) according to different depths in the water column. The last values correspond to the total mean considering all the observations. Observations are made by ARPA FVG.*

LAYER	DEPTH (m)	MEAN (°C)	±SD (°C)	N of observations
Surface	0 – 5	17.2	5.9	56699
	0 - 8	17.1	5.8	87314
Intermediate	5 - 15	16.6	5.3	87446
	8 - 18	16.2	5.0	70541
Bottom	15 - 26	15.4	4.3	29781
	18 - 26	15.3	4.1	15345
Bottom^{+}	20 - 26	15.1	4.0	8211
ALL DATA	0 – 26	16.6	5.3	169782

Table 12. *Salinity mean (±SD) in the Gulf of Trieste in the time period 2014-2022 (January-December) according to different depths in the water column. The last values correspond to the total mean considering all the observations. Observations are made by ARPA FVG.*

LAYER	DEPTH (m)	MEAN (PSU)	±SD (PSU)	N of observations
Surface	0 - 5	35.8	2.8	56699
	0 - 8	36.2	2.4	87314
Intermediate	5 - 15	37.2	0.9	87446
	8 - 18	37.5	0.7	70541
Bottom	15 - 26	37.8	0.5	29781
	18 - 26	37.8	0.5	15345
Bottom^{+}	20 - 26	37.8	0.5	8211
ALL DATA	0 – 26	36.9	1.9	169782

[40] Schlitzer, Reiner, Ocean Data View, https://odv.awi.de, 2023.

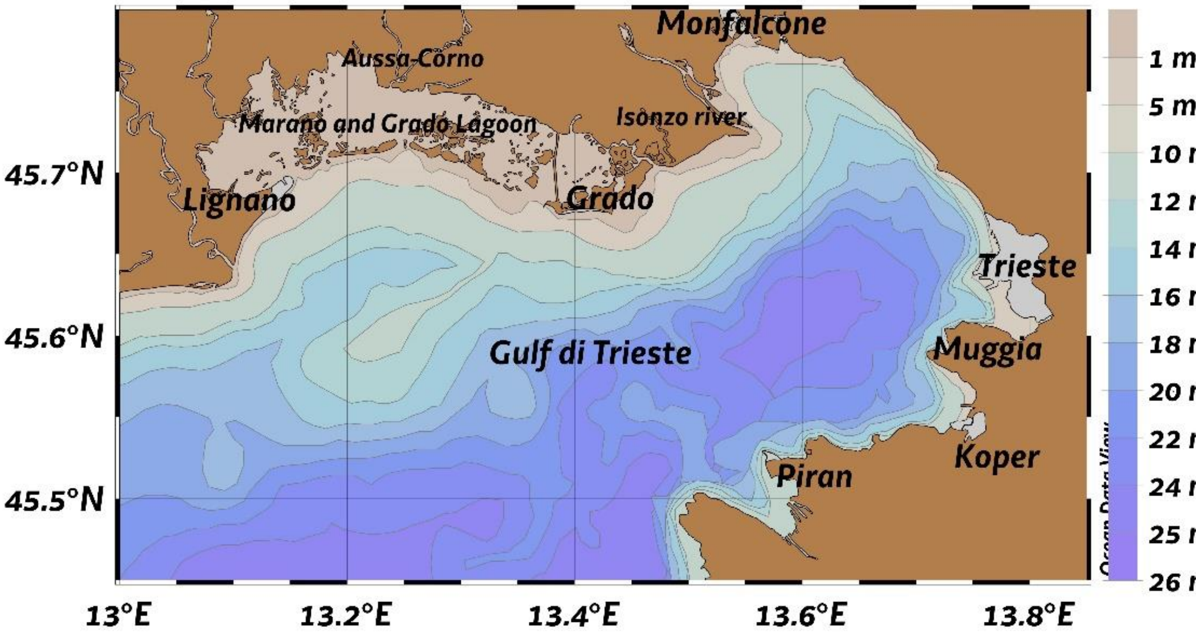

***Figure 23**. Bathymetry representation in the Gulf of Trieste according to Ocean Data View Software.*

Moreover, temperature and salinity data has been divided in 3 sub-dataset each covering a 3-year period each, starting from 2014 (**Table 13**). In each sub-dataset, data has been clustered according to the season in which they have been collected.

As for temperature, the seasonal average value over 3 years does not show substantial changes, and every season maintains stable temperatures from one three-year period to the next. On the contrary, salinity displays a steady increase expressed as mean seasonal value over the three-year periods considered in spring, summer, autumn and winter. In fact, in the period 2014-2016, the average inter-seasonal variation ranged from 36.0 to 36.9, while in 2020-2022 it ranged from 36.6 to 37.8, with peaks up to 38.8. This is strongly associated with the general decrease in river discharges at the mouth that has occurred in recent years, which causes fresh water not to dilute seawater and lead to increase in salinity. Moreover, in 2021 and 2022, the water masses of southern origin entering the GoTS probably had a higher salinity in itself (ARPA FVG 2022a, b)[41, 42].

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[41] ARPA FVG (2022a). Bollettino mensile Oceanografico ed ecologico del Golfo di Trieste – Novembre 2022. Edited by SOS Qualità delle acque marine e di transizione, 8 pp.

[42] ARPA FVG (2022b). Bollettino mensile Oceanografico ed ecologico del Golfo di Trieste – Dicembre 2022. Edited by SOS Qualità delle acque marine e di transizione, 8 pp.

Table 13. *Temperature and salinity seasonal mean for each considered triennium (from 2014 to 2022).*

TEMPERATURE (°C)	2014-2016				2017-2019				2020-2022			
SEASON	**MEAN**	**±SD**	**MIN ÷ MAX**	**N**	**MEAN**	**±SD**	**MIN ÷ MAX**	**N**	**MEAN**	**±SD**	**MIN ÷ MAX**	**N**
WINTER (JAN-FEB-MAR)	10.5	1.2	7.0 ÷ 14.3	13813	9.2	1.2	3.7 ÷ 12.1	14492	9.9	1.1	6.5 ÷ 12.6	13232
SPRING (APR-MAY-JUN)	16.4	3.6	10.9 ÷ 27.3	15809	15.9	3.3	9.1 ÷ 24.7	9512	16.7	3.4	10.7 ÷ 25.3	12212
SUMMER (JUL-AUG-SEP)	23.0	1.9	16.6 ÷ 29.7	17580	22.5	2.4	15.1 ÷ 28.5	15532	22.9	2.7	14.7 ÷ 28.2	14955
AUTUMN (OCT-NOV-DEC)	16.1	2.7	8.9 ÷ 21.6	17673	16.4	2.7	7.9 ÷ 20.4	11334	16.3	2.8	8.6 ÷ 21.3	13638
SALINITY (PSU)	**2014-2016**				**2017-2019**				**2020-2022**			
SEASON	**MEAN**	**±SD**	**MIN ÷ MAX**	**N**	**MEAN**	**±SD**	**MIN ÷ MAX**	**N**	**MEAN**	**±SD**	**MIN ÷ MAX**	**N**
WINTER (JAN-FEB-MAR)	36.9	1.7	10.0 ÷ 38.2	13813	37.5	1.5	< 5.0 ÷ 38.5	14492	37.8	1.0	21.0 ÷ 38.8	13232
SPRING (APR-MAY-JUN)	36.0	2.0	10.5 ÷ 38.4	15809	36.3	2.4	9.6 ÷ 38.2	9512	36.7	2.2	10.0 ÷ 38.9	12212
SUMMER (JUL-AUG-SEP)	36.4	1.8	13.9 ÷ 38.3	17580	36.8	1.5	6.8 ÷ 38.3	15532	37.2	1.4	17.6 ÷ 38.6	14955
AUTUMN (OCT-NOV-DEC)	36.4	2.6	< 5.0 ÷ 37.7	17673	36.8	2.2	7.5 ÷ 38.4	11334	37.4	1.3	13.3 ÷ 38.8	13638

Regarding temperature, **Figure 24** shows how the values are distributed across seasons (a-d) in each of the years of the period under consideration (2014-2022), but without the division into three-year periods seen above. Graphs confirm what aforementioned, that no evidence of significant seasonal variation in temperature over the period 2014-2022 occurred.

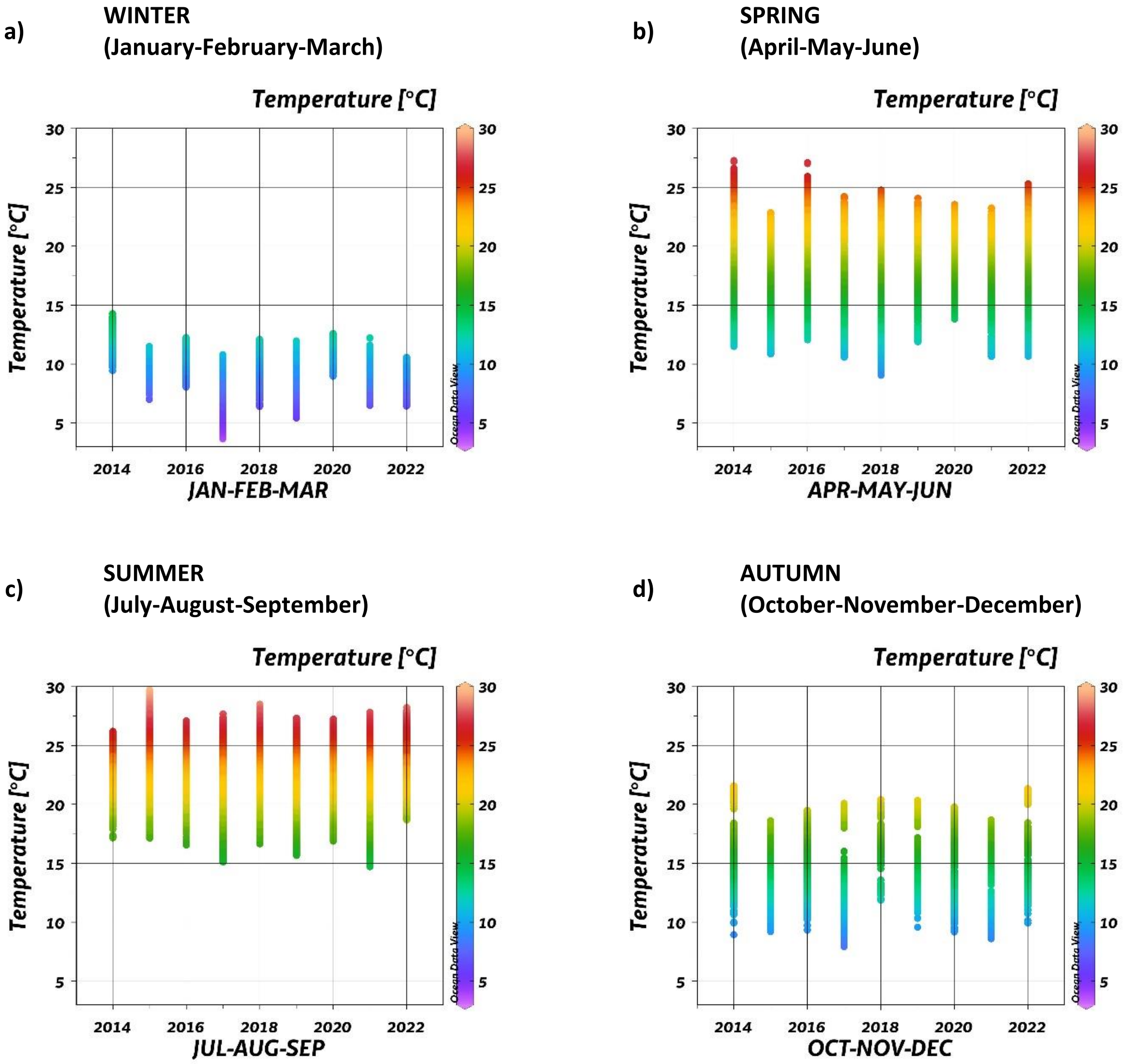

Figure 24*. Seasonal temperature values (a-d) during 2014-2022 in the Gulf of Trieste. Measurements taken at all depths were considered. Graphs created with Ocean Data View software.*

As evidenced in the following paragraphs (see 4.4 – Sea climate change: evidences), it is notable that different available sources furnish different information and measurements. In detail, these sources are not always in accordance in displaying significant trends and variations, especially depending on the dataset considered. In fact, a trend may or may not be visible depending on the time period considered and the type of data collected. Regarding the monitoring of marine and coastal waters, we should remember that ARPA FVG collects with monthly or bi-monthly frequency. These are the data reported in this section.

Moreover, the period from 2014 to 2022 could not be sufficient to show a significant change in physical quantities, due to the limited time period considered. On the contrary, an 8-year period could provide a more or less clear picture of what is happening in the short-term.

4.2 – Atmosphere climate change: evidences

Temperature

As for the rest of the world, the last decades show a rapidly changing climate in Friuli Venezia Giulia as well. The effects are particularly evident on temperatures. The longest and most reliable time series is the one related to the city of Udine (about 120 years, **Figure 25**), which ARPA FVG uses to provide evidence of the magnitude of changes in annual and seasonal mean temperature, compared to last century data. This historical series shows that the average annual temperature, despite the intrinsic and natural climatic variability, is definitely increasing. It was 12.8 °C in the thirty years of reference 1961-1990, very close to the averages of the previous periods (1901-1930, 1931-1960) and to the value calculated on the entire dataset of the last century (12.7 °C in the period 1901-1999). In the most recent climatological thirty years (1991-2020) the average annual temperature has increased up to 13.5 °C. Before 2000, in rare cases, an average annual temperature equal to or higher than 13.5 °C was recorded, while 2022 was the ninth consecutive year in which (on average in the Friuli Venezia Giulia plain) this value was reached or exceeded, The2022 average annual temperature was 14.7 °C: the highest annual temperature ever recorded in Udine.

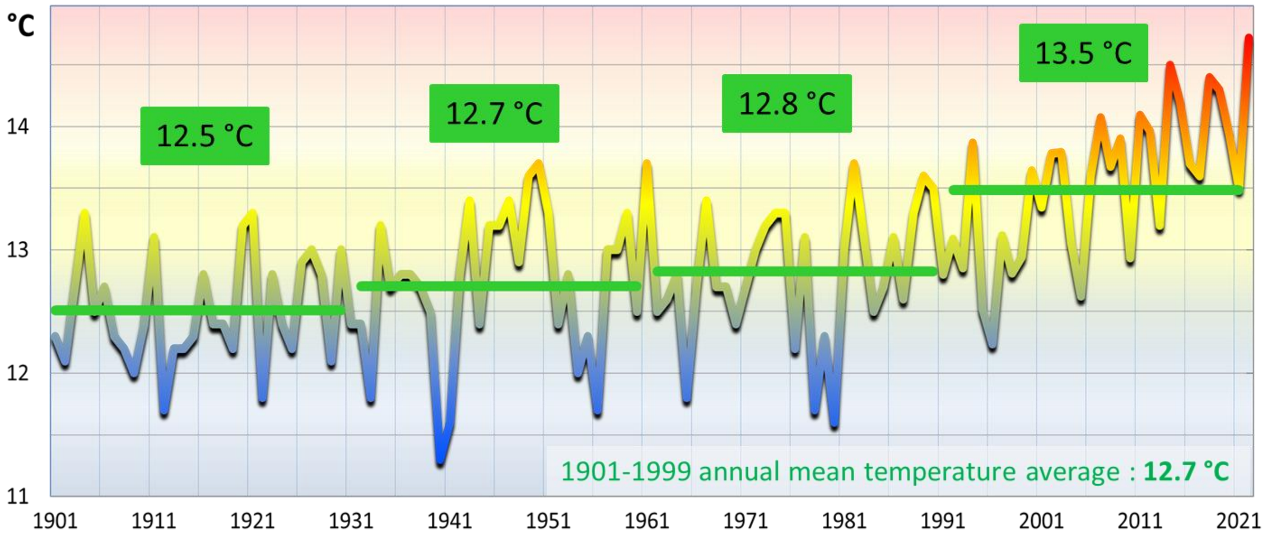

Figure 25*. Annual mean temperature in Friuli Venezia Giulia (Udine) and 30-year periods averages (Data series HistAlp1915-1991, Osmer-RAFVG1992-2019).*

The increase in summer mean temperature is even more pronounced (**Figure 26**).

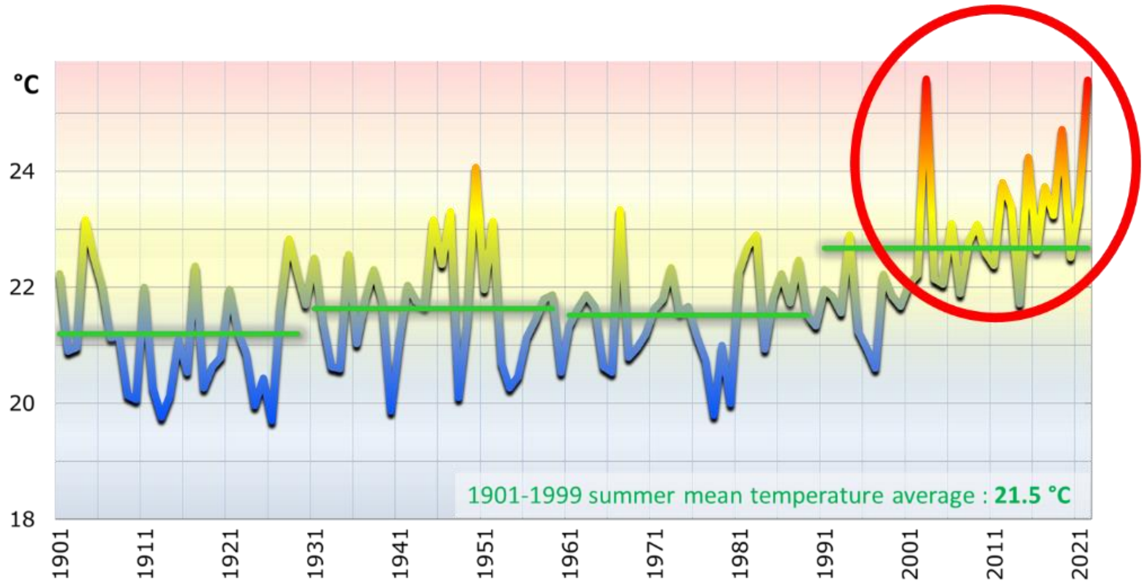

***Figure 26**. Summer mean temperature in Friuli Venezia Giulia (Udine) and 30-year periods averages (Data series HistAlp1915-1991, Osmer-RAFVG1992-2019).*

In order to provide a more representative information, on the other hand, ARPA FVG processes data coming from a certain number of meteorological stations in Friuli's plain area (the time series is shorter than Udine's, but still long enough to highlight the trends).

Temperature increase is becoming more pronounced over the last decades (**Figure 27**).

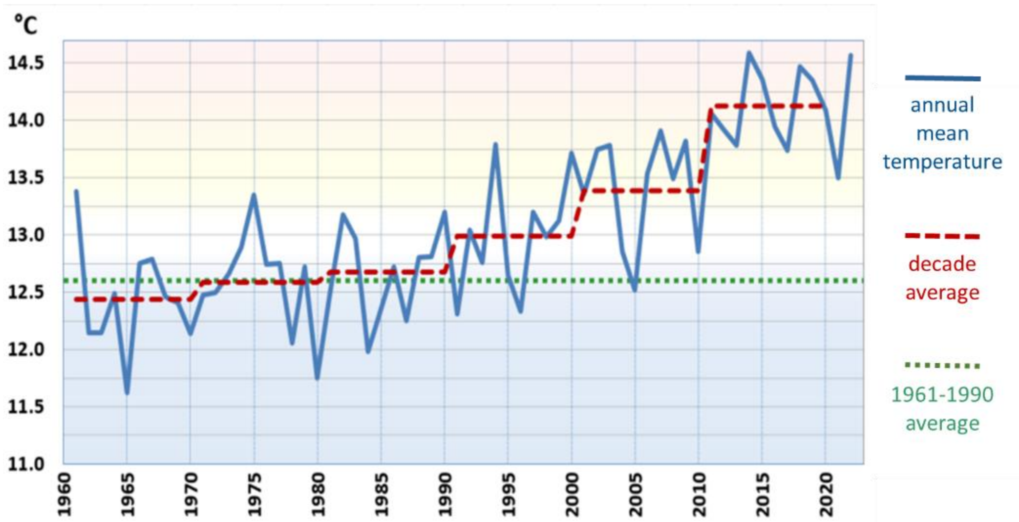

***Figure 27**. Annual mean temperature in Friuli Venezia Giulia plain area and 10-year periods averages (data from several local series, 1961-2022).*

Extreme temperature

As our health and wellbeing is usually affected by temperature extremes and heat extremes are the increasing ones, ARPA FVG usually processes related climate indicators, such as:

- **Hot days**. The total number of days in a year registering maximum daily temperature above a fixed threshold of 30°C
- **Tropical nights**. The annual number of days experiencing minimum daily temperature not lower than 20°C.

The number of hot days has nearly doubled compared to the average in the '90s (**Figure 28**).

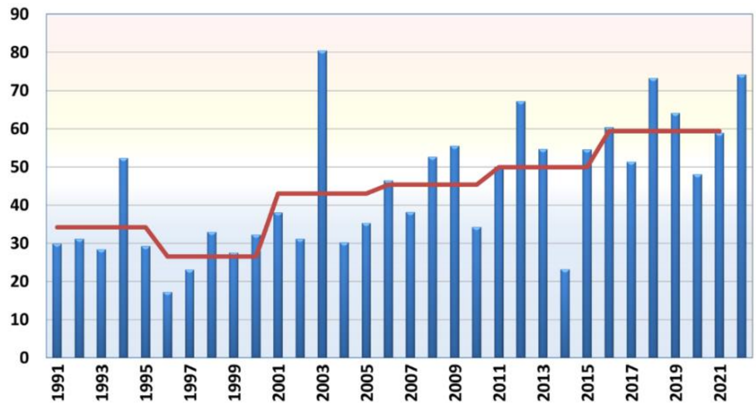

Figure 28. Number of hot days (maximum daily temperature above 30°C) in Friuli Venezia Giulia plain, 1991-2022.

The number of tropical nights is increasing (**Figure 29**).

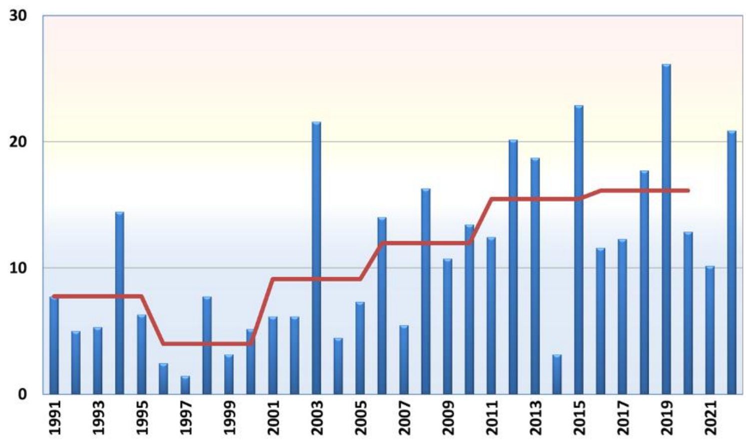

Figure 29. Number of tropical nights (minimum daily temperature above 20°C) in Friuli Venezia Giulia plain, 1991-2022.

Rainfall

Trends in the total amount of rain are very difficult to detect: statistically significant tendencies emerge only in some areas and in some seasons.

On the other hand, we can notice a shift in the monthly amounts of rain, which are diminishing in June (it used to be a typical spring month and it is now a true summer month) and increasing in autumn while comparing the two thirty-year periods (**Figure 30**).

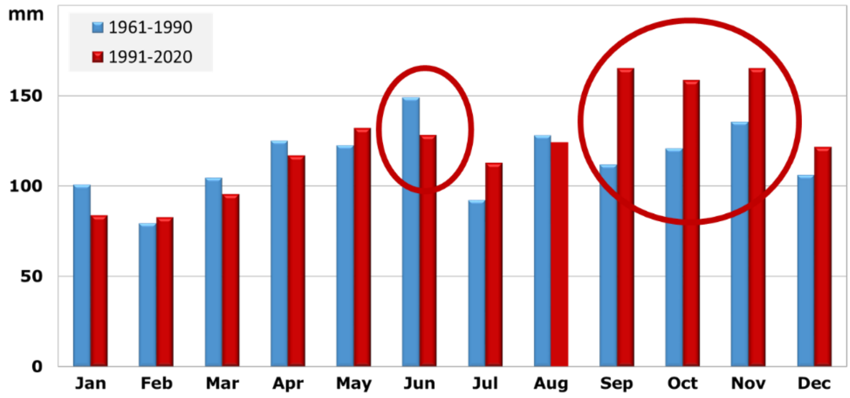

***Figure 30**. Monthly rainfall in Udine: comparison between 1961-1990 and 1991-2020 averages.*

Processing the data from several meteorological stations in Friuli Venezia Giulia plain area, a diminishing trend in summer rainfall emerges (**Figure 31**).

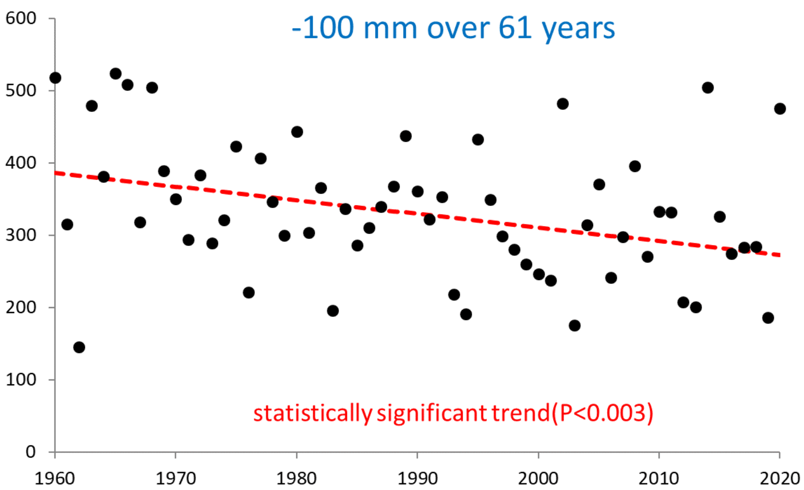

***Figure 31**. Summer rainfall average: data from 36 meteorological stations in FVG plain area.*

4.3 – Atmosphere climate change: projections

Temperature Projections

Tailored climate projections for Friuli Venezia Giulia region were obtained from existing climate models (GCM and RCM, Eurocordex) by ICTP – The International Centre for Theoretical Physics in Trieste, for two time periods (2051-2070 and 2070-2100) and three scenarios (RCP2.6, RCP4.5, RCP8.5) corresponding to different future paths in greenhouse gas emissions.

The following maps and charts belong to the first Friuli Venezia Giulia integrated climate change study that ARPA FVG published in 2018 together with the Universities of Udine and Trieste and other research centres (ICTP, OGS, CNR-ISMAR): *Studio conoscitivo dei cambiamenti climatici e di alcuni loro impatti in Friuli Venezia Giulia* (ARPA 2018).

Mean temperature will increase in all scenarios, more remarkably in summer. If greenhouse gas emission will be rapidly and significantly reduced, winter will be about 1-2°C warmer and summer about 2-3°C warmer. In a rising emissions scenario, temperature increase will be much more pronounced, reaching 5°C in winter and 6°C in summer (**Figure 32**).

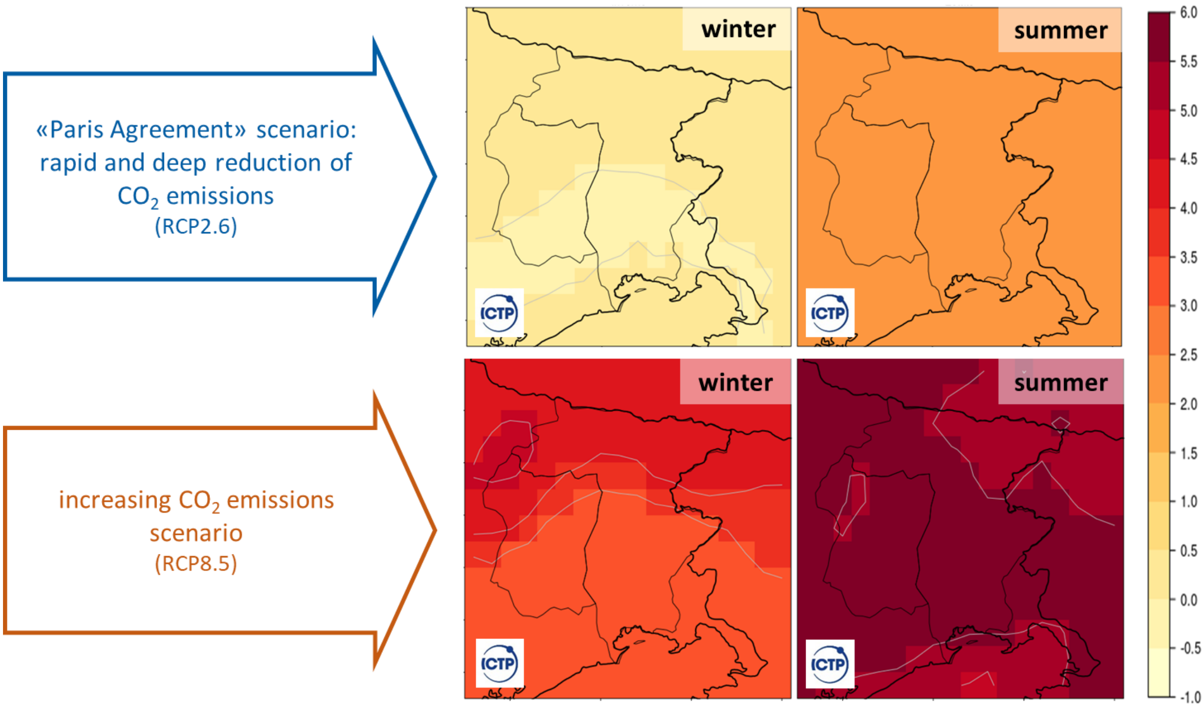

Figure 32*. Increasing temperature in FVG in different seasons (winter on the left, summer on the right) according to 2 RCPs. (top RCP2.6, bottom RCP8.5).*

Extreme heat indices (hot days and tropical nights) obtained from temperature projections are available for the main towns in FVG, for different emission scenarios (**Figure 33 A-B**). Changes in temperature extremes will also vary greatly depending on future emissions scenarios.

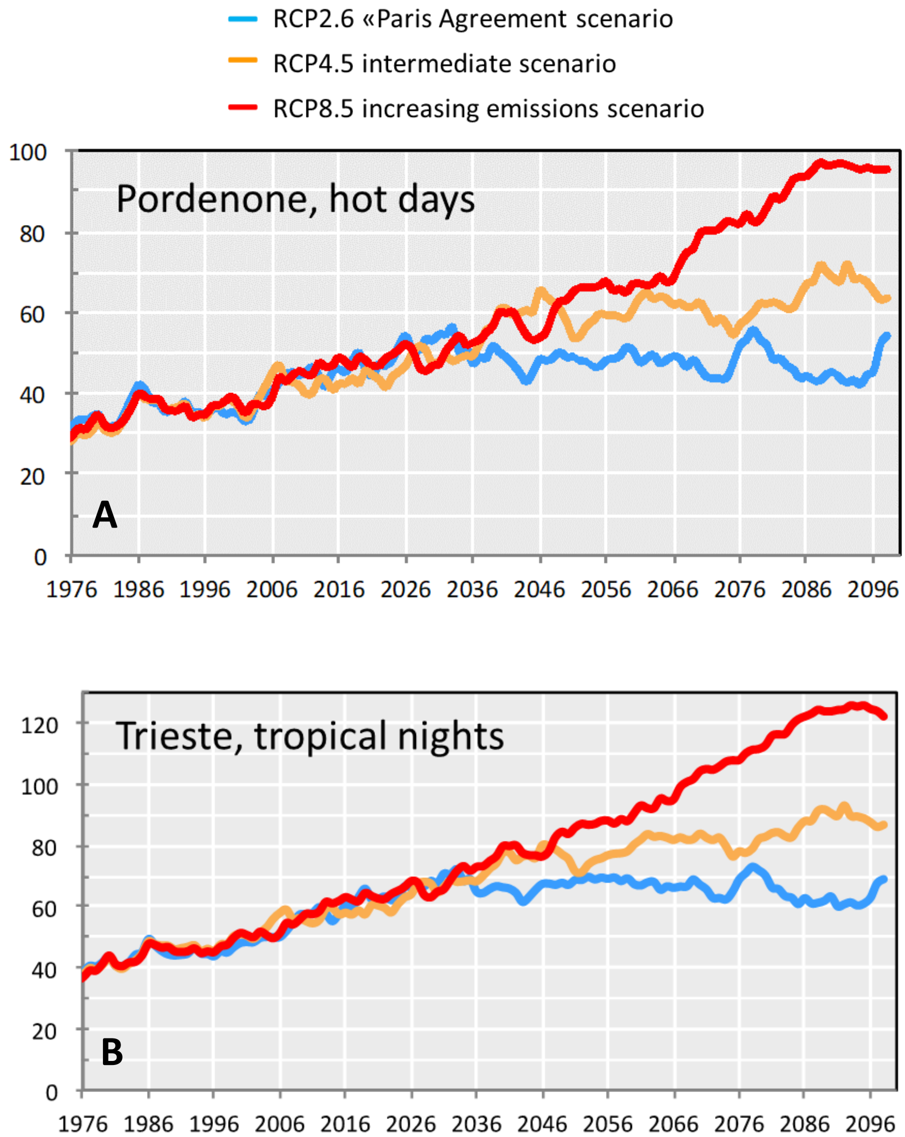

Figure 33 A-B*. (A) Hot days in Pordenone and tropical nights in Trieste (B) obtained from temperature projections for different emission scenarios.*

Rainfall projections

Future changes in rainfall are more complex to outline. Climate projections show a general increase in winter rainfall, in both the considered scenarios, but the difference is remarkable if we look at summer precipitation: in the increasing emissions scenario, a 15-20 % reduction in summer rainfall can be expected (**Figure 34**).

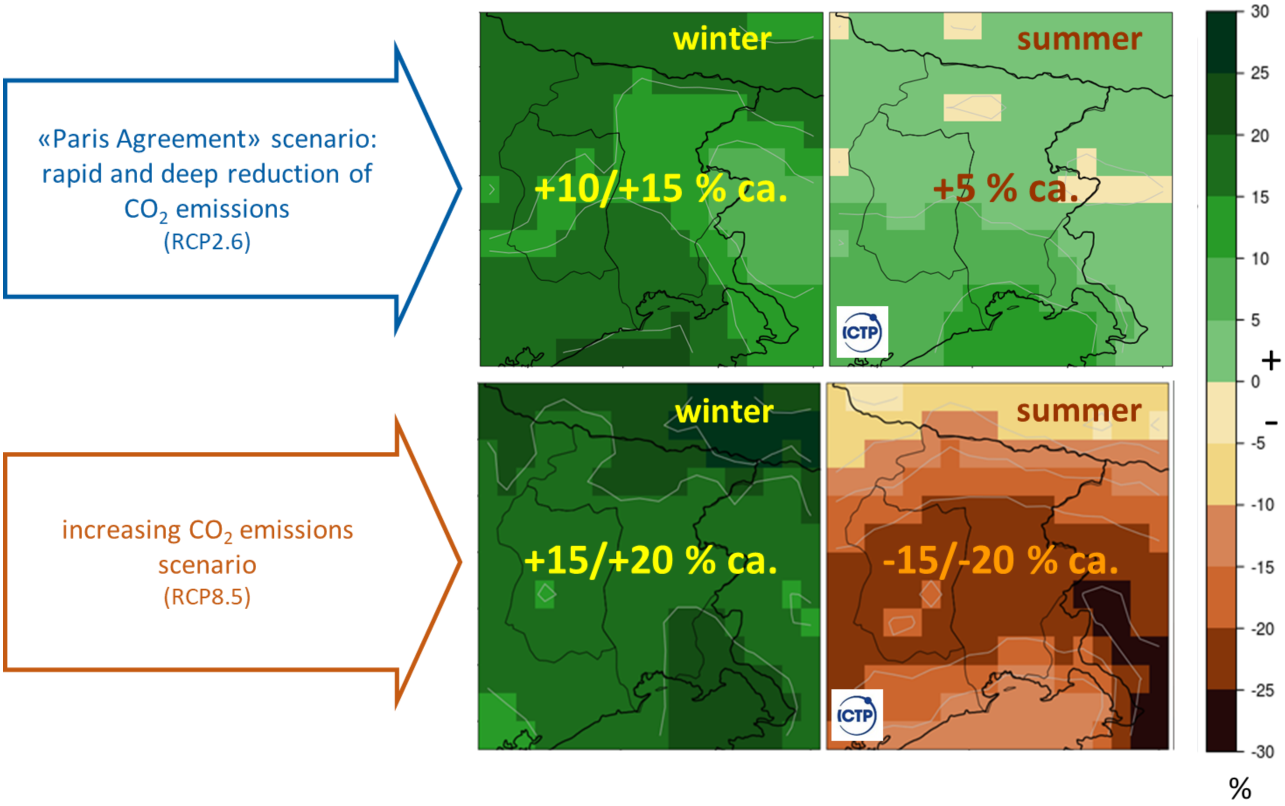

Figure 34*. Variation of the rainfall regime in FVG in different seasons (winter on the left, summer on the right) according to 2 RCPs. (top RCP2.6, bottom RCP8.5).*

Climate Scenarios of Bora and Sirocco Winds, expected on the Gulf of Trieste and the Northern Adriatic Sea, in the XXI century

Climate change affects wind patterns, with differences from region to region. A study by ARPA FVG (2023a)[43] showed the projections of Bora and Sirocco winds expected during the XXI century on the Gulf of Trieste and the Northern Adriatic Sea, respectively.

In this study, an ensemble of 14 EURO-CORDEX scenarios of the atmospheric sea level pressure field with daily time resolution was considered for three RCPs (2.6, 4.5 and 8.5). Starting from the pressure field, the authors computed the geostrophic wind speed between two pairs (one for each wind studied) of specific geographical points at the synoptic scale (**Figure 35**).

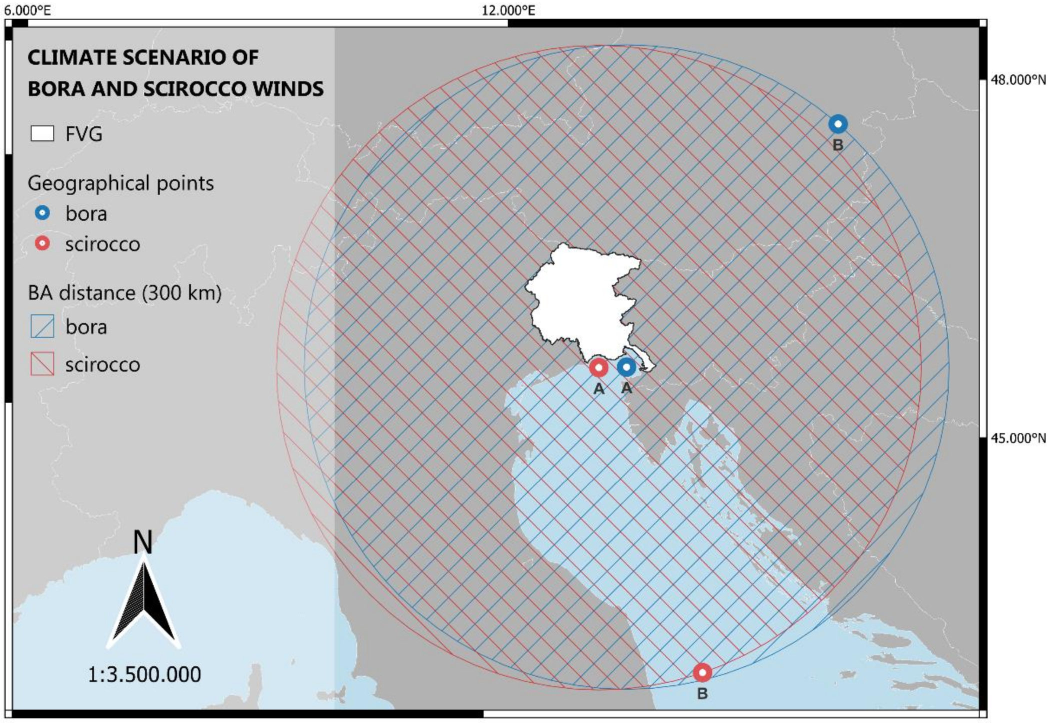

***Figure 35**. Geographical points (A and B) were established to study the Bora (light blue) and Sirocco (red) climatic scenarios.*

The first point is representative of the specific wind in the area of interest (*A*). The second point (*B*) was placed at a distance of 300 km from A (d_{AB}), in accordance with the synoptic scale. In order to find the location of B, the direction ($\widehat{BA}$) was determined for each of the winds under consideration.

[43] ARPA FVG (2023a). *Climate Scenarios of Bora and Sirocco Winds, expected on the Gulf of Trieste and the Northern Adriatic Sea, in the XXI century*. Edited by Alessandro Minigher & Giorgia Bulli. Internal document, 23 pp.

For the Bora wind, $\widehat{BA}$ represents the direction along which there is the strongest correlation between the wind at the local and synoptic scales (Minigher 2020, master degree thesis)[44]. In the case of the Sirocco, $\widehat{BA}$ is the direction along which the wind blows with greater intensity towards *A*. In fact, differently from the Bora, the Sirocco is not strongly dependent on local effects (e.g. orography), hence a less sophisticated approach was considered (ARPA FVG 2023a).

Once the points were defined, the computation of the atmospheric pressure gradient ($\vec{\nabla} p_{AB}$) between *A* and *B*, and of the corresponding geostrophic wind ($\vec{\nabla} p_{AB}$), were performed.

Then, local boundary layer effects were introduced into the geostrophic wind using measurements to downscale the synoptic scale information. Specifically, hourly wind observations were obtained from the Molo Fratelli Bandiera meteomarine station (Trieste) operated by CNR-ISMAR in collaboration with OSMER-ARPA FVG, and the Lignano Sabbiadoro meteorological station (Udine) operated by Regional Civil Protection for Bora and Sirocco, respectively.

For both winds, only episodes with a speed greater than or equal to 5 m s^{-1} were considered. Regarding the direction, episodes characterised by a direction lying between 30 and 120° N were considered for the Bora. For the Sirocco, on the other hand, episodes characterised by a direction of origin between 140 and 200° N were taken into account. For the latter, only the months between October and March were considered (including the extremes), as these are typical for Sirocco episodes.

Finally, for each RCP, any trend expressed as the number of days characterised by Bora and Sirocco winds with speeds greater than or equal to a given threshold was examined. Two thresholds were set, the first at 5 m s^{-1} and the second at 10 m s^{-1}.

In general, the study shows that the number of Bora and Sirocco wind days is expected to increase and decrease respectively, especially during the summer season (June ÷ September) and for RCP 8.5. For the winter season (November ÷ February), there are no remarkable trends. All the results are showed in **Table 14** (Bora) and **Table 15** (Sirocco).

However, more detailed considerations are worthwhile (ARPA FVG 2023a):

- the number of Bora wind days is generally expected to increase with climate change, especially during Summer;
- the number of days characterized by Bora wind faster than 5 m s^{-1} is expected to increase (about three days every two years) according to RCP 8.5 only, especially during the summer season;

[44] Minigher A (2020). *Study of the Atmosphere-Ocean Interaction in the Summer Episodes of Coastal Upwelling in the Gulf of Trieste* [Unpublished master degree thesis]. Trieste, Università degli Studi di Trieste, 116 pp.

- the number of days characterized by Bora wind faster than 5 m s^{-1} is expected to decrease (less than one day every two years) according to RCP 2.6 and during the summer season only;
- the number of days characterized by Bora wind faster than 10 m s^{-1} is expected to increase (about one day every two years) according to RCP 8.5 only, almost exclusively during the summer season;
- the number of days characterized by Bora wind faster than 10 m s^{-1} is expected to decrease (about two days every ten years) according to RCP 2.6 and during Summer only;
- for the Bora wind, no remarkable trends are found during the winter season;
- the number of Sirocco wind days is generally expected to decrease with climate change, quite only during Summer;
- the number of days characterized by Sirocco wind faster than 5 m s^{-1} is expected to decrease (about one day per year) according to RCP 8.5 only, almost exclusively during Summer;
- the number of days characterized by Sirocco wind faster than 10 m s^{-1} is expected to decrease (about one day every two years) according to RCP 8.5 only, almost exclusively during Summer;
- for the Sirocco wind, no trends are found during the winter season;
- for the Sirocco wind, weaker trends than those obtained for the Bora wind were found, maybe due to the fact that the chosen wind speed thresholds are more selective for the former than for the latter, which generally blows with larger intensity.

ARPA FVG's results for the summer season are consistent with several studies, but generally disagree with regard to the winter season for which significant trends are found in other researches (e.g. Belušić Vozila et al. 2019; Belušić Vozila et al. 2021). This may be due to the different length of the winter season considered (in ARPA FVG study the authors used the period November ÷ February instead of the standard December ÷ February).

It should be noted that this study deals with wind frequency, but not with its intensity and persistence. Further studies should therefore be carried out to investigate any trends in phenomena such as coastal erosion or flooding. In addition, scenarios with higher time resolution should be used to study wind episodes rather than wind days.

Nevertheless, some conclusions can be drawn regarding the strong relationship between the Bora wind and the coastal upwelling in the Gulf of Trieste. In fact, mainly due to the shallow bathymetry of this basin, intense Bora wind episodes mix the water column in about 12 hours (about 24 hours are needed to completely homogenise the water column), regardless of the strength of a typical summer vertical stratification (Minigher 2020, master degree thesis). Therefore, the increasing trend found in the number of Bora wind days, especially during Summer, most likely leads to an increasing trend in coastal upwelling episodes.

***Table 14**. Results of the linear regression analysis, performed on the ensemble mean and median, expressed as increasing/decreasing number of days per year of Bora events according to different RCPs. The different colours highlight the strong or weak correlation, according to three different ranges in which the p-value lies:*

0.00 ≤ p-value ≤ 0.01	*strong correlation*
0.01 < p-value ≤ 0.03	*medium correlation*
0.03 < p-value ≤ 0.05	*weak correlation*

BORA - YEAR (JAN-DEC)					
RCP	STATISTICAL ESTIMATOR	THRESHOLD: **5** m s^{-1}		THRESHOLD: **10** m s^{-1}	
		N. OF DAYS/YEAR (slope)	P-VALUE	N. OF DAYS/YEAR (slope)	P-VALUE
2.6	median	0.31	0.52	0.19	0.60
2.6	mean	0.41	0.21	0.30	0.19
4.5	median	0.16	0.57	-0.17	0.25
4.5	mean	0.22	0.33	-0.11	0.18
8.5	**median**	1.53	0.00	0.51	0.02
8.5	**mean**	1.43	0.00	0.36	0.04
BORA - SUMMER (JUN-SEP)					
RCP	STATISTICAL ESTIMATOR	THRESHOLD: **5** m s^{-1}		THRESHOLD: **10** m s^{-1}	
		N. OF DAYS/YEAR (slope)	P-VALUE	N. OF DAYS/YEAR (slope)	P-VALUE
2.6	**median**	-0.42	0.00	-0.18	0.01
2.6	**mean**	-0.36	0.02	-0.19	0.00
4.5	median	0.23	0.14	0.09	0.39
4.5	**mean**	0.43	0.04	0.18	0.07
8.5	**median**	1.67	0.00	0.58	0.00
8.5	**mean**	1.61	0.00	0.66	0.00
BORA - WINTER (NOV-FEB)					
RCP	STATISTICAL ESTIMATOR	THRESHOLD: **5** m s^{-1}		THRESHOLD: **10** m s^{-1}	
		N. OF DAYS/YEAR (slope)	P-VALUE	N. OF DAYS/YEAR (slope)	P-VALUE
2.6	median	0.48	0.09	0.27	0.14
2.6	**mean**	0.47	0.02	0.35	0.02
4.5	median	-0.18	0.35	-0.25	0.08
4.5	mean	-0.09	0.54	-0.17	0.28
8.5	median	-0.03	0.92	-0.01	0.96
8.5	mean	-0.12	0.49	-0.19	0.18

***Table 15**. Results of the linear regression analysis, performed on the ensemble mean and median, expressed as increasing/decreasing number of days per year of Sirocco events according to different RCPs. The different colours highlight the strong or weak correlation, according to three different ranges in which the p-value lies:*

0.00 ≤ p-value ≤ 0.01	*strong correlation*
0.01 < p-value ≤ 0.03	*medium correlation*
0.03 < p-value ≤ 0.05	*weak correlation*

SIROCCO - YEAR (JAN-DEC)					
RCP	STATISTICAL ESTIMATOR	THRESHOLD: **5** m s^{-1}		THRESHOLD: **10** m s^{-1}	
		N. OF DAYS/YEAR (slope)	P-VALUE	N. OF DAYS/YEAR (slope)	P-VALUE
2.6	median	0.05	0.89	0.00	0.98
2.6	mean	-0.23	0.42	-0.12	0.47
4.5	median	0.32	0.66	0.02	0.95
4.5	mean	-0.12	0.81	-0.03	0.94
8.5	**median**	-1.09	0.05	-0.48	0.04
8.5	mean	-0.74	0.06	-0.21	0.07
SIROCCO - SUMMER (JUN-SEP)					
RCP	STATISTICAL ESTIMATOR	THRESHOLD: **5** m s^{-1}		THRESHOLD: **10** m s^{-1}	
		N. OF DAYS/YEAR (slope)	P-VALUE	N. OF DAYS/YEAR (slope)	P-VALUE
2.6	median	-0.11	0.15	0.03	0.39
2.6	mean	-0.05	0.54	0.00	0.93
4.5	median	-0.26	0.12	-0.11	0.07
4.5	mean	-0.31	0.07	-0.11	0.10
8.5	**median**	-0.66	0.02	-0.19	0.06
8.5	**mean**	-0.71	0.00	-0.17	0.00
SIROCCO - WINTER (NOV-FEB)					
RCP	STATISTICAL ESTIMATOR	THRESHOLD: **5** m s^{-1}		THRESHOLD: **10** m s^{-1}	
		N. OF DAYS/YEAR (slope)	P-VALUE	N. OF DAYS/YEAR (slope)	P-VALUE
2.6	median	-0.26	0.50	-0.02	0.86
2.6	mean	-0.26	0.15	-0.12	0.38
4.5	median	-0.06	0.83	0.05	0.82
4.5	mean	0.04	0.89	0.06	0.81
8.5	median	-0.41	0.22	-0.23	0.09
8.5	mean	-0.03	0.90	0.08	0.65

As mentioned in the following paragraph (see 4.4 – Sea climate change: evidences), the Gulf of Trieste has a pivotal role in the circulation dynamics of the Mediterranean Sea, since it acts as a hotspot site for the North Adriatic Dense Water (NadDW) formation, thanks to the Bora effect. Therefore, Bora jets are responsible for most of the mean net heat loss of the Adriatic Sea, as well as for the vertical mixing of the water column and for the renewal of intermediate and bottom water masses.

From a biological point of view, Bora's action of mixing and cooling of seawater masses contributes to the oxygenation of bottom water and is also responsible for the exchange of nutrients between the surface and deep layers. Benthic species benefit from homogenising of the water column, as the occurrence of both hypoxic and anoxic events, especially in summer, are avoided. However, in the context of climate change and the phenomenon of "southernisation" of the Northern Adriatic, the improvement of conditions at the bottom level could lead to the spread of alien species, whose presence and acclimatisation is already favoured by milder winter temperatures.

In addition, due to the multi-factorial nature of climate change impacts, rainfall patterns are also changing (ARPA FVG 2018) and a decrease of river discharges at the mouth is expected. Regarding the recent past, in 2015 Djakovac et al.[45] observed a positive trend in dissolved oxygen (DO) concentrations in the northern Adriatic Sea waters. This was confirmed in 2019 by Kralj et al.[46], which found a similar trend in bottom waters in the Gulf of Trieste together with the observation of fewer recent hypoxic/low DO events if compared to the end 80' first 90' years (Djakovac et al. 2015). The positive trend of DO parallels the oligotrophication trend reported in the same area by Solidoro et al.[47] (2009) probably as a consequence of the marked decrease in the continental discharge of nutrients (Cozzi et al. 2012)[48].

In this context, the role to be played by the possible increase in the number of Bora summer jets in the future has yet to be studied. This could lead to an increase in productivity, with positive effects on fishery and marineculture, as well as negative effects with the spread of non-indigenous species. In addition, when assessing the possible increase in summer Bora episodes, the contribution of positive DO trends coupled with decreased nutrient supply must also be considered.

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[45] Djakovac T, Supic N, Bernardi Aubry F, Degobbis D & Giani M (2015). *Mechanisms of hypoxia frequency changes in the northern Adriatic Sea during the period 1972-2012, 2015*. J. Mar. Syst. 141, 179–189. DOI: https://doi.org/10.1016/j.jmarsys.2014.08.001.

[46] Kralj M, Lipizer M, Čermelj B, Celio M, Fabbro C, Brunetti F, Francé J, Mozetic P & Giani, M. (2019). *Hypoxia and dissolved oxygen trends in the northeastern Adriatic Sea (Gulf of Trieste)*. Deep Sea Research Part II: Topical Studies in Oceanography, 164, 74-88. DOI: https://doi.org/10.1016/j.dsr2.2019.06.002.

[47] Solidoro C, Bastianini M, Bandelj V, Codermatz R, Cossarini G, Melaku Canu D, Ravagnan E, Salon S & Trevisani S (2009). *Current state, scales of variability, and trends of biogeochemical properties in the northern Adriatic Sea*. J. Geophys. Res. 114, C07S91. DOI: https://doi.org/10.1029/2008JC004838.

[48] Cozzi S, Falconi C, Comici C, Čermelj B, Kovac N, Turk V & Giani M (2012). *Recent evolution of river discharges in the Gulf of Trieste and their potential response to climate changes and anthropogenic pressure*. Estuar. Coast Shelf Sci. 115, 14–24. DOI: https://doi.org/10.1016/j.ecss.2012.03.005.

4.4 – Sea climate change: evidences

Temperature and Sea Level Rise time series

In 2018 ARPA FVG, in close collaboration with the Scientific Community and supported by the Friuli Venezia Giulia Region, published the volume entitled "*Climate change in FVG, first study*" (ARPA FVG 2018). In this preliminary study, ARPA FVG collected and synthesized a considerable amount of data on climate and its changes over time with the aim to support the regional climate change adaptation strategy and mitigation actions. The trends of temperature, salinity and mean sea level, which are considered in the WP3 modelling activities, are well described in the aforementioned study.

Sea temperature is one of the indicators of climate evolution. Due to its semienclosed morphology and shallow depth, the changes of temperature in the GoT are strongly influenced by heat exchanges with the atmosphere. This influence can be observed even on relatively short time scales (i.e. few weeks). On the other hand, on seasonal and longer time scales the temperature is also influenced by the water mass exchange due to the Adriatic circulation, which modulates its trend in the medium-long term.

In the period 1991-2003, Malačič et al. (2006)[49] found a significant temperature increase (0.1°C/yr) in surface water layer that occurred in both spring and summer, whereas no significant change were found in the other seasons. The same trend was found at 10-meter depths where a higher increase (0.2°C/yr) occurred in summer. These trends are consistent with the warming of the atmosphere and oceans.

In the coastal area of the Friuli Venezia Giulia, and generally in the shallow areas of the Northern Adriatic Sea, a long time series of more than 120 years, based on measurements at the Port of Trieste at 2 m depth are available. The average annual temperature in 2022 was of 17.4°C, which is almost 1°C higher than the average calculated for the 20-year period 2001-2020 and is the third highest value in the series after 2014 (17.6°C) and 2018 (17.5°C) (ARPA FVG 2023b)[50].

In detail, the high average value found in 2022 was almost due to the high atmosphere temperatures that occurred in the first half of the summer (June and July) and in autumn. This latter was the warmest one since observations began probably as a consequence of the almost total absence of cold air inputs and Bora wind. On the other hand, the winter temperature was comparable to the 20-year (2001-2020) calculated average (ARPA FVG 2023b).

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[49] Malačič V, Celio M, Čermelj B, Bussani A & Comici C (2006). *Interannual evolution of seasonal thermohaline properties in the Gulf of Trieste (northern Adriatic) 1991-2003*. Journal of Geophysical Research, Vol. 111, C08009. DOI: https://doi.org/10.1029/2005JC003267.

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

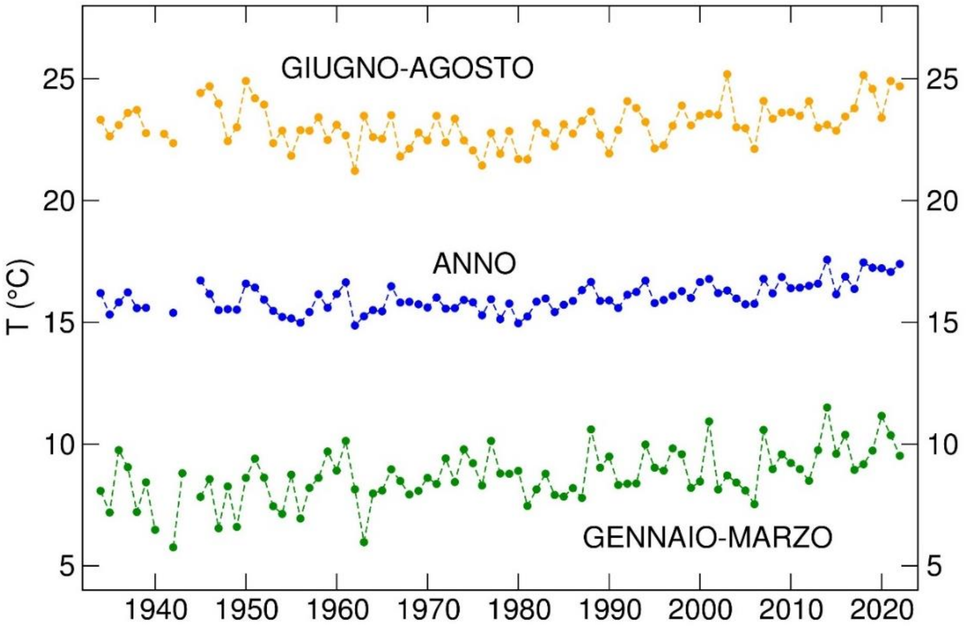

Figure 36. Average annual (1934-2022, blue line), summer (June-August, yellow line) and winter (January-March, green line) sea temperatures from 1934 to 2022 at 2 m depth. Data from: CNR-ISMAR Trieste, ARPA FVG-OSMER e GRN.

Figure 36 highlights the rising trend in sea temperature, especially in the last decade (from 2010), in correspondence with ongoing atmospheric warming. In **Figure 37**, in fact, the sea surface temperature increase compared with the increasing of the air mean temperature at 10 m is shown. On the other hand, **Figure 38** shows annual estimates of changes in ocean heat content obtained from analysis of different data sets in the surface (a) and deep (b) water layers.

Regarding **Figure 36** and **Figure 37**, it is notable that since the 1930s (the beginning of the observations) the temperature trend remained stable, while an upward trend is visible since the 1980s. This confirms that global warming has dramatically accelerated in recent decades due to increasing climate-altering emissions, owing largely to human activities. In fact, climate-altering gases such as carbon dioxide (CO_2) trap heat in the atmosphere and the increasing concentrations of these gases have driven an increase in global temperatures (IPCC 2018)[51].

In particular, taking into consideration the CO_2, the U.S. Global Change Research Program confirms that the global monthly average concentrations have risen from around 339 ppm in 1980 (averaged over the year) to 415 ppm in 2021, an increase of more than 20%[52].

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[51] IPCC (2018). *Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty*.

[52] Atmospheric Carbon Dioxide – GlobalChange.gov

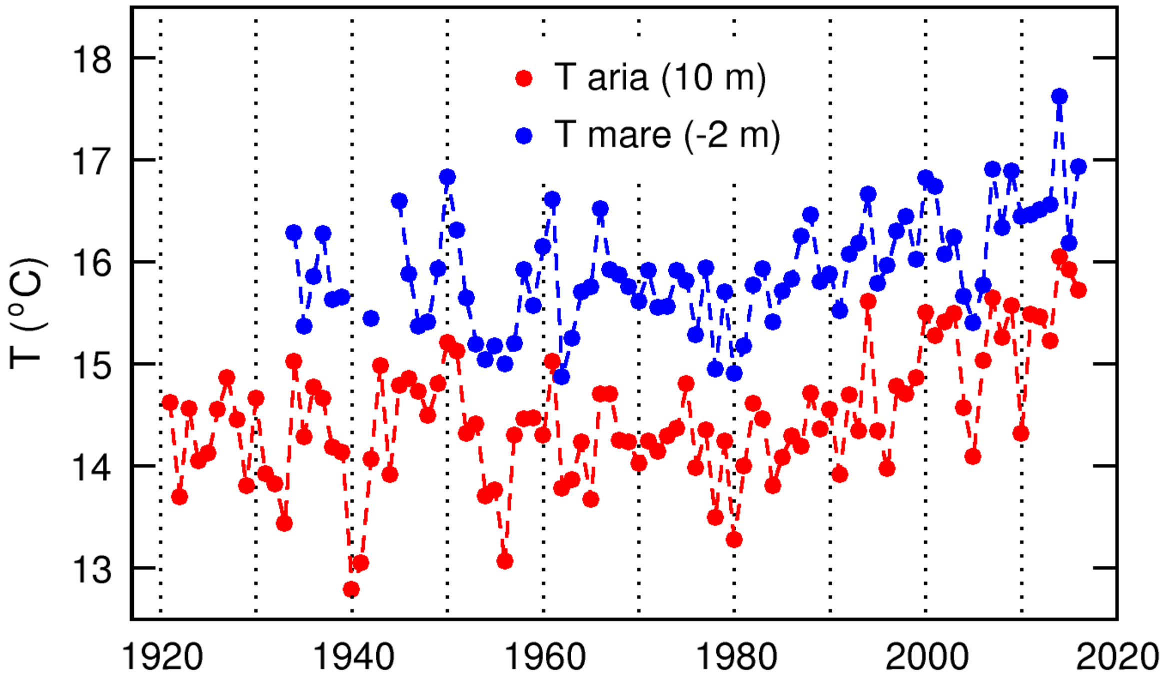

Figure 37*. Average annual air temperature at 10 m (red line) and sea temperature at 2 m depth (blue line) in Trieste, Italy. Data from CNR-ISMAR Trieste and ARPA FVG-OSMER (From: ARPA FVG 2018).*

The city of Trieste hosts one of the oldest tide gauge station in the Adriatic[53] for **sea level** observation (active since early 1859), that has been progressively implemented in accuracy of measurements as the improvement in technology becomes available.

It notable that for sea level measurements it is necessary to consider also the vertical land motion, mainly due to subsidence, which can vary from site to site. In the coastal area of Friuli Venezia Giulia subsidence reaches important values, in particular in the lagoon area where the lowering of the ground is significant. In these cases, compared to the coast, the mean sea level rises more rapidly. In contrast, the coastal territory of Trieste exhibits relative stability (ARPA FVG 2018, 2023b).

[53] http://www.ts.ismar.cnr.it/node/34

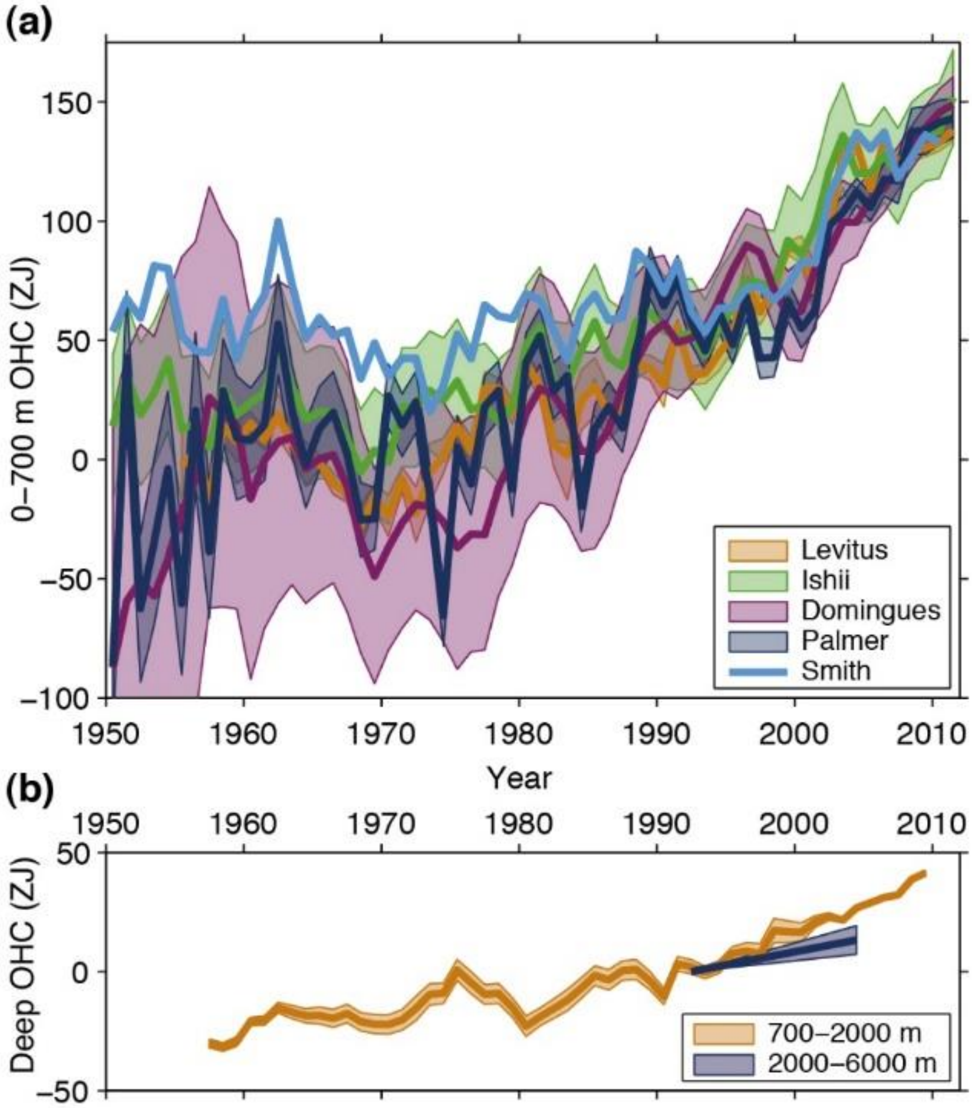

__Figure 38__. Annual estimates, based on observations, of global ocean heat content in the 0-700 m layer (a) and deep layers (b). 1 ZJ = 1 zettajoule = 1021 J. (From: Rhein et al. (2013)[54], fig. 3.2, p. 262, mentioned in Climate change in FVG, first study – ARPA FVG, 2018).

[54] Rhein M, Rintoul SR, Aoki S, Campos E, Chambers D, Feely RA, Gulev S, Johnson GC, Josey SA, Kostianoy A, Mauritzen C, Roemmich D, Talley LD & Wang F (2013). *Observations: Ocean*, in: Stocker TF, Qin D, Plattner GK, Tignor M, Allen SK, Boschung J, Nauels A, Xia Y, Bex V & Midgley PM. *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, UK and New York, NY, USA, Ed., 1552 pp.

Overall, the mean sea level observed in Trieste well represents that of the entire regional coastal area and is consistent with the global trend (ARPA FVG 2018), which increased at a rate of 1.5-2.0 mm/yr in the 20th century, while in the last 30 years it has reached a value of about 3 mm/year (ARPA FVG 2023b). It is well established that as the mean sea level rises, the risks of coastal flooding and erosion increase, the river runoff to the sea is hindered, the water table rises, and salty sea water penetrates more easily into the coastal subsoil.

On a secular scale, a mean sea level rise has been recorded in Trieste with an average rate of 1.3±0.2 mm/yr (Zerbini et al. 2017)[55]. If this trend is compared to the global trend, it appears that local assessment is lower than the global estimate. This is mainly due to the interruption of sea level rise in the Mediterranean from the mid-1960s to the early 1990s, which was followed by a much higher arise rate than the secular average (4.4 mm/yr from 1992 to 2016 in Trieste) (Marcos & Tsimplis 2008)[56].

Taking into consideration the measurements collected at the Trieste's Sartorio pier, where the tide gauge station is located, the sea level is measured with respect to the "Zero Istituto Talassografico" datum, which is positioned 166.2 cm below the "Zero IGM42" chart datum of the Italian Military Geographic Institute, the Italian datum commonly taken as a reference.

In 2022, the mean sea level was 165.5 cm, the second lowest value in the last decade, but higher than the levels observed in the last century (**Figure 39**) (ARPA FVG 2023b). Overall, it is visible a rapid increase of SLR (Sea Level Rise) starting from 2010. This could indicate a rapid increase in SLR in the last decade.

One of the consequences of the mean sea level rise affecting the coasts of our region is, on average, an increase in the frequency of "high water" (*"acqua alta"*) events. Such phenomena occur in the presence of low atmospheric pressure and marine currents due to winds of southern origin along the Adriatic Sea, typically in autumn and winter. These extreme events cause flooding and increase the coastal erosion, in part due to the strong wave motion that are often coupled to these events (ARPA FVG 2023b).

Two episodes of "*acqua alta*" occurred on November 4 and 22-23, 2022. The latter episode, when the sea level rose 30 cm above the Sartorio Pier, was particularly significant (ARPA FVG 2023b).

In **Figure 39** are reported the number of days/year when the sea level exceeded Sartorio Pier (histogram in yellow) from 1905 to 2022. One-third of these events (21 out of 64) have been observed since 2010. Their average frequency almost quadrupled from 0.4 events/yr before 2010 to 1.5 events/yr after 2010.

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[55] Zerbini S, Raicich F, Prati C, Bruni S, Del Conte S, Errico M & Santi E (2017). *Sea-level change in the Northern Mediterranean Sea from long-period tide gauge time series*. Earth-Science Reviews, Vol. 167, 72-87.

[56] Marcos M & Tsimplis MN (2008). *Coastal sea level trends in southern Europe*. Geophysical Journal International, Vol. 175, 70–82.

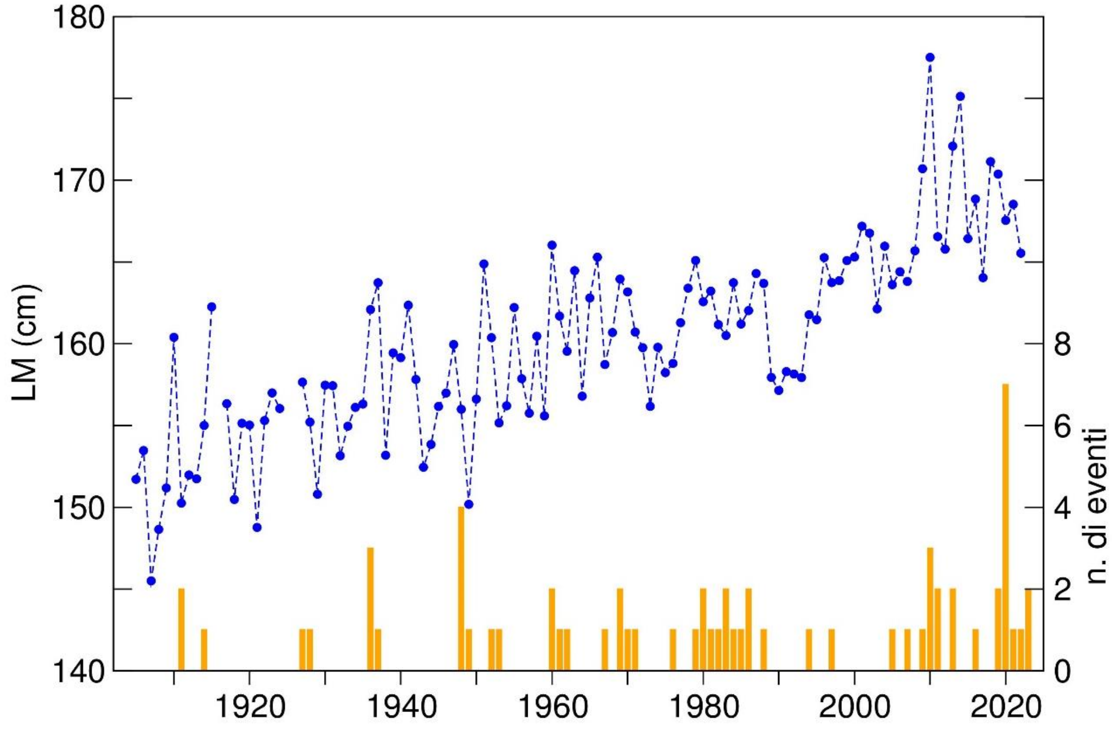

Figure 39. Blue line: mean annual sea level from 1905 to 2022 observed at Sartorio pier; height is measured relative to the "Zero Istituto Talassografico". Orange Histogram: annual number of events in which the sea level exceeded the level of Sartorio pier. Data from CNR-ISMAR Trieste.

Temperature anomalies

Regarding temperature anomalies, we report two representative cases: an offshore and an inshore situation. The considered stations are (1) PALOMA-P555 and (2) MOLO FRATELLI BANDIERA (**Figure 40**).

The first one belongs to the network where ARPA FVG conducts the periodic marine-coastal water monitoring campaigns. Temperature data are collected monthly or bi-monthly using a multi-parametric probe (CTD) at the PALOMA buoy operated by CNR-ISMAR and corresponds to the deepest point of the GoT (26 m). PALOMA is about 8 nautical miles (15 km) from the Trieste coast.

The second station, on the other hand, is located along the Fratelli Bandiera pier[57] near the Trieste port area. This is a meteo-marine site operated by CNR-ISMAR in collaboration with OSMER-ARPA FVG for the synoptic station. The data from this station represent the daily average sea surface temperature.

[57] http://www.ts.ismar.cnr.it/node/49

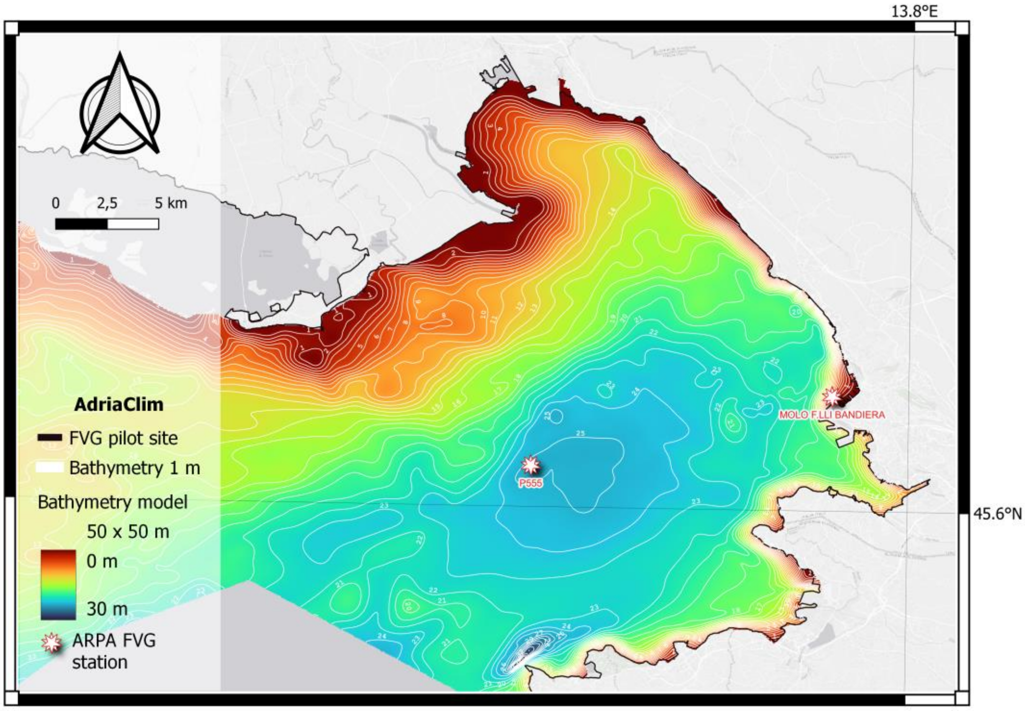

***Figure 40**. PALOMA-P555 and Molo Fratelli Bandiera monitoring stations. The bathymetry layers are from Trobec & Busetti (2017) of the National Institute of Oceanography and Applied Geophysics[58].*

PALOMA OFFSHORE MONITORING STATION

The PALOMA station displays oceanographic characteristics influenced by the action of meteorological and marine forcing.

Regarding salinity, the station PALOMA it is generally affected by a low-salinity water supply, that especially occurred in March-April and November. In addition, different layers of the water column have different salinity values. For example, the sub-surface layer is characterized by salinity values above 38 in winter and during periods of increased ingression into the GoT of water of Istro-dalmatian origin. This is associated with the cyclonic circulation of water masses caused by the different density of seawater between the eastern and western sides of the GoT (gradient current) and convective and mechanical action due to wave motion and wind.

Although the PALOMA is located in the centre of the GoTS, the lack of freshwater from the main contributor, the Isonzo River, is also notable offshore. In fact, when major river flooding of the

[58] Trobec A & Busetti M (2017). *Models of the bathymetry, of the base and of the thickness of Holocene marine sediment in the Gulf of Trieste (Northern Adriatic Sea)*. OGS SNAP System, DOI: https://doi.org/10.6092/6ad9b1e6-c977-cec9-8a2d-db10c7f90adc.

Isonzo River occurs, it can overtake the Miramare promontory and even reach the town of Muggia (ARPA FVG 2018), located at the southern end of the Trieste coast.

Regarding general temperature characteristics, in autumn-winter the surface release heat to the atmosphere, reaching temperatures below 9-10°C. In addition, the low stability of the water column promotes the mixing of water masses, causing the water column to be homogeneous. On the other hand, during summer the stability of the water column permit the heat accumulation and the surface temperature reaches values above 25°C. In offshore waters, where the bathymetry reaches 20 to 26 m depth, a temperature gradient of 10-12°C from the surface to the bottom water column is measured (ARPA FVG 2020)[59].

The time series from 2009 to 2022 shows increasing trends in temperature (**Figure 42**) and salinity (**Figure 41**), for both the surface (A) and lower layers (B) of the water column. The trends are significant at $p < 0.01$.

The salinity trends of the PALOMA station, compared to those found by Malačič et al. (2006) for the GoT area, shows few differences. In fact, these latter found a significant trend of 0.2-0.3/yr in spring, summer and winter, while autumn shows no significant trends. At 10 m depth, the trend was significant only for autumn and winter (+0.1/yr). This is probably due to (*i*) the different time series considered (1991-2003 VS 2009-2022), (*ii*) the subdivision of the dataset (season VS year-round) and (*iii*) the different location where the data were collected (GoT VS PALOMA) in the study by Malačič and colleagues and in the present work.

Overall, the trends depicted in **Figure 41** support the salinity increase aforementioned in each season for the three-year periods 2014-16, 2017-19, 2020-22 (**Table 13**). In turn, the significant offshore increase in salinity over the years could be related to the progressive decrease in rainfall and, consequently, river discharges at the Isonzo River mouth. Taking as an example, the period of prolonged drought experienced in 2022 led to a shortage of freshwater supply from rivers, which consequently greatly altered the salinity of the sea (ARPA FVG 2022c, d)[60, 61]: as a result, very high salinity values, which normally characterize the southern basins of the Mediterranean (Nittis & Lascarotes 1999, Sammartino et al. 2022)[62, 63], were reached in the GoT.

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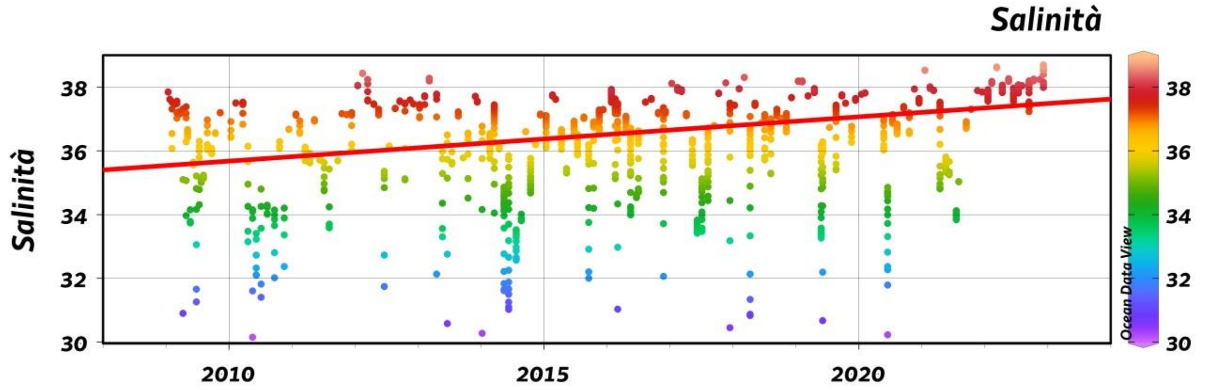
[59] ARPA FVG (2020). *Caratteristiche idrologiche delle acque al largo del golfo di Trieste – Stazione P555 (gennaio 2008-dicembre 2019)*. Edited by SOS Quaità delle acque marine e di transizione. Released on the previous version of ARPA FVG website, downloadable in the drop-down menu under "*Pubblicazioni*".
[60] ARPA FVG (2022c). *Bollettino mensile stato oceanografico ed ecologico del golfo di Trieste – Luglio 2022*. Edited by SOS Qualità delle acque marine e di transizione, 8 pp.
[61] ARPA FVG (2022d). *Bollettino mensile stato oceanografico ed ecologico del golfo di Trieste – Agosto e Settembre 2022*. Edited by SOS Qualità delle acque marine e di transizione, 11 pp.
[62] Nittis K & Lascaratos A. (1999). *Intermediate Water Formation in the Levantine Sea: The Response to Interannual Variability of Atmospheric Forcing*. 10.1007/978-94-011-4796-5_31. DOI:10.1007/978-94-011-4796-5_31.
[63] Sammartino M, Aronica S, Santoleri R & Buongiorno Nardelli B (2022). *Retrieving Mediterranean Sea Surface Salinity Distribution and Interannual Trends from Multi-Sensor Satellite and in Situ Data*. Remote Sensing, 14(10), 2502. DOI: 10.3390/rs14102502.

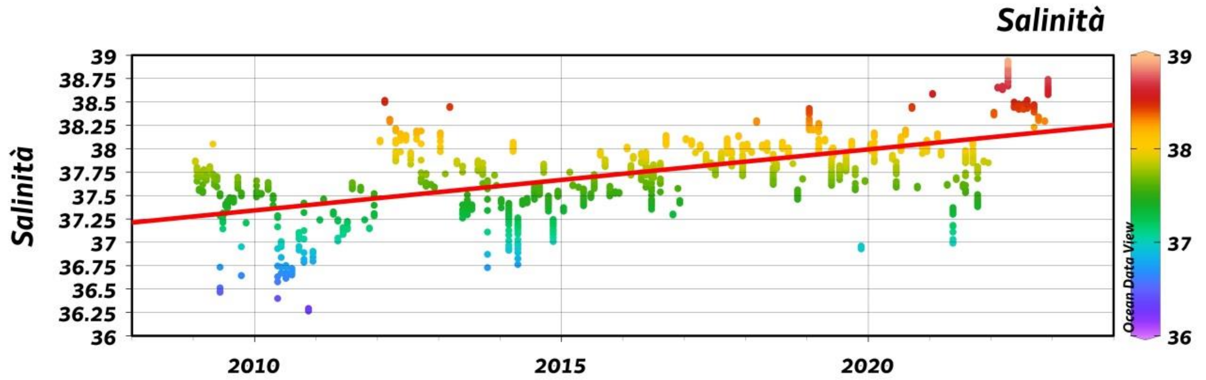
A



SALINITY (N=2481): +0.14/yr (0-5m) – PALOMA (2009-2022)

$r(2479) = .34$, $p < .00001$

B



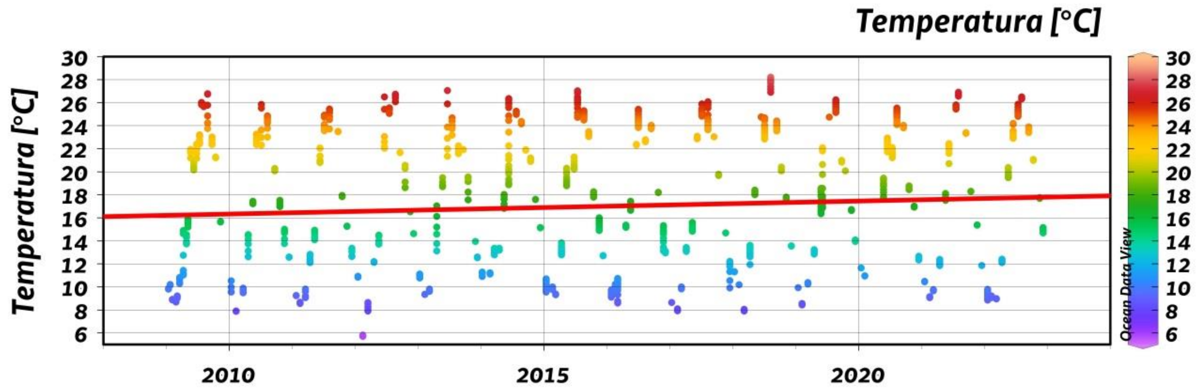
SALINITY (N=3714): +0.07/yr (18-26m) – PALOMA (2009-2022)

$r(3712) = .59$, $p < .00001$

Figure 41. *Salinity trend in station PALOMA at the surface (0-5m) (A) and in the bottom (18-26m) (B). Pearson's* r (Pearson's *Correlation Coefficient) is reported for each trend. Graphic elaborations with Ocean Data View software.*

For seawater temperature, the increase in both atmospheric temperature and surface and deeper layers ocean warming showed in **Figure 37** and **Figure 38**, suggest that the observed warming in offshore waters for the GoT (**Figure 42**) is presumably caused by global warming and subsequent climate change.

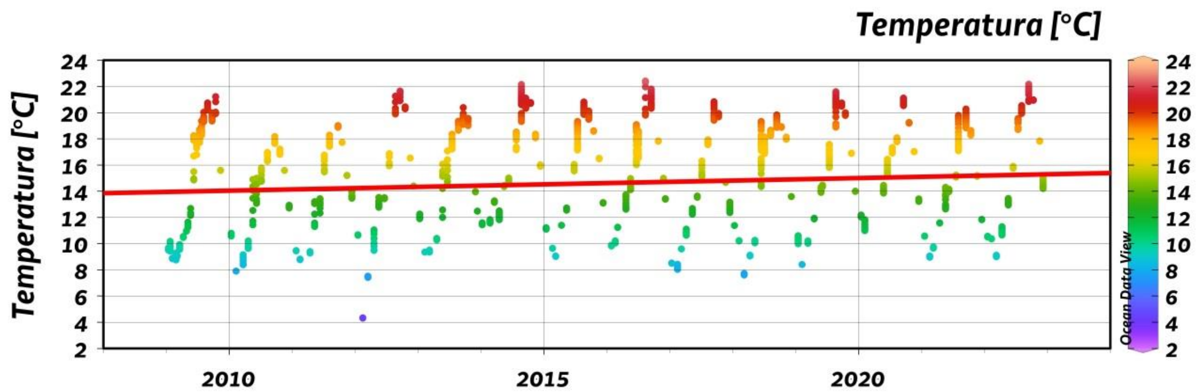
A



TEMPERATURE (N=2505): +0.11°C/yr (0-5m) – PALOMA (2009-2022)

***r*(2503) = .07, *p* = .000422**

B

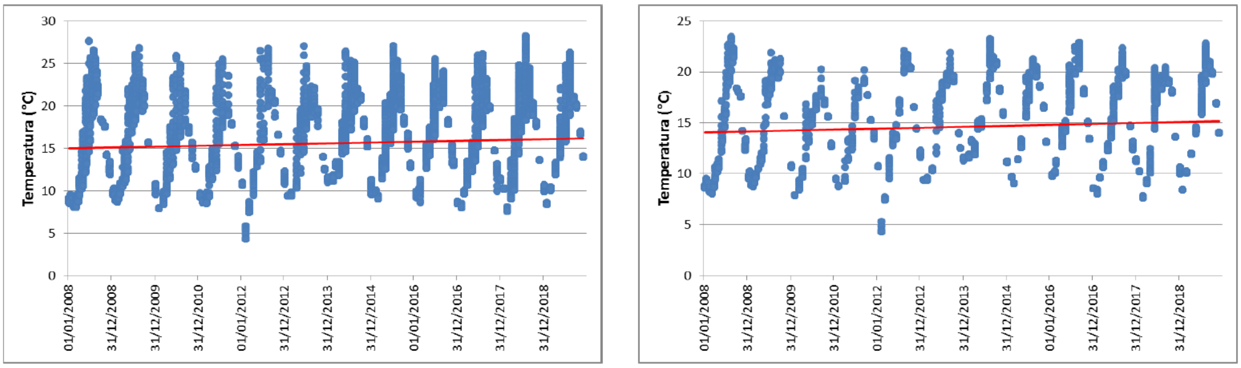


TEMPERATURE (N=3714): +0.10°C/yr (18-26m) – PALOMA (2009-2022)

r(3712) = .09, p < .00001

***Figure 42**. Temperature trend in station PALOMA at the surface (0-5m) (A) and in the bottom (18-26m) (B). Pearson's* r (Pearson's *Correlation Coefficient) is reported for each trend. Graphic elaborations with Ocean Data View software.*

A previous analysis of a time series conducted from 2008 to 2019 (ARPA FVG 2020) by the Marine-Coastal Water Group of ARPA FVG showed a significant temperature increase (at $p < .01$) of 0.10°C/year in the water column (0-25 m) and 0.09°C/year in the deeper layer (15-25 m) (**Figure 43**).



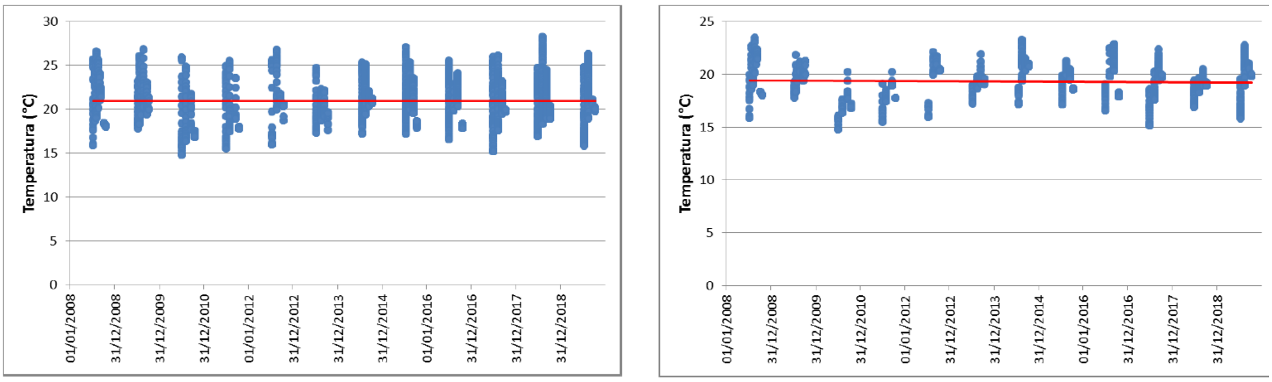
WATER COLUMN (0-25m) TEMPERATURE

+0.10°C/yr – PALOMA (2008-2019)

BOTTOM (15-25m) TEMPERATURE

+0.09°C/yr – PALOMA (2008-2019)

Figure 43*. Temperature increase in the water column (L) and lower layer (R) at PALOMA station in the 2008-2019 time series (From:* ARPA FVG 2020*).*



WATER COLUMN (0-25m) TEMPERATURE

JUL-AUG-SEP-OCT

no trend

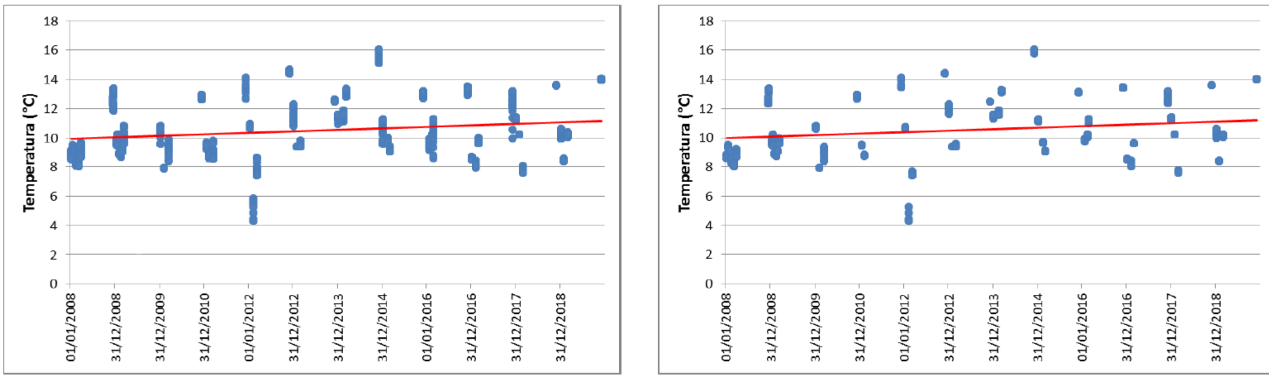
BOTTOM (15-25m) TEMPERATURE

JUL-AUG-SEP-OCT

no trend

Figure 44*. Temperature increase in the water column (L) and lower layer (R) at PALOMA station in the 2008-2019 in summer-early autumn time series (From:* ARPA FVG 2020*).*

The most interesting aspect concerns the seasonality of the temperature increase, since in summer-early autumn (from July to October) there is no significant trend, both for the surface layer and the lower layer (**Figure 44**). On the other hand, winter (from December to March) is the season when a significant temperature increase is observed (at p < .01), amounting to 0.11°C/year in the water column (0-25 m) and 0.10°C/year at the depth of 15-25 meters (**Figure 45**). These trends could lead to an increase of 1°C in a decade and 10°C in a century.



WATER COLUMN (0-25m) TEMPERATURE

DEC-JAN-FEB-MAR

+0.11°C/yr – PALOMA (2008-2019)

BOTTOM (15-25m) TEMPERATURE

DEC-JAN-FEB-MAR

+0.10°C/yr – PALOMA (2008-2019)

Figure 45*. Temperature increase in the water column (L) and lower layer (R) at PALOMA station in the 2008-2019 time series (From:* ARPA FVG 2020*).*

Reyes Suàrez et al. (2022) also considered a dataset (2008-2020) from ARPA FVG measurements, collected on monthly or bi-monthly basis at PALOMA station, in their analysis on *Rhizostoma pulmo* bloom occurred in April 2021 in the GoT. They found that the positive linear trends found in winter and spring (slopes equal to 0.10 and 0.09°C yr^{-1}, respectively) are statistically significant (*p* values < .05). In contrast, the linear regression calculated for summer and autumn is not statistically significant (**Figure 46**, **Figure 47**).

	Slope (°C yr^{-1})	Standard error	p value	R^2
Winter	0.1042	0.0148	1.4572×10^{-11}	0.1460
Spring	0.0935	0.0263	0.0005	0.0415
Summer	0.0071	0.0331	0.8297	0.0002
Autumn	0.0232	0.0168	0.1695	0.0070

Figure 46*. Linear regression statistics for GoT temperature data collected by ARPA FVG in the time series 2008-2020 (From: Reyes Suàrez et al. 2022).*

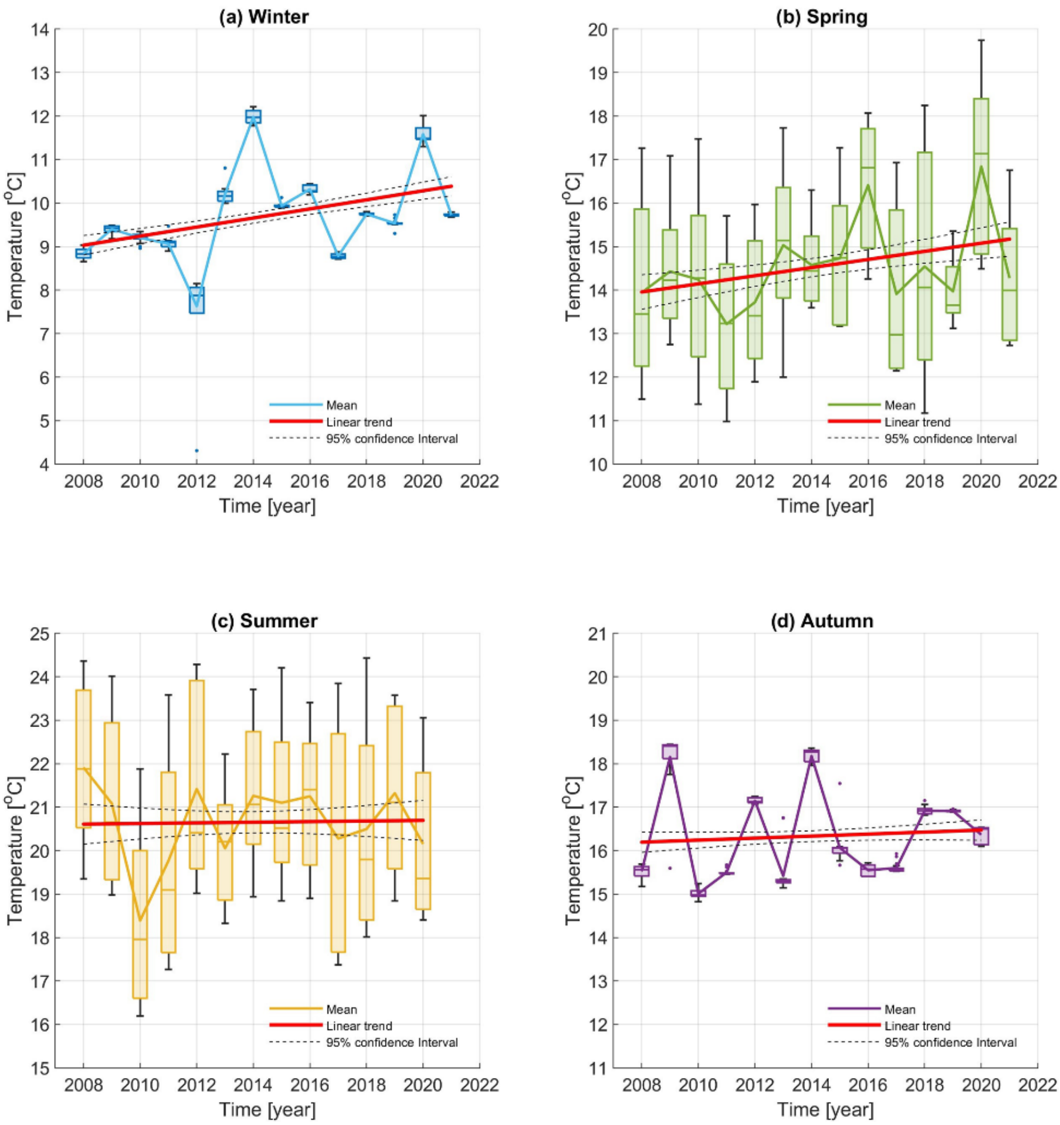


***Figure 47**. Box plot of seasonal temperature time series from CTD casts performed at the Paloma site in the centre of the Gulf of Trieste. Blue = winter (a), green = spring (b), yellow = summer (c) and purple = autumn season (d). Horizontal lines inside the boxes = median for each year and season, whiskers = max and min values, dots = outliers. Solid blue, green, yellow and purple lines represent the average values of each seasonal time series. Red lines depict the linear trend for each season. Dashed black lines represent the 95 % confidence interval (From: Reyes Suàrez et al. 2022).*

These results are in contrast with those obtained from a time series (1991-2003) analysis performed by Malačič et al. (2006) and may indicate that the increase in sea temperatures for the winter months has occurred mainly in the last 10 years. On the contrary, the increase affecting the summer months, may probably have been in an active phase during 1991-2003 and currently be in stasis (ARPA FVG 2020).

This suggests that the waters of the GoT, as a consequence of the basin's geographical and bathymetric conformation and the atmospheric forcing acting on them, are particularly sensitive to climate change. Therefore, climate change could occur in different ways and at different times from the rest of the Mediterranean, highlighting to a greater or lesser extent the ongoing global warming processes.

In conclusion, due to the location in the center of the GoT and the depth of the seafloor in which it is located, the evolution of oceanographic characteristics of the waters off the GoTS has been studied since 2008 at the PALOMA station. Because the GoT exhibits pronounced seasonal variability, this site is well suitable for studying seasonal variations in offshore waters.

In fact, the summer season corresponds to marked stratification of the water column, while in winter there is a homogeneous water column due to both convective mixing and mechanical mixing by wave motion. In addition, the circulation of water masses at depth is almost always counterclockwise with very low velocities (2-3 cm/s), while at the surface the waters generally move clockwise[64].

For all these reasons, the data collected at the PALOMA station are used by CNR-ISMAR and ARPA FVG for the study and monitoring of climate change. Not coincidentally, the PALOMA station is part of the Italian Fixed Point Observatory Network (IFON), a national multidisciplinary, high temporal resolution system for monitoring coastal and deep-water environments[65].

MOLO FRATELLI BANDIERA INSHORE MONITORING STATION

The Molo Fratelli Bandiera station well represents the coastal waters of the GoT and showed anomalous temperature values in January 2023 (**Figure 40**.

In fact, over the whole month, temperatures averaged higher than the reference average (months of January from 1996 to 2022) with peaks of even more than 3 degree difference (days of January 19 and 20). The difference between the January daily average and the reference average has narrowed to about one degree more only since Jan. 26 (**Figure 48**).

This anomaly can be explained considering the upwelling and the accumulation of heat during the summer season by water masses, including those offshore.

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64 http://cmsarpa.regione.fvg.it/cms/tema/acqua/acque-marino-costiere-e-lagunari/approfondimenti/schede/Misure-idrologiche-in-prossimit-della-meda-Paloma.html

65 CNR (2017). *La rete scientifica italiana di siti fissi per l'osservazione del mare – IFON Stato dell'arte e upgrades durante il Progetto RITMARE* (2012 – 2016). Edited by Ravaioli M, Bergami C, Riminucci F. Roma, CNR Pubblicazioni, pp. 50, ISBN 978-88-80802-44-0 (online).

Typically, when the most significant atmospheric disturbances occur (mid/late April-mid/late November) the water masses in the GoT exhibit a negative temperature gradient between surface and bottom, i.e. warmer surface waters and colder deep waters.

During strong Bora events the water in the surface layer is removed offshore (westward), thus inducing a pressure gradient which generates a compensating eastward bottom countercurrent. This, in turn, induces upwelling and mixing along the eastern coastal area of the GoT to maintain the mass balance (Reyes Suàrez et al. 2022).

In autumn (mid-November-mid/late December), in addition to mechanical mixing and convective motion, there is a heat transfer to the atmosphere by the surface layer of water. Therefore, the surface layer gradually cools down, while the sub-surface and deep layers warm up due to heat accumulation during the summer.

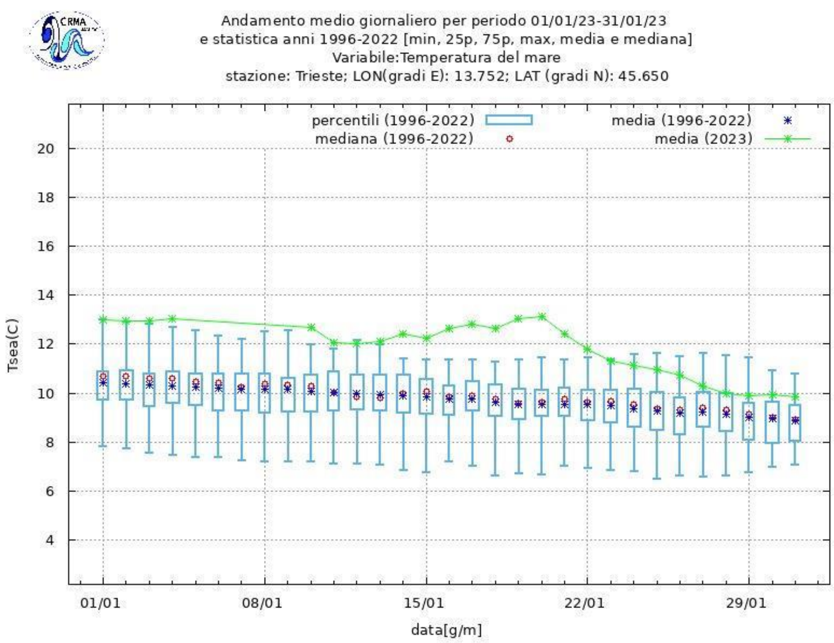


***Figure 48**. Average daily temperatures recorded at the Molo Fratelli Bandiera station in January 2023.*

In this situation, the upwelling associated with the Bora will draw deeper but warmer than surface water masses toward the coast. These deeper and warmer water masses will undergo mechanical and convective mixing, reaching the surface. As a final effect, an increase in the surface temperature of coastal waters will be observed.

Gradually, with the Bora still blowing, the surface layer will get colder. This, from January to March, will result in the GoT water masses being thermally homogeneous. In contrast, in January 2023 the water masses were still stratified, probably due to the high summer temperatures that led to heavy heat accumulation in the deeper layers of the offshore water masses.

Figure 49 shows temperature surface anomalies (B) in two ARPA FVG station (A). It can be observed that the sub-surface and deep layers temperature is higher than that of the surface, especially at MA213, which is probably more affected by the Bora cooling effect at the surface because of its location closer to the coast. Temperature profiles (B) were realised from data collected with a multi-parametric probe (CTD) during the monthly marine-coastal water monitoring campaign by ARPA FVG on January 11 and 13, 2023.

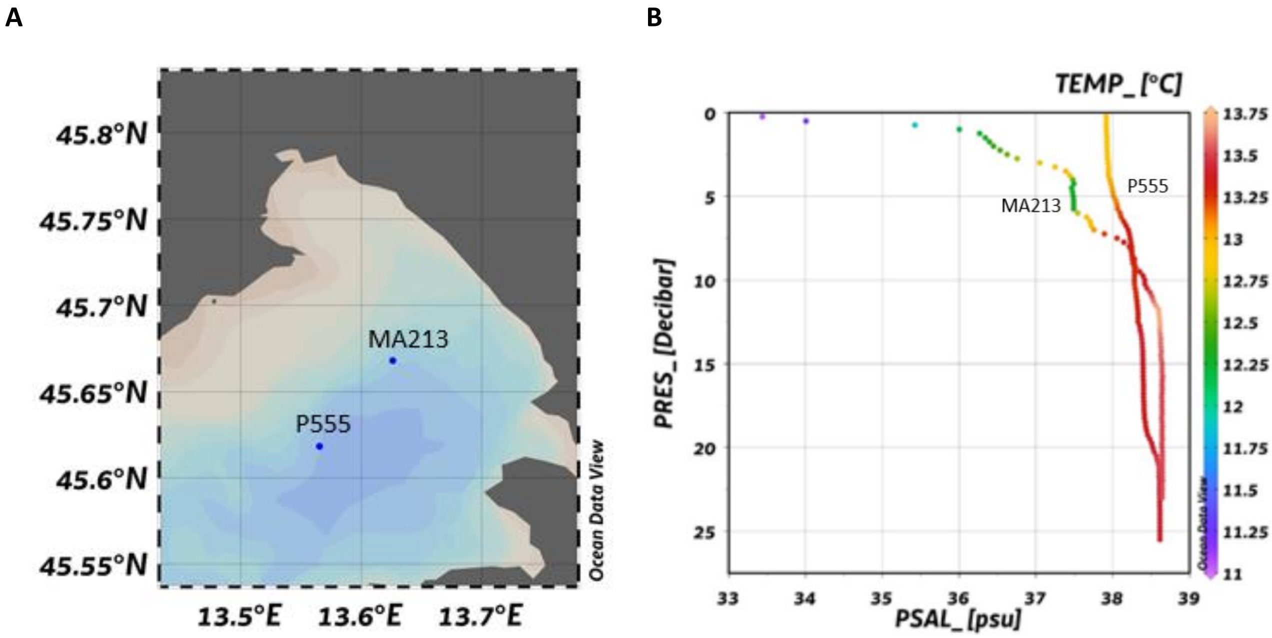


Figure 49. Anomalies in surface temperature (B) in two station (A) (P555, MA213) in the GoT. Graphic elaborations with Ocean Data View software.

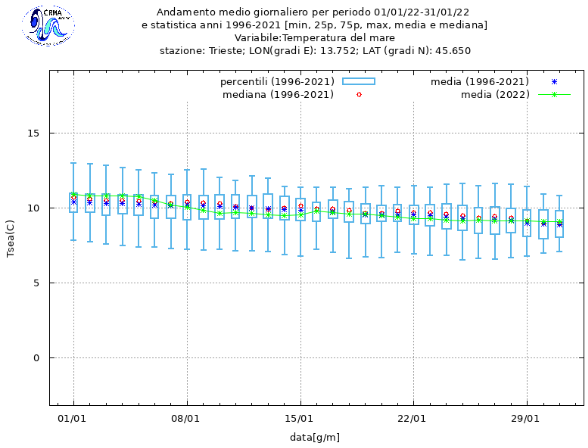
The average temperature of the GoT at 5 m from the bottom was of 13.3±0.4°C in January 2023, while the average temperature at the same depth and period was of 10.3±1.2°C for the 2014-2022 time series.

To compare different years, in **Figure 50** are reported the value referred to January 2022 (A), 2021 (B), 2020 (C) and 2019 (D). It can be observed that the Molo Fratelli Bandiera was characterised by similar event in 2021 with an increase in sea surface temperature in the first half of the month, probably due to the Bora.

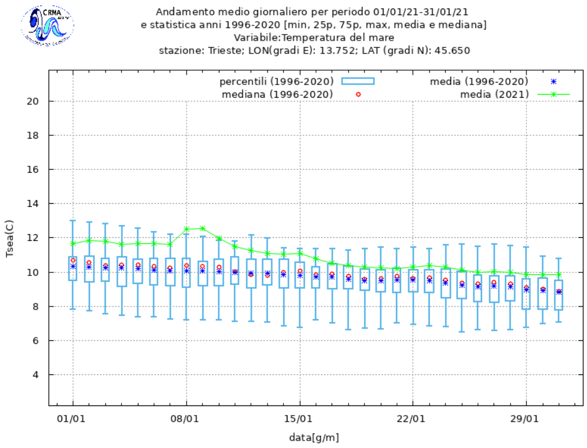
On the contrary, in 2022, 2020 and 2019 no particular events of warmer coastal surface waters occurred, but in January 2022 and 2019 the average daily temperature was similar to the reference value, while in 2020 the difference between the two averages was more pronounced. According to

NASA-Global Climate Change[66], the 2020 statistically tied with 2016 as the hottest year on record. This demonstrates how the effects of global climate change are also visible on a local scale.

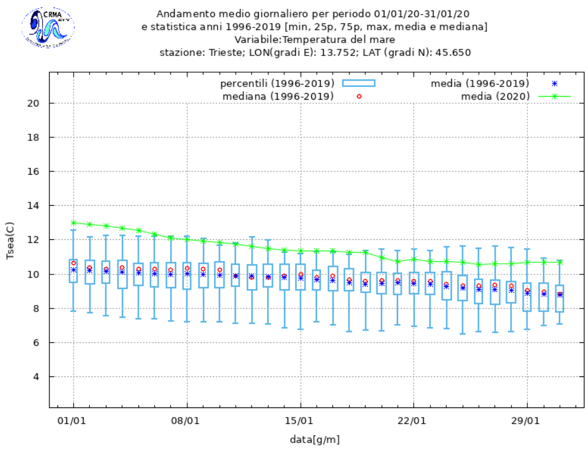
A) 2022



B) 2021



C) 2020



D) 2019

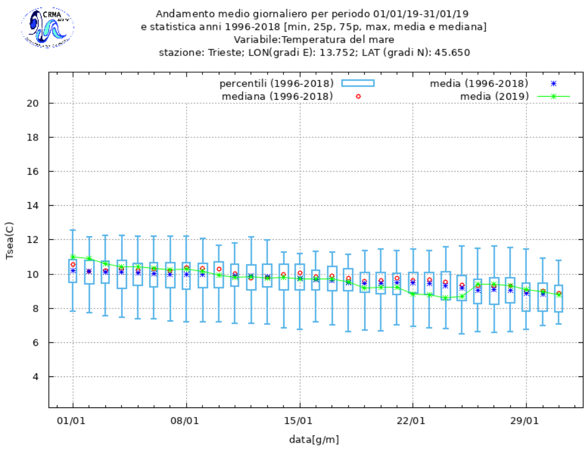


Figure 50. *Average daily tempearature in January in 2022 (A), 2021 (B), 2020 (C) and 2019 (D).*

66 [NASA Global Climate Change – Vital Signs of the Planet]()

RHIZOSTOMA PULMO BLOOMS

Figure 51*. An individual of* Rhizostoma pulmo *photographed in the MPA Miramare (From: https://www.ampmiramare.it/amp/immagini/).*

The scyphomedusa *Rhizostoma pulmo* (Macri, 1778) (**Figure 51**) is widely distributed in the Mediterranean Sea, where represents one of the largest and most abundant jellyfish (Fuentes et al. 2011)[67], observed mainly in coastal areas and lagoons. In the GoT this species is present throughout the year, while in the central and southern Adriatic the barrel jellyfish is usually present from summer to fall.

According to Faleh et al. (2017)[68], the Northern Adriatic hosts one of three distinct populations of *R. pulmo* identified in the Mediterranean, whose adaptation to one of the colder areas of the basin has yet to be elucidated.

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[67] Fuentes V, Straehler-Pohl I, Atienza D, Franco I, Tilves U, Gentile M, Acevedo M, Olariaga A & Gili JM (2011). *Life cycle of the jellyfish Rhizostoma pulmo (Scyphozoa: Rhizostomeae) and its distribution, seasonality and interannual variability along the Catalan coast and the Mar Menor (Spain, NW Mediterranean)*. Mar. Biol., 158, 2247–2266. DOI: https://doi.org/10.1007/s00227-011-1730-7.

[68] Faleh AB, Allaya H, Armani A & Shahin A (2017). *Significant genetic differentiation among meroplanktonic barrel jellyfish Rhizostoma pulmo (Cnidaria: Scyphozoa) in the Mediterranean Sea*. Afr. J. Mar. Sci., 39, 1–8. DOI: https://doi.org/10.2989/1814232X.2017.1303395.

R. pulmo is observed in the Adriatic Sea during the winter season at temperatures often below 10°C. This indicates that the Adriatic population has a wider thermal niche than populations in the rest of the Mediterranean (Reyes Suàrez et al. 2022). In fact, according to their study, Leoni et al. (2021a)[69] set the thermal window of *R. pulmo* in the Mediterranean between 15 and 22°C (or between 13 and 29°C based on local-scale observations).

As for GoT, exceptional blooms of barrel jellyfish were recorded in April 2021[70] and 2022 (ARPA FVG 2022e)[71], reaching a density of more than 10 ind/m^2 in some areas (Reyes Suàrez et al. 2022), with many large individuals (adults) (**Figure 52**).

Figure 52. R. pulmo *aggregation along the Trieste coast in April 2021 (photo by ARPA FVG)*

Reyes Suàrez et al. (2022) showed how hydrologic and oceanographic properties of the water column, meteorological conditions and sea temperature seasonality might have influenced jellyfish aggregation on the Trieste and Grado coasts.

In fact, due to wind action, water was pushed westward in the surface layer, causing it to move away from the shoreline (**Figure 53** a, b, c). As a result, an eastward compensatory countercurrent formed in the lower layer (**Figure 53** d, e, f). It is well known that the bora wind pushes water out of

[69] Leoni V, Molinero JC, Meffre M & Bonnet D (2021a*). Variability of growth rates and thermohaline niches of Rhizostoma pulmo's pelagic stages (Cnidaria: Scyphozoa).* Mar. Biol., 168, 107. DOI: https://doi.org/10.1007/s00227-021-03914-y.
[70] ARPA FVG (2021). *Bollettino sullo "Stato oceanografico ed ecologico del Golfo di Trieste" - Aprile 2021*.
[71] ARPA FVG (2022e). *Bollettino mensile stato oceanografico ed ecologico del Golfo di Trieste – Aprile 2022*. Edited by SOS Qualità delle acque marine e di transizione, 8 pp.

the GoT at the surface, particularly under low runoff conditions in the Isonzo River (Querin et al. 2006)[72], as occurred in spring 2021 and 2022.

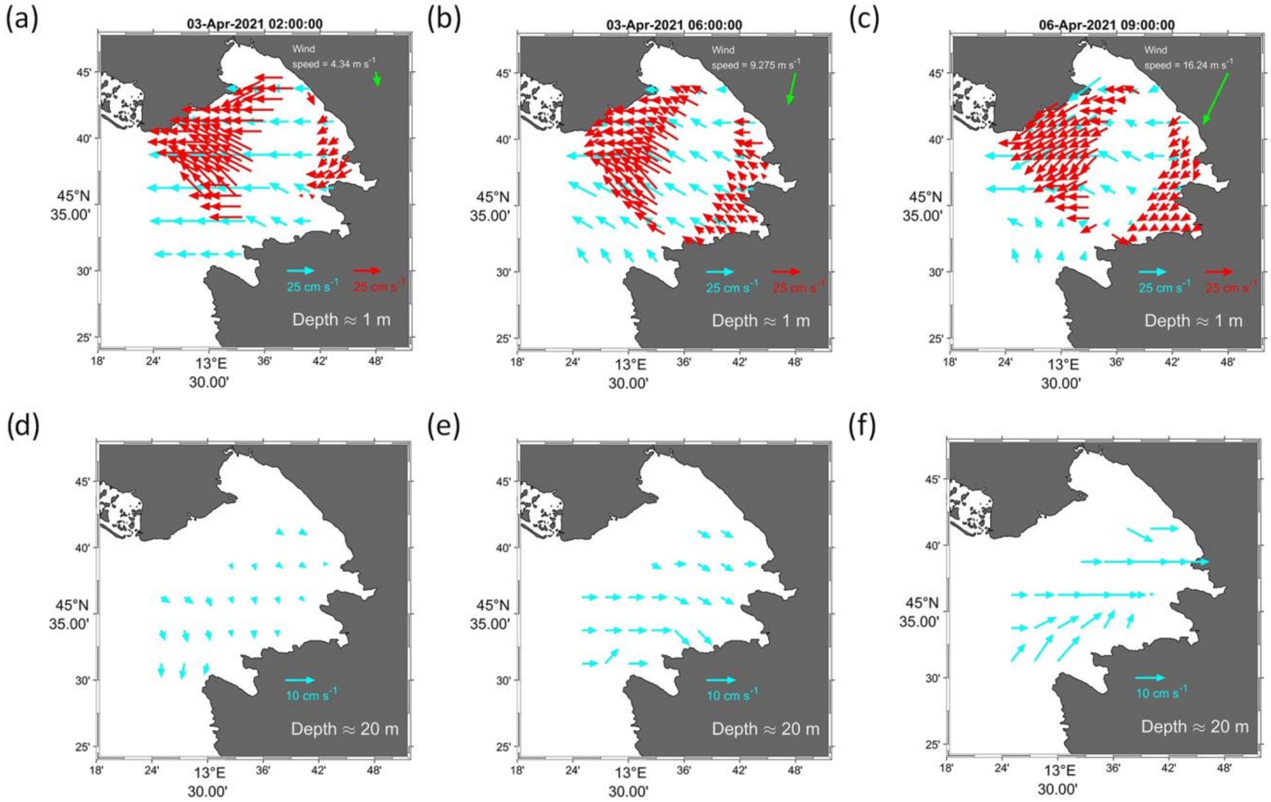

Figure 53*. A-B-C: maps of surface currents at ~1 m from two different models (blue and red arrows); D-E-F: maps of bottom currents at ~20 m from one model (blue arrows), at different hours and days (A and D= 03/04/2021, 02:00 UTC; B and E = 03/04/2021, 06:00; C and F =06/04/2021, 09:00 UTC). Green arrows = wind speed in metres per second (m s−1) (From: Reyes Suàrez et al. 2022).*

To balance the shift in water mass, water from the lower layer is pumped up vertically, increasing upwelling on the eastern side of the gulf and replacing surface water that had been pushed away. During this process, sub-surface water masses are pushed inward and the countercurrent is set up in the deeper layers (Malačič & Petelin 2009; Querin et al. 2006, 2021)[73,74].

[72] Querin S, Crise A, Deponte D & Solidoro C (2006). *Numerical study of the role of wind forcing and freshwater buoyancy input on the circulation in a shallow embayment (Gulf of Trieste, Northern Adriatic Sea)*. J. Geophys. Res.-Oceans, 111, C03S16. DOI: https://doi.org/10.1029/2006JC003611.
[73] Malačič V & Petelin B (2009). *Climatic circulation in the Gulf of Trieste (northern Adriatic).* J. Geophys. Res.-Oceans, 114, C07002. DOI: https://doi.org/10.1029/2008JC004904.
[74] Querin S, Cosoli S, Gerin R, Laurent C, Malačič V, Pristov N and Poulain PM (2021). *Multi-Platform, High-Resolution Study of a Complex Coastal System: The TOSCA Experiment in the Gulf of Trieste*. J. Mar. Sci. Eng., 9, 469. DOI: https://doi.org/10.3390/jmse9050469.

Intense aggregations of barrel jellyfish were observed in both Grado and Trieste thanks to the Bora–countercurrent–upwelling mechanism. In fact, while the Bora moved the eastern surface waters of the Gulf westward, bringing many jellyfish to the coast of Grado, it simultaneously pushed the deeper waters upward and subsequently transported them toward the coast, thanks to the countercurrents' contrary action. Because of this movement, jellyfish then accumulated on the shores of the city of Trieste (Reyes Suàrez et al. 2022).

Although jellyfish of the genus Rhizostoma cannot be considered fully drifting, it is unlikely that *R. pulmo* could have actively swum against the strong current generated by the action of the wind (> 0.25 m s^{-1} at the surface and > 0.15 m s^{-1} at the bottom). Therefore, Reyes Suàrez et al. (2022) suggest that, thanks to the countercurrent, the upwelling that occurred in the eastern part of the GoT caused the numerous jellyfish present in the deep layers of the water mass to gather towards the coast of the city of Trieste.

In addition, there is also an influence by temperature. According to Leoni et al. (2021b)[75] during 2008-2018, spring temperatures in the Mediterranean Sea were found to be significantly correlated with the onset and duration of the season of *R. pulmo* (defined as the first and last observations of the species in a given area).

Since in the Adriatic Sea, *R. pulmo* showed an early presence during the warm spring, and the bloom duration was also positively correlated with winter SST (Leoni et al. 2021b), this supports the possibility that the increase in abundance of this jellyfish is correlated with increasing temperatures in this region.

Therefore, warmer springs could cause *R. pulmo* to appear earlier and anticipate strobilation activity more intensely and for a longer period of time (Purcell et al. 2012)[76]. In addition, warmer winters could promote polyps survival and lead adult stages to last longer (Boero et al. 2016)[77].

In this context, data collected with the multi-parametric sonde CTD (**Figure 47**) also support this hypothesis in the GoT, where the spring and winter preceding the April 2021 bloom were warmer than the same seasons in the previous 4 years (**Figure 47 A-B**). In addition, most of the jellyfish sighted were very large individuals, probably overwintering specimens born in 2020.

[75] Leoni V, Bonnet D, Ramírez-Romero E & Molinero JC (2021b). *Biogeography and phenology of the jellyfish Rhizostoma pulmo (Cnidaria: Scyphozoa) in southern European seas*. Global Ecol. Biogeogr., 30, 622–639. DOI: https://doi.org/10.1111/geb.13241.
[76] Purcell JE, Atienza D, Fuentes V, Olariaga A, Tilves U, Colahan C & Gili JM (2012). *Temperature effects on asexual reproduction rates of scyphozoan species from the northwest Mediterranean Sea*, in: Purcell J, Mianzan H & Frost JR. *Jellyfish Blooms IV: Interactions with humans and fisheries*. Springer Netherlands, Dordrecht, 169–180. DOI: https://doi.org/10.1007/978-94-007-5316-7_13.
[77] Boero F, Brotz L, Gibbons MJ, Piraino S & Zampardi S (2016). *3.10 Impacts and effects of ocean warming on jellyfish, Explaining ocean warming: Causes, scale, effects and consequences*. IUCN Gland, Switzerland, 213–237, 2016.

Observations of *R. pulmo* in the GoT are consistent with increasing blooms in recent decades (Kogovšek et al. 2010, Pierson et al. 2020, Pestorić et al. 2021)[78, 79, 80]. At the same time, being one of the coldest areas in the Mediterranean, the intense blooms in the GoT represent an exception to the latitudinal temperature gradient.

This, in fact, contrasts with the results of Leoni et al. (2021b) which found that the long-term intensity of the bloom and the biogeographic pattern of the species are determined primarily by a latitudinal temperature gradient, in which northern sites (low temperatures) showed the least intense bloom events, while southern sites (high temperatures) showed the most intense ones.

In conclusion, the mechanism that led to the massive aggregation of *R. pulmo* along the coasts of Grado and Trieste (Bora–countercurrent–upwelling), is the same as seen previously in the description of the coastal sea surface temperature anomaly (see MOLO FRATELLI BANDIERA INSHORE MONITORING STATION), associated with rising temperatures in usually cold seasons. Thus, high temperatures occurring in summer, which lead to heat accumulation by water masses in winter, coupled with warmer temperatures in winter and spring can lead to different impacts. These can be considered extreme events in their own right, in which climate change manifests itself through both physical and biological impacts.

4.5 – Sea climate change: projections

Thanks to WP3 activities, ARPA FVG, as AdriaClim project partner, had the opportunity to enhance climate change monitoring capacity building. Indeed, for Pilot Site 1 (PS1), several activities have been carried out to implement observation and modelling systems focused on coastal and marine areas, and many high spatial resolution climate sensitivity tests have been conducted at the local scale.

In the following paragraphs are shown the climate elaborations developed by ARPA FVG in the PS1 in the context of AdriaClim activities.

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[78] Kogovšek T, Bogunović B & Malej A (2010). *Recurrence of bloom-forming scyphomedusae: wavelet analysis of a 200-year time series*. Springer Netherlands, Dordrecht, 81–96. DOI: https://doi.org/10.1007/978-90-481-9541-1_7.

[79] Pierson J, Camatti E, Hood R, Kogovšek T, Lučić D, Tirelli V & Malej A (2020). *Mesozooplankton and Gelatinous Zooplankton in the Face of Environmental Stressors*, in: *Coastal Ecosystems in Transition: A Comparative Analysis of the Northern Adriatic and Chesapeake Bay*. Edited by Malone T, Malej A & Faganeli J. Chap. 6, American Geophysical Union (AGU), Wiley & Sons Ltd, Geophys. Monogr., 105–127. DOI: https://doi.org/10.1002/9781119543626.ch6.

[80] Pestorić B, Lučić D, Bojanić N, Vodopivec M, Kogovšek T, Violić I, Paliaga P & Malej A (2021). *Scyphomedusae and Ctenophora of the Eastern Adriatic: Historical Overview and New Data*. Diversity, 13, 186. DOI: https://doi.org/10.3390/d13050186.

SHYFEM model and sensitivity tests

As described in D3.2.1-*Summary description of modelling systems and results*, a very high-resolution coastal integrated model has been set-up in the PS1. The Pilot Site includes the Marano-Grado Lagoon, the Gulf of Trieste and a large portion of open sea, whose boundaries at the coast are the town of Eraclea (Veneto) to the north-west and the town of Poreč to the south. The choices that led to the selection of the Pilot Site for FVG have already been described in Chapter 3 – FVG Pilot Site identification

As regards modelling activities, SHYFEM (Shallow water HYdrodynamic Finite Element Model) is the finite element, 3D numerical model used. It has been developed at CNR-ISMAR (Umgiesser et al. 2004)[81] and already successfully applied to several coastal environments[82]. It is especially suitable to domains characterised by complicated morphology and bathymetry, thanks to the spatial discretization method with which it was conceived. The model applies well in shallow water conditions, such as lagoons, coastal seas, estuaries and lakes.

Thanks to its fine spatial resolution, from a few kilometres in the open sea to about ten metres in lagoon channels, SHYFEM allows regional or sub-regional information to be transferred to a local scale, according to a downscaling process. This makes it possible to implement knowledge on the physical state of the sea and on physical phenomena at local level, such as currents, storm surges and salt wedge intrusion. Furthermore, as far as model inputs are concerned, SHYFEM is highly and simply customisable by setting input parameter files according to one's needs.

In this perspective, within the AdriaClim project context, the question was how the Gulf of Trieste and the lagoon of Marano and Grado will respond to climate variability, from a physical-oceanographic point of view. To answer the question, sensitivity tests has been conducted using the SHYFEM model (**Figure 54**).

Basically, in a sensitivity test, the so-called "boundary conditions" (the conditions defined at the open boundaries of a domain for the entire duration of the simulation) and meteorological forcing are changed. The aim is to observe how the output values of the variables (e.g. temperature) change compared to the benchmark (the unperturbed simulation taken as a reference).

In more detail, as a first step, the benchmark was carried out for an entire year in the past (2018). Inputs have included marine, meteorological and hydrological data. Among these inputs, only some of them were perturbed according to three RCPs (2.6, 4.5 and 8.5): (*i*) air temperature and specific humidity; (*ii*) mean sea level, salinity and sea temperature; (*iii*) certain river discharges at the mouth.

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[81] Umgiesser G, Canu DM, Cucco A & Solidoro C (2004). *A finite element model for the Venice Lagoon. Development, set up, calibration and validation*. Journal of Marine Systems,51(1-4), 123-145. DOI: https://doi.org/10.1016/j.jmarsys.2004.05.009

[82] https://sites.google.com/site/shyfem/project-definition visited on March 2023 (website no more available).

Data on climate scenarios used for the perturbation were retrieved in the Med-CORDEX and EURO-CORDEX initiatives (see the *FOCUS BOX* below), for the marine and meteorological part respectively.

Subsequently, as many simulations were ran as the possible combinations of the Med-CORDEX and EURO-CORDEX models used as forcing, in order to obtain an ensemble (a set of simulations describing the same process). These simulations were carried out for some future reference time periods divided into *decades*[83] (2025-2035, 2045-2055, ..., 2085-2095). Each *decade* is represented by one year of simulation with hourly resolution, which is the perturbed benchmark with boundary conditions defined through the Med-CORDEX and EURO-CORDEX anomalies of the future *decade* with respect to the reference *decade* (**Figure 55**), which was chosen 2010-2020.

Specifically, an hourly dataset representative of the *decade* was obtained for each monitored point, according to the considered RCP (2 for RCP2.6, 4 each for RCP4.5 and RCP8.5). Finally, results were collected in relative terms, i.e. as differences compared to the benchmark (2018) (**Figure 55**).

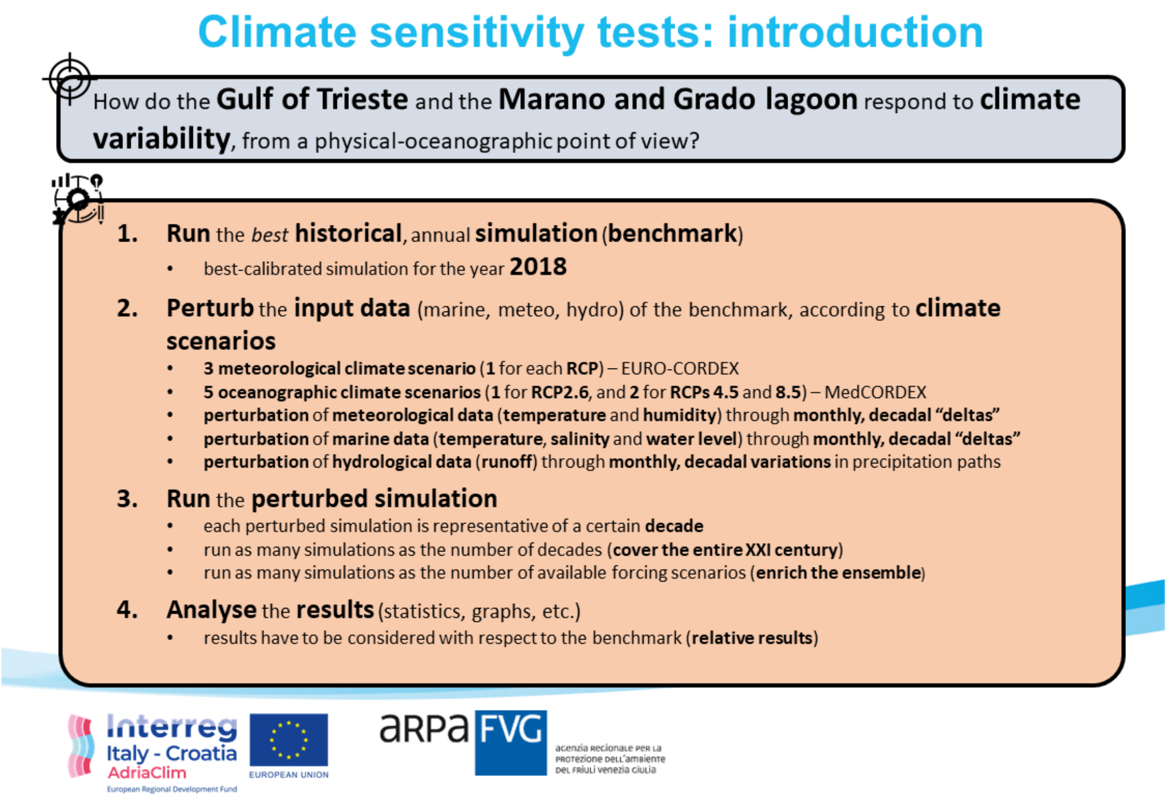


***Figure 54**. Workflow showing the operational steps of sensitivity testing implementation at the pilot site.*

[83] Since the extremes are included, the periods indicated do not consist of ten years (decades), but of eleven.

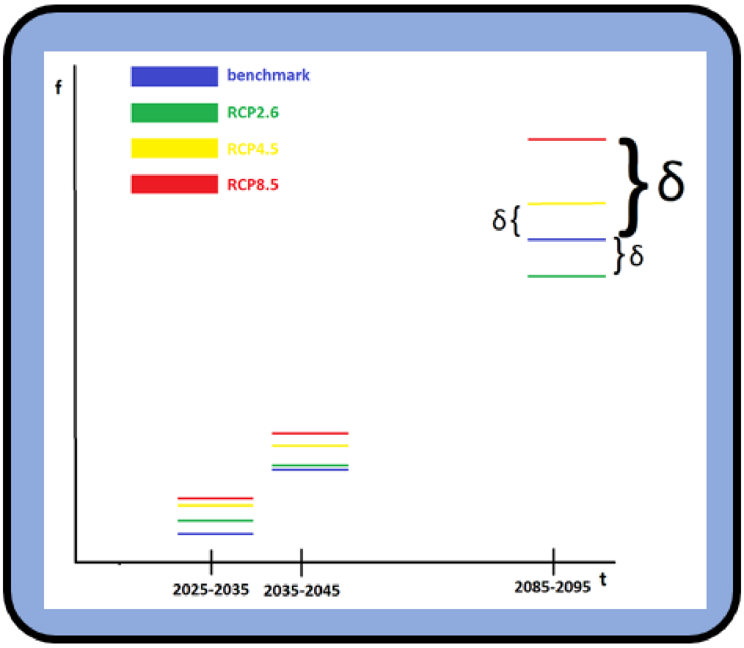


Figure 55*. Graphic representation of differences (δ = delta) with respect to the benchmark (blue) in 3 RCPs (2.6-green, 4.5-yellow, 8.5-red) over the considered decades*

The boxplots in **Figure 56** show, for two of the monitored points in the domain, the result of the perturbation of the inputs with respect to the benchmark, referring to 3 RCPs (2.6-green, 4.5-yellow and 8.5-red). The blue dash in the boxes represents the median temperature value of the ensemble; the dot represents the mean value. The boxes, on the other hand, represent the distribution of temperature values of the ensemble that fall between the 25th and 75th percentiles. More details on the boxplot elements and their significance are illustrated in **Figure 57**.

As far as boxplots are concerned, it must be kept in mind that they represent how conditions at a single point vary over a long period of time. Therefore, to explore how a physical quantity such as temperature varies over a larger area, it is necessary to compare several boxplots, as many as there are points monitored in the domain.

The boxplots refer to a single point in space and they contain a lot of information, such as the position of the mean and median with respect to the ensemble values, as well as the minimum and maximum value for each *decade* and outliers.

Maps, on the other hand, show a snapshot of a single moment over a larger area and, in general, it is only possible to represent one statistical indicator at a time (mean or median, for example). In our case, maps show how a physical quantity, e.g. temperature, may vary across the domain at a specific time compared to 2018 (benchmark). To understand how this physical quantity varies over time in a given area under different climate scenarios, it is therefore necessary to compare several maps, depending on the number of scenarios and *decades* considered.

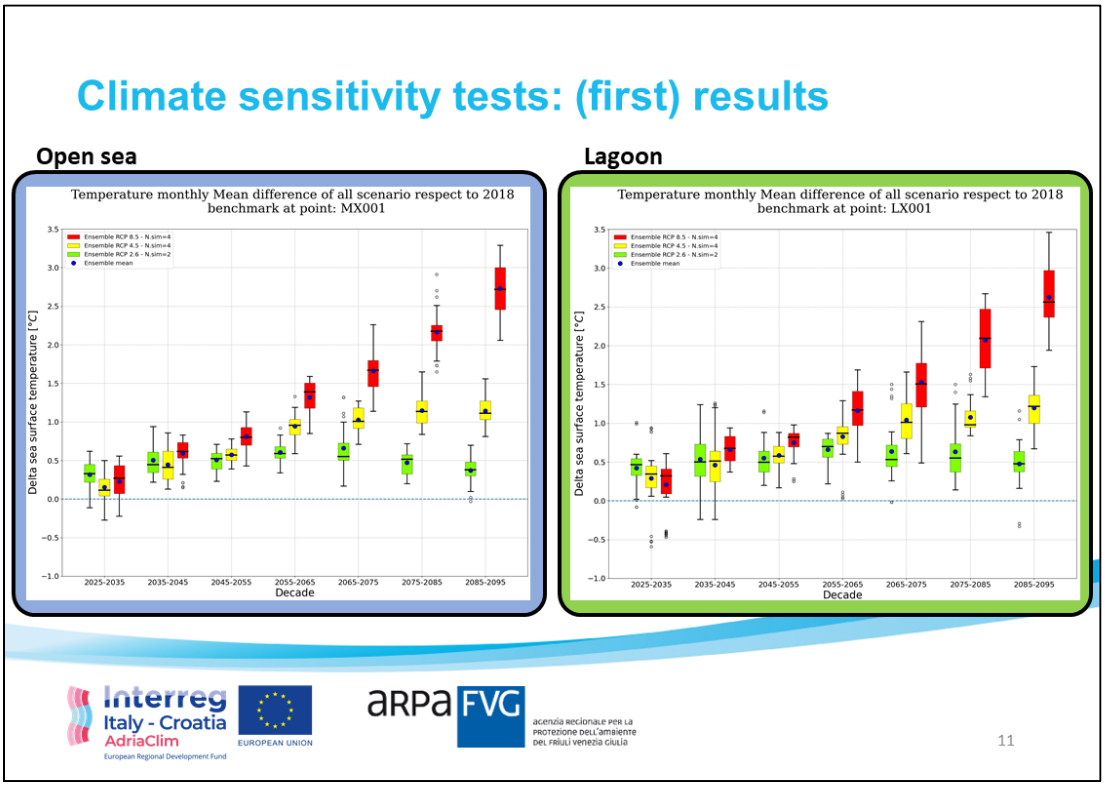


***Figure 56**. Example of climate sensitivity test results for temperature in two monitored points, one in the open sea (left) and one in the lagoon (right). The boxplots were realized starting from the monthly mean differences between the reference scenario in the future decades and the 2018 benchmark. Results have been divided into three subgroups according to the reference RCP (RCP2.6-green, RCP4.5-yellow and RCP8.5-red). On the top left is the number of Med-CORDEX scenarios used to perturb the benchmark.*

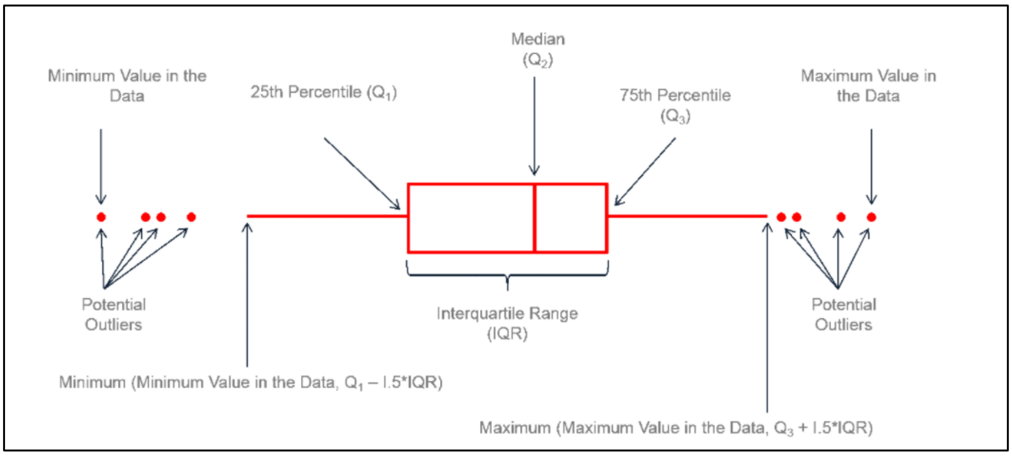


***Figure 57**. Boxplot: elements and meaning.*

To best adapt to climate change, decision-makers and stakeholders must gather all available information on how the climate is changing. Even though the boxplots and maps considered here relate to the variation of the same physical quantity (e.g. temperature) in the same scenarios, domain and time period, they represent different tools for understanding climate variations, taking into account complementary information.

In this regard, more climate simulations are available at http://interreg.c3hpc.exact-lab.it/AdriaClim/, the repository where ARPA FVG has deposited the results of the modelling activities carried out through the AdriaClim project. For the Manual User, refer to D.3.4.1-*Product User Manual*.

FOCUS BOX - Med-CORDEX and EURO-CORDEX initiatives

The Med-CORDEX[84] project concerns climate modelling activities focused on the Mediterranean area. It is part of CORDEX (Coordinated Regional Downscaling Experiment), an international initiative that aims to improve understanding of climate projections on a regional scale. Med-CORDEX uses advanced climate models to analyse climate forecasts over the Mediterranean basin, providing detailed information on future climate trends in this region.

The EURO-CORDEX[85] (Coordinated Downscaling Experiment - European Domain) research project is concerned with the production of regional climate models in Europe, drawing on the collaboration of several European research institutions. As an objective, EURO-CORDEX aims to improve understanding of climate phenomena on a regional scale and provide useful information for climate risk planning and management. Finally, the main objective of EURO-CORDEX is to provide reliable information on climate variability in order to support policy and decision makers in planning actions to address climate change.

Sea Surface Temperature projections

The following paragraphs present a series of digital cartography showing sea surface temperature (SST) variations with respect to the benchmark, under different climate scenarios, depending on the considered *decades* (**Figure 60**-**Figure 68**). These maps are the result of the modelling activities of WP3 and reflect its results and projections. The dataset used in the digital maps comes from downscaling simulations carried out with the SHYFEM model.

[84] https://www.medcordex.eu/
[85] https://www.euro-cordex.net/

The maps were processed in a GIS environment (QGIS software, version 3.26.3). They show the mean value of the simulations ensemble, for each monitored point. Each map corresponds to a specific *decade* and RCP. Other relevant values (min and max) are shown in **Table 16**.

It is worth noting that the following maps show the temperature variation (δ = delta) with respect to the benchmark, namely the value to be added to (or taken away from) the reference (benchmark) value, for that point, RCP and *decade*.

118 SHYFEM grid points (**Figure 58**) were considered, among a total of 18311. For an in-depth analysis on the modelling activities development, please refer to D3.2.1-*Summary description of modelling systems and results*.

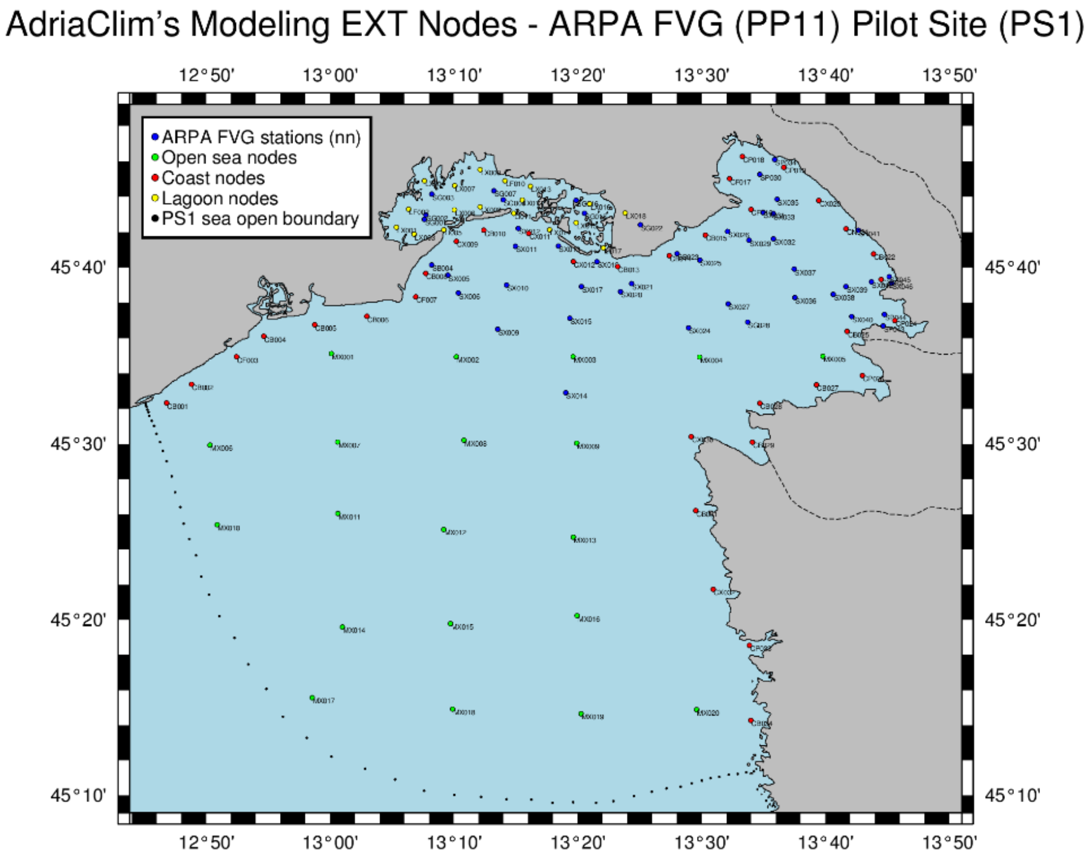


Figure 58. *Domain of the FVG pilot site. The nodes represent the monitored points selected from those in the SHYFEM grid.*

Considering all the monitored points showed in **Figure 58**, the average annual temperature for the benchmark year is:

Benchmark (2018)	mean (°C)	min ÷ max (°C)
Temperature	17.26	16.16 ÷ 18.19

In **Figure 59** are shown the results of the overall sensitivity tests, putting together the 3 considered RCPs. Data are presented as annual mean differences from the benchmark for each considered *decade*. The large dot in the graph represent the mean of the average temperature differences considering all the 118 monitored points in the Pilot Site. For detailed values see **Table 16**, in which statistics for the Pilot Site are reported.

In this case, the average represents a value that summarises the expected temperature increase for that area. The min-max values, instead, represent the range in which the mean value lies. The median value was also calculated, but it is not reported because it is close to the mean.

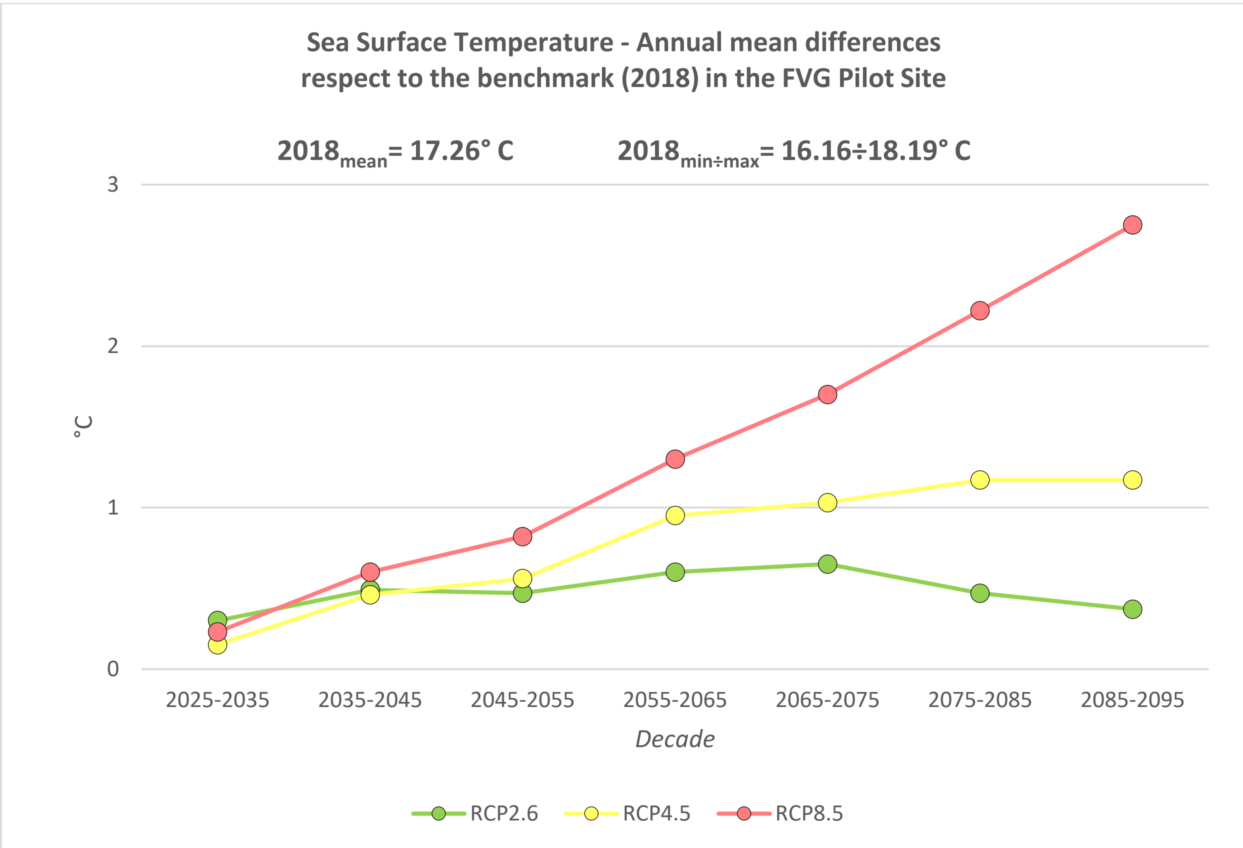


Figure 59*. Sea Surface Temperature - Annual mean differences respect to the benchmark (2018) in the FVG Pilot Site for each considered decade (2030-2090) and RCPs (2.6-green, 4.5 yellow, 8.5-red). Large dot = mean of the average temperature differences considering the 118 monitored points.*

Table 16. Pilot Site mean of the annual average temperature differences from the benchmark for each considered decade and RCP. Pilot Site min ÷ max = minimum and maximum value in the considered dataset.

Decade	Temperature (°C)	Pilot Site mean	Pilot Site min ÷ max
2025-2035	RCP2.6	0.30	0.15 ÷ 0.44
	RCP4.5	0.15	0.00 ÷ 0.33
	RCP8.5	0.23	0.20 ÷ 0.28
2035-2045	RCP2.6	0.49	0.42 ÷ 0.56
	RCP4.5	0.46	0.40 ÷ 0.54
	RCP8.5	0.60	0.52 ÷ 0.70
2045-2055	RCP2.6	0.47	0.38 ÷ 0.57
	RCP4.5	0.56	0.48 ÷ 0.70
	RCP8.5	0.82	0.73 ÷ 0.92
2055-2065	RCP2.6	0.60	0.52 ÷ 0.70
	RCP4.5	0.95	0.79 ÷ 1.05
	RCP8.5	1.30	1.13 ÷ 1.49
2065-2075	RCP2.6	0.65	0.58 ÷ 0.72
	RCP4.5	1.03	0.97 ÷ 1.11
	RCP8.5	1.70	1.48 ÷ 1.92
2075-2085	RCP2.6	0.47	0.35 ÷ 0.65
	RCP4.5	1.17	1.02 ÷ 1.33
	RCP8.5	2.22	2.03 ÷ 2.43
2085-2095	RCP2.6	0.37	0.31 ÷ 0.51
	RCP4.5	1.17	1.12 ÷ 1.32
	RCP8.5	2.75	2.56 ÷ 2.90

Regarding **Figure 59**, it can be seen that temperatures are similar until the 2035-2045 *decade*. This fact can be viewed from two perspectives, depending on whether one considers adaptation or mitigation.

If mitigation is the focus, one has to be aware that the effects of climate-altering gases reduction policies adopted in the present will be seen at least later than two *decades*. Only then it is possible to distinguish among the scenarios which is in progress and if we are pursuing the best or the worst possible RCP. It is therefore crucial to adopt the best possible climate policies, here and now, to stay on the “green line”, i.e. the most ambitious climate scenario (RCP2.6).

Adaptation, on the other hand, raises the question of how to face climate change on our territory. In fact, decisions on adaptation measures must be taken with reference to the present time. For example, in 2030, adaptation measures do not depend on the scenario, as temperature projections give similar results for all considered RCPs in that *decade*. The situation changes from 2050 onwards. In fact, if decisions are to be made on the basis of the temperature at that time, it is possible to define adaptations actions according to the RCP.

Therefore, climate projections comparing different RCPs help policy makers in making decisions.

The values shown in **Table 16** represent an overall average temperature referring to the Pilot Site. The following maps (**Figure 60**, **Figure 68**), on the other hand, show the annual average temperature difference at each monitored point, with respect to the benchmark. In this way, it is possible to appreciate the temperature differences that monitored points have at different locations. To compare 3 different climate scenarios, 3 maps were prepared each, considering the *decades* 2025-2035, 2045-2055 and 2085-2095. These *decades* were chosen because 2025-2035 represents a short-term scenario, temporally close to the present; 2045-2055 a mid-term, mid-century scenario and 2085-2095 a long-term, end-of-century scenario.

Starting from SHYFEM simulations, the annual average temperature was calculated for each point, for each *decade*, for each of the 3 considered RCPs. The average temperature difference with respect to the benchmark is showed for each monitored point in the following maps (**Figure 60**-**Figure 68**).

As can be seen, depending on the climate scenario, the temperatures in the Pilot Site varies over the *decades*. It is important to note that temperature variations in the domain, with regard to a single climate scenario and *decade*, are of the order of a tenth of degree. Indeed, as the values shown in **Table 16** confirm (min-max) the temperature differences for each monitored point do not differ particularly from the overall average for the pilot area, within the same *decade* and climate scenario. It should also be kept in mind that these maps cover the sea surface layer and not the entire water column.

While within a single scenario and *decade*, the temperature difference between the monitored points is low, on the contrary it is considerable comparing the same decade with different RCPs. In fact, comparing the medium-term scenarios (2045-2055) with each other it is possible to see a temperature increase between 0.38 and 0.57°C for the most optimistic scenario (RCP2.6, **Figure 61**), between 0.48 and 0.70°C for the intermediate scenario (RCP4.5, **Figure 64**), to get at a temperature increase over the benchmark between 0.73 and 0.92°C in the "*business as usual scenario*" (RCP 8.5, **Figure 67**), the most pessimistic.

Leaving aside the short-term scenarios (2025-2035), which do not differ substantially from each other (overall, the temperature increase ranges from a minimum of 0 to a maximum of 0.44°C more than the benchmark) (**Figure 60**, **Figure 63**, **Figure 66**), for the end-of-century (2085-2095) scenarios, however, the differences between the three projections are quite marked. While in scenario RCP2.6

the temperature increase over the benchmark remains between 0.51°C and 0.31°C (**Figure 62**), for RCP4.5 the increase exceeds 1°C (**Figure 65**). Finally, the most pessimistic scenario sees a temperature increase of more than 2°C (**Figure 68**) over the 2018 annual average in the considered area.

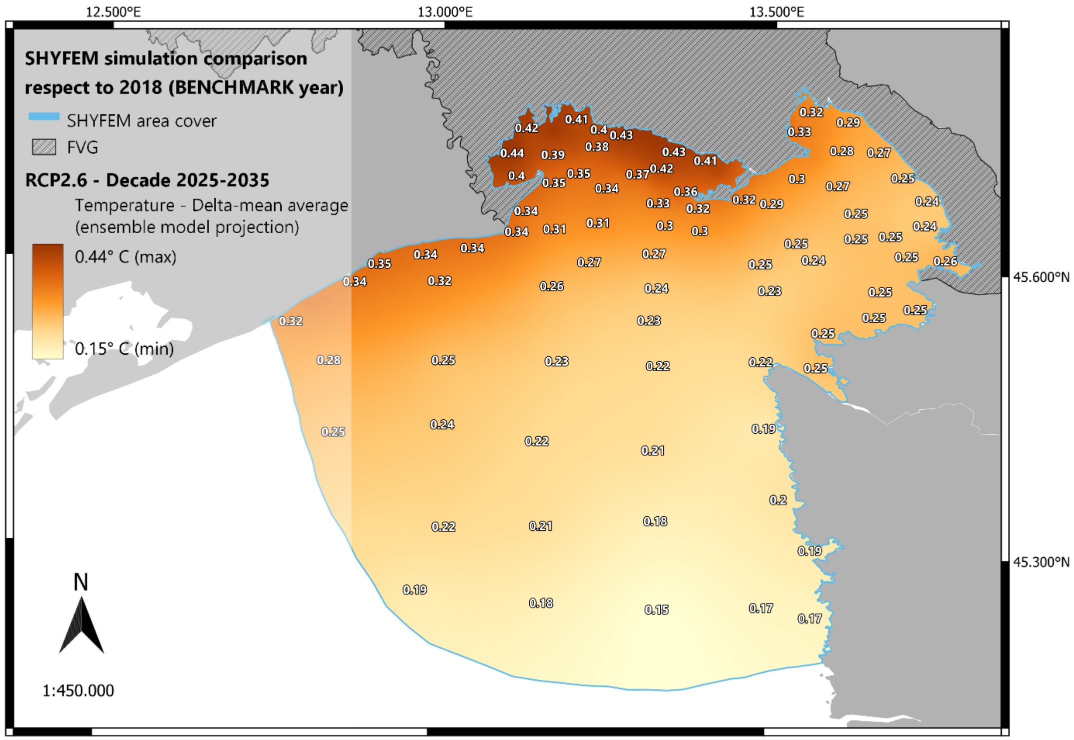
So, basically, sensitivity tests confirm global projections also for the northernmost area of the Adriatic Sea. An increase between 0.48°C and 0.70°C in the RCP4.5 or between 0.73°C and 0.92°C in the RCP8.5 at mid-century and, even more so, an increase between 1.12°C and 1.31°C (RCP4.5) or between 2.56°C and 2.90°C (RCP8.5) at the end of the century, will result in the occurrence of numerous impacts in different sectors. Not only marine, coastal and transitional ecosystems may undergo profound changes, but also sectors such as fisheries and aquaculture and tourism may be severely affected by rising sea temperatures, with serious impacts on the local economy and quality of life. A checklist of climate change impacts, which also describes impacts related to rising sea temperatures, is attached to this document (see Chapter 6 – Climate change impacts).

Comparing the different scenarios, a different warming of the surface water layer can be observed depending on the areas considered within the Pilot Site. While in the RCP2.6 and RCP4.5 the areas that experience the greatest increase in temperature are the lagoon and coastal areas, in RCP8.5 it is the area in front of the Istrian coast that is most affected, i.e. the area where the warmer and saltier Levantine Intermediate Water (LIW) enters in the Pilot Site (Kubin et al. 2019)[86].

An interpretation of this evidence could be the change in the LIW properties due to the effects of climate change in the Mediterranean basin. Anyway, there is no explanation why the lagoon does not reach the equilibrium with the open sea. In fact, the sea level rise will bring the lagoon more responding to the forcing of the open sea.

However, it is important to highlight that the climate model can be improved and it is not excluded that ARPA FVG may provide more accurate climate information in the near future.

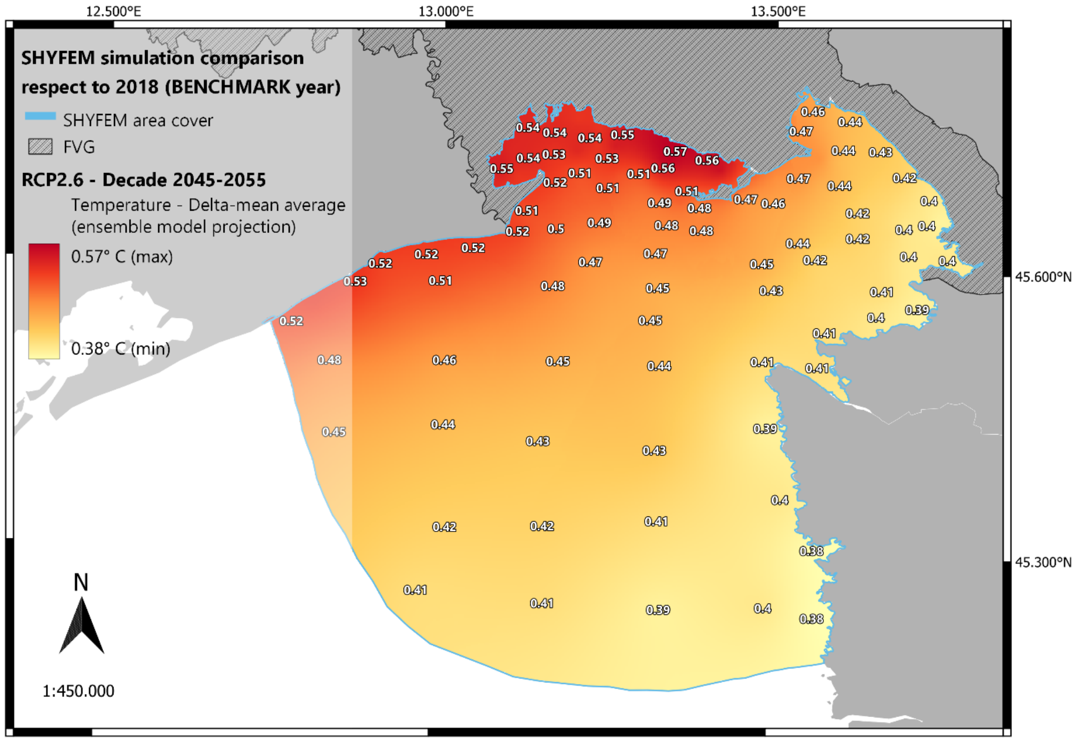
[86] Kubin E, Poulain PM, Mauri E, Menna M & Notarstefano G (2019). *Levantine intermediate and Levantine deep water formation: An Argo float study from 2001 to 2017*. Water, 11(9), 1781. DOI: https://doi.org/10.3390/w11091781.



Climate scenario: RCP2.6

Reference *decade*: 2025-2035

***Figure 60**. RCP2.6 - Decade 2025-2035: annual average temperature difference from the benchmark, for each monitored point of the pilot site. On the right, the minimum and maximum values.*



Climate scenario: RCP2.6

Reference *decade*: 2045-2055

Figure 61. *RCP2.6 - Decade 2045-2055: annual average temperature difference from the benchmark, for each monitored point of the pilot site. On the right, the minimum and maximum values.*

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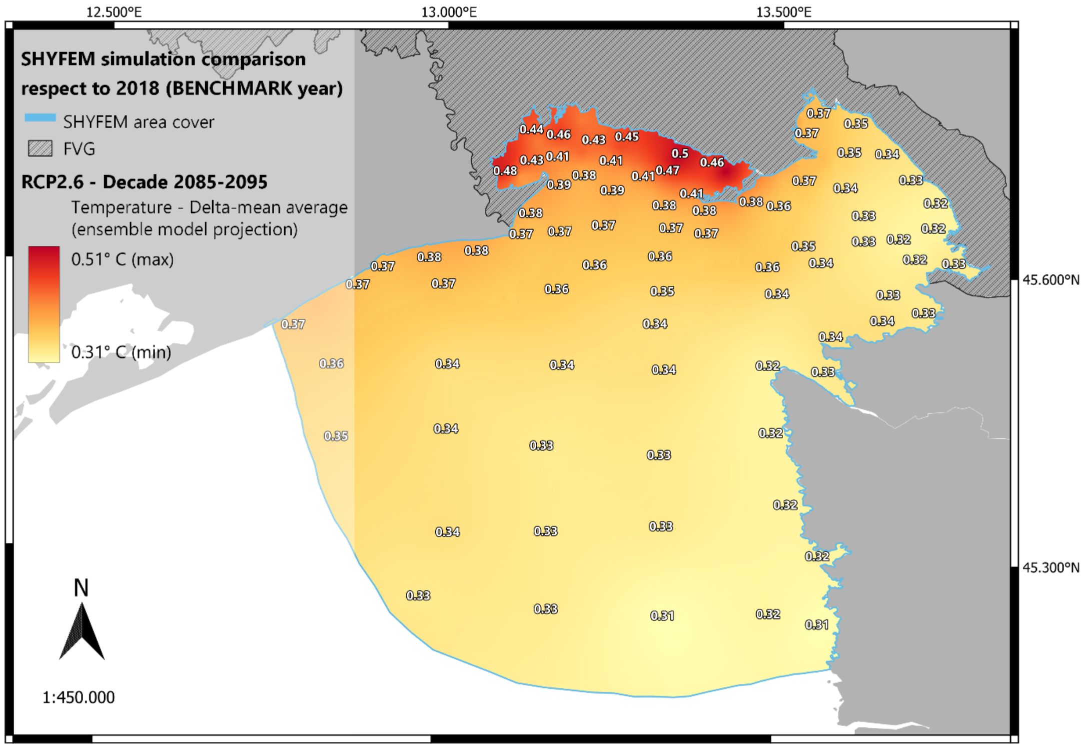
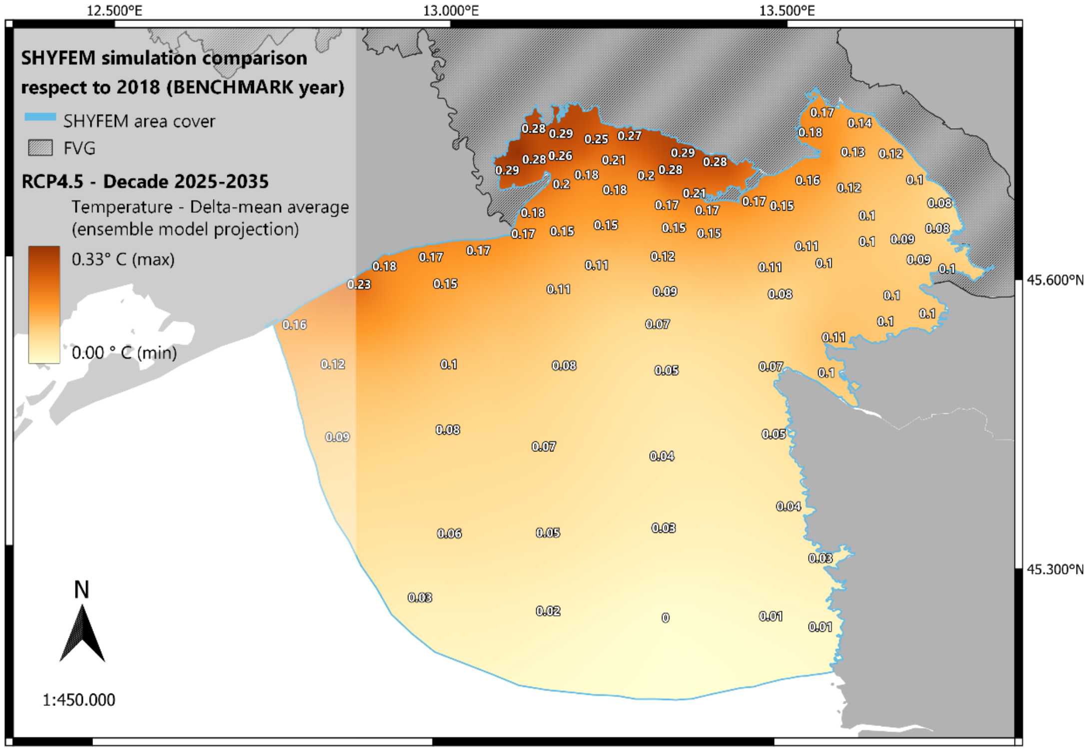


Climate scenario: RCP2.6

Reference *decade*: 2085-2095

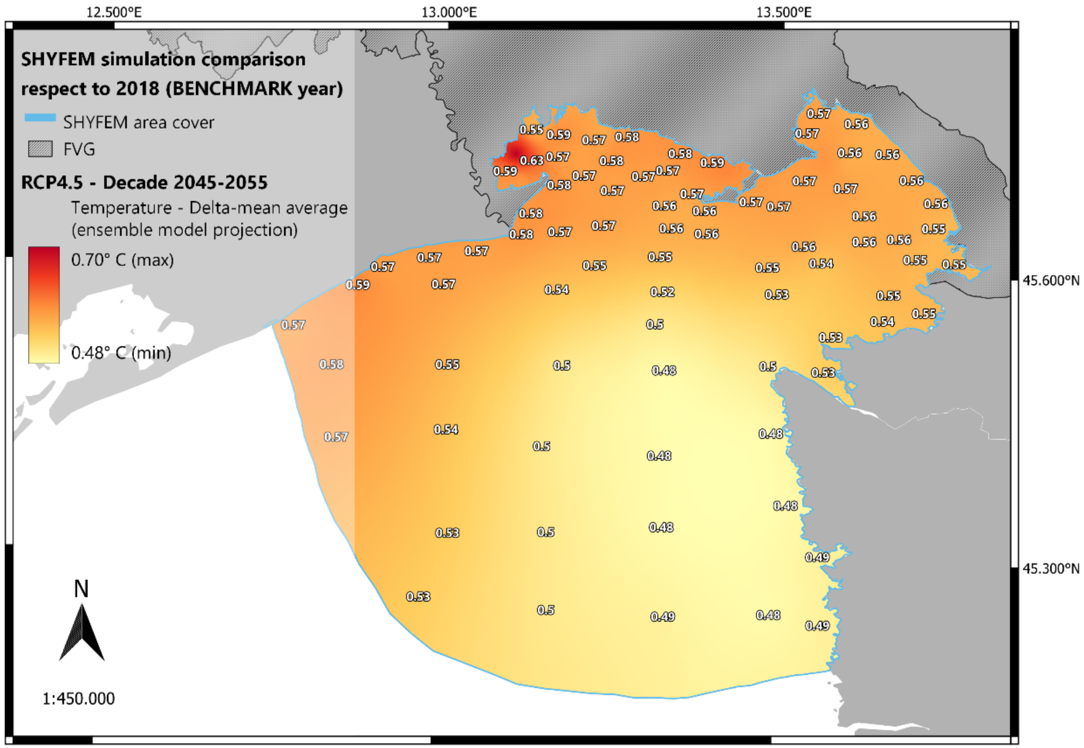
Figure 62*. RCP2.6 - Decade 2085-2095: annual average temperature difference from the benchmark, for each monitored point of the pilot site. On the right, the minimum and maximum values.*



Climate scenario: RCP4.5

Reference *decade*: 2025-2035

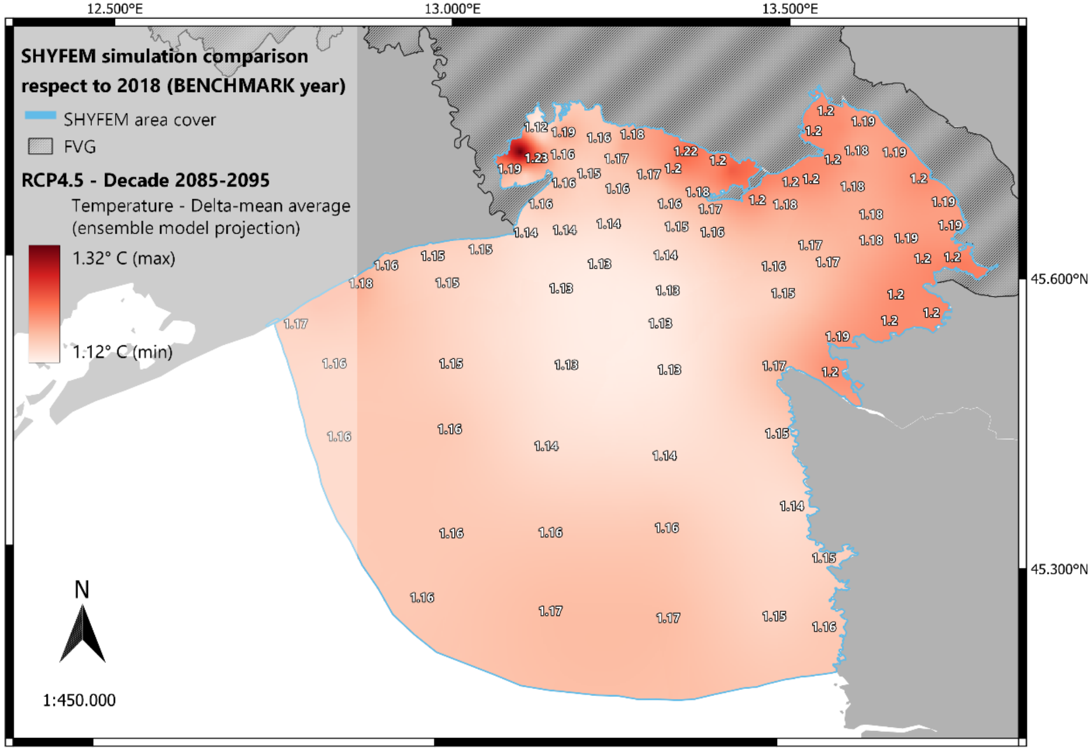
Figure 63. *RCP4.5 - Decade 2025-2035: annual average temperature difference from the benchmark, for each monitored point of the pilot site. On the right, the minimum and maximum values.*



Climate scenario: RCP4.5

Reference *decade*: 2045-2055

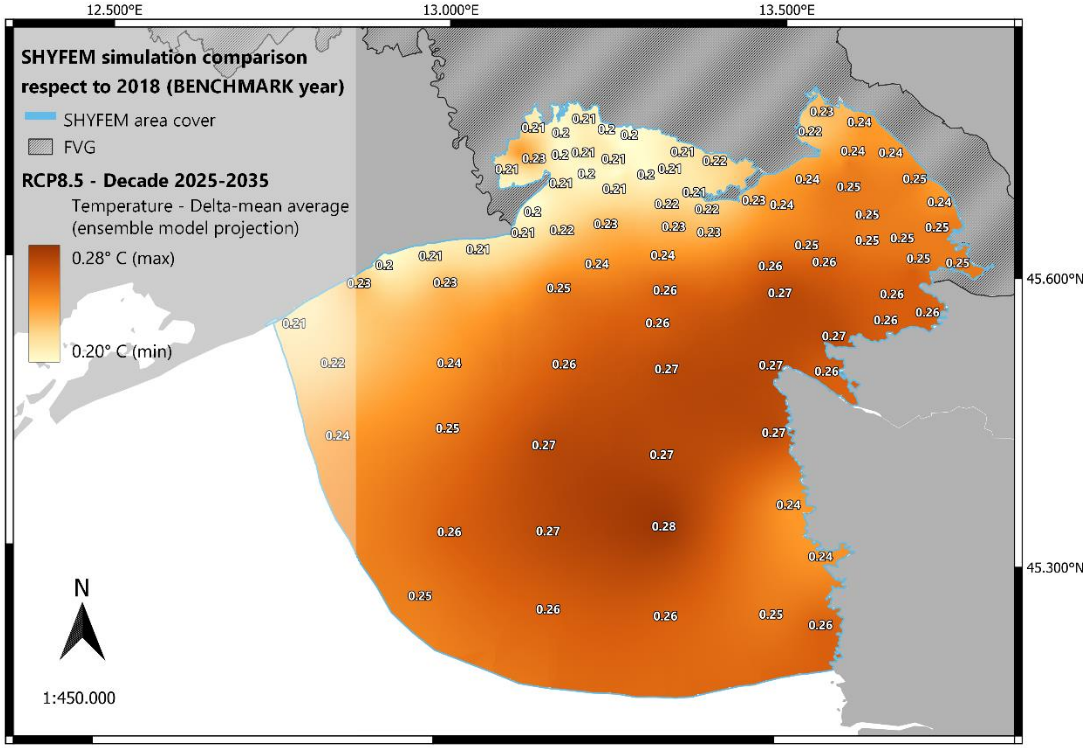
Figure 64. *<u>RCP4.5 - Decade 2045-2055</u>: annual average temperature difference from the benchmark, for each monitored point of the pilot site. On the right, the minimum and maximum values.*



Climate scenario: RCP4.5

Reference *decade*: 2085-2095

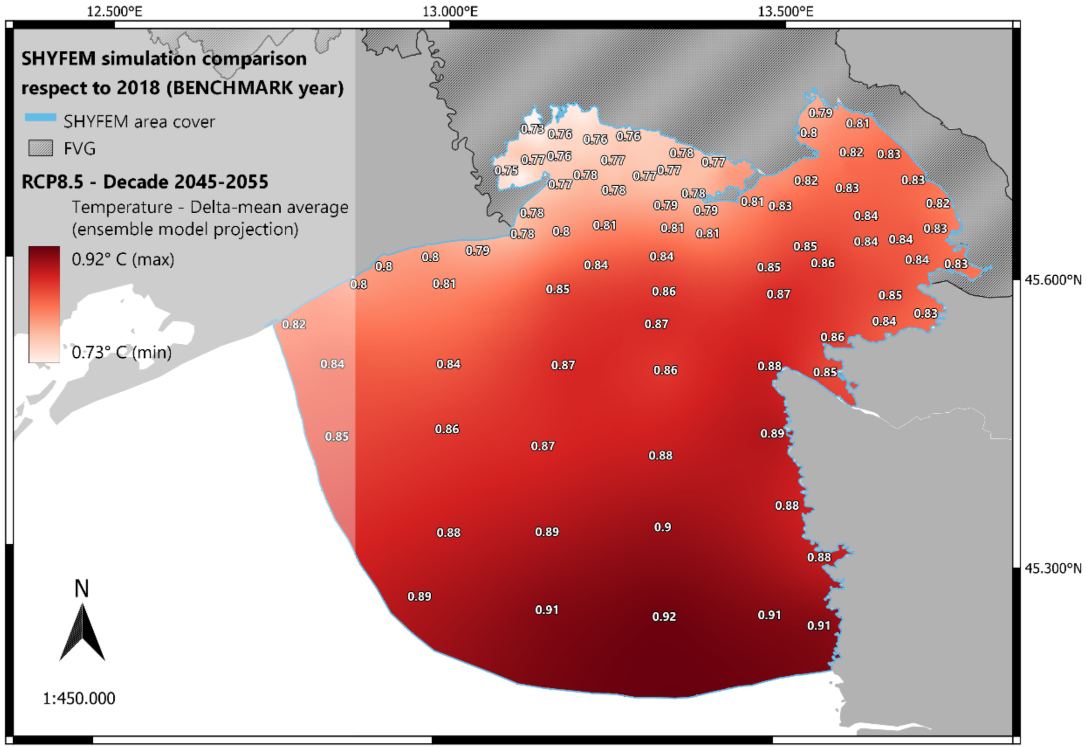
Figure 65. *RCP4.5 - Decade 2085-2095: annual average temperature difference from the benchmark, for each monitored point of the pilot site. On the right, the minimum and maximum values.*



Climate scenario: RCP8.5

Reference *decade*: 2025-2035

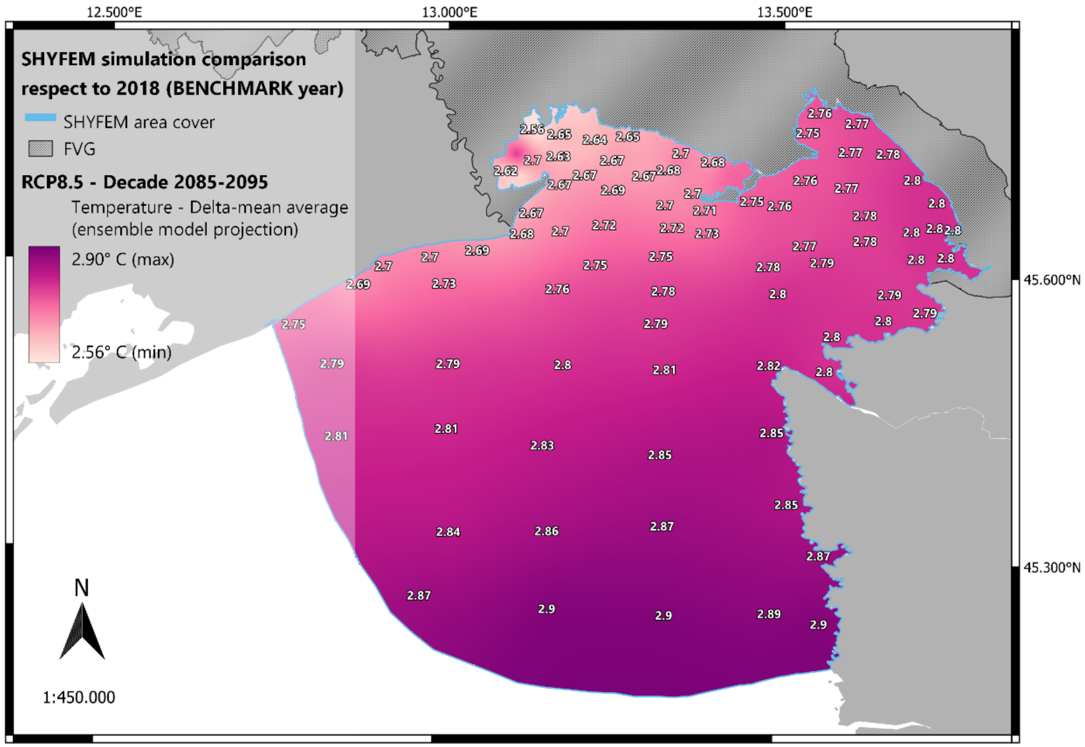
Figure 66*. <u>RCP8.5 - Decade 2025-2035</u>: annual average temperature difference from the benchmark, for each monitored point of the pilot site. On the right, the minimum and maximum values.*



Climate scenario: RCP8.5

Reference *decade*: 2045-2055

Figure 67. *RCP8.5 - Decade 2045-2055: annual average temperature difference from the benchmark, for each monitored point of the pilot site. On the right, the minimum and maximum values.*



Climate scenario: RCP8.5

Reference *decade*: 2085-2095

Figure 68*. RCP8.5 - Decade 2085-2095: annual average temperature difference from the benchmark, for each monitored point of the pilot site. On the right, the minimum and maximum values.*

Med-CORDEX and EURO-CORDEX preparatory work

A preparatory work was made by ARPA FVG before the SHYFEM simulations. Thanks to the Med-CORDEX and EURO-CORDEX initiatives, several meteo-marine data with daily resolution was extracted from the available simulation outputs (**Figure 69** and **Figure 70**). Regarding the Med-CORDEX grid points, different points were chosen to cover a representative area for the FVG Pilot Site (**Figure 70**). Note that the lagoon and the near-shore areas are not fully covered by the CORDEX initiatives grid points.

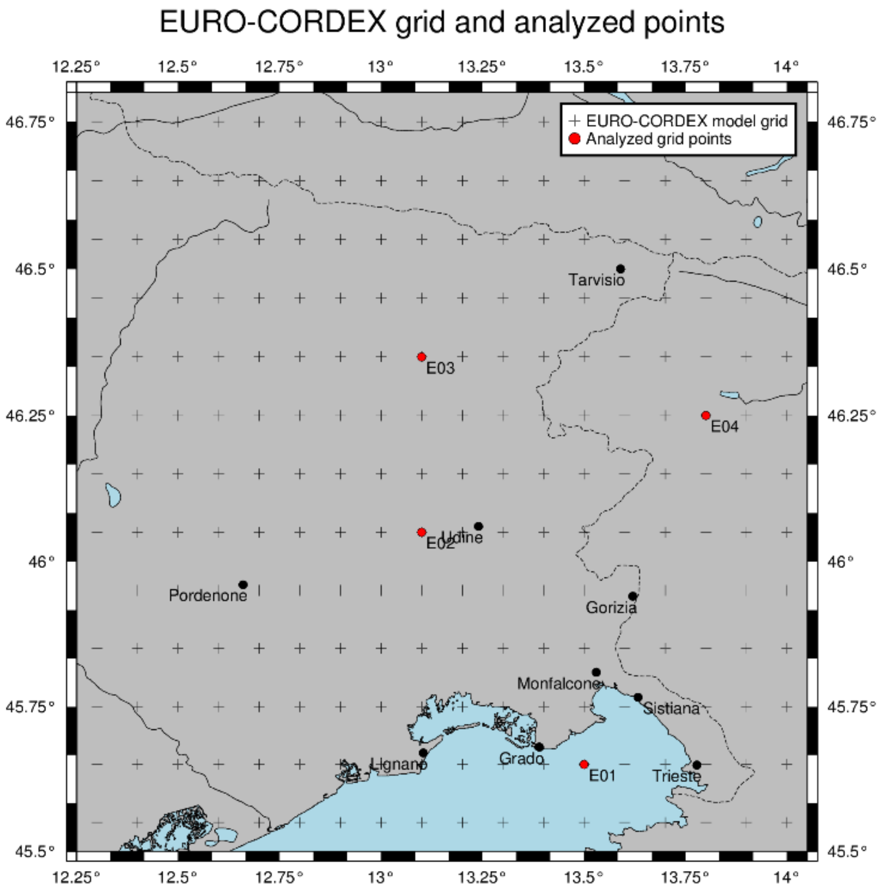


Figure 69. EURO-CORDEX grid points (crosses) and analyzed points (red) for which simulations outputs were available.

The climate elaborations from Med-CORDEX and EURO-CORDEX models cover a time period up to 2100, divided into decades, and show the future average variation in some physical quantities (such as sea surface temperature), compared to the reference decade 2010-2020, which is the one considered as representative of the current environmental state. These climate elaborations show the possible future evolution of some meteo-marine variables in the Gulf of Trieste, according to three different scenarios of climate-altering gas emissions (RCP2.6, RCP4.5, RCP8.5).

In addition, Med-CORDEX and EURO-CORDEX outputs were used for the implementation of SHYFEM model runs in the high resolution downscaling. Focusing on the marine area, an *ensemble* of Med-CORDEX projections was elaborated first, in order to compare successive SHYFEM results and observe any deviation of the downscaled outputs (SHYFEM) from the regional ones (Med-CORDEX).

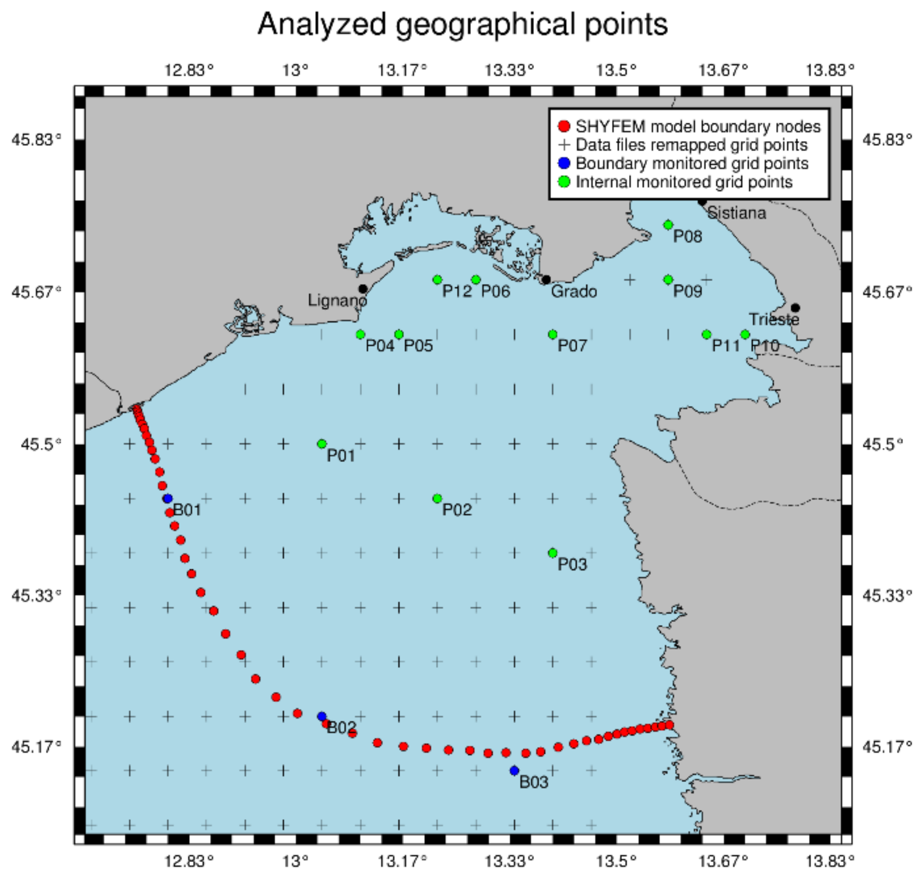


***Figure 70**. Remapped Med-CORDEX grid points. For the sensitivity tests only the B02 point was considered for the perturbation of the boundary conditions.*

Thanks to these outputs, it was possible to attribute mean sea temperature variation values to different sector of the FVG Pilot Site, in accordance with the available simulations at certain Med-CORDEX grid points. Furthermore, additional information - such as bathymetry, river inputs and current direction - was taken into account, in order to take up the same methodology that ARPA FVG applies to identify reference water bodies in the monitoring of marine and transitional water quality.

Accordingly, the FVG Pilot Site has been divided into several units that can be considered homogeneous in terms of oceanographic characteristics and that were identified with the support of ARPA FVG marine biologists engaged in the daily monitoring of the regional marine-coastal waters.

Therefore, several thematic maps were derived, per different emission scenarios and *decades*. These maps show the possible future average variation in water surface temperature, compared to the decade 2010-2020, in the different marine units of the pilot area. The following maps illustrate the possible situation at mid- and end-of-century for the most ambitious and the most pessimistic emission scenario (RCP2.6 and RCP8.5 respectively).

Comparing the following maps with those seen above, some differences in minimum and maximum values emerge. For example, in the RCP8.5 end-of-century scenario, the values indicate a temperature increase between 2.5 and 3.5°C and between 2.6 and 2.9°C for the Med-CORDEX and SHYFEM elaborations, respectively. This could be due to the models grid points (compare **Figure 70** for Med-CORDEX and **Figure 58** for SHYFEM) and the downscaling process by which SHYFEM was set up to obtain more precise results at local scale.

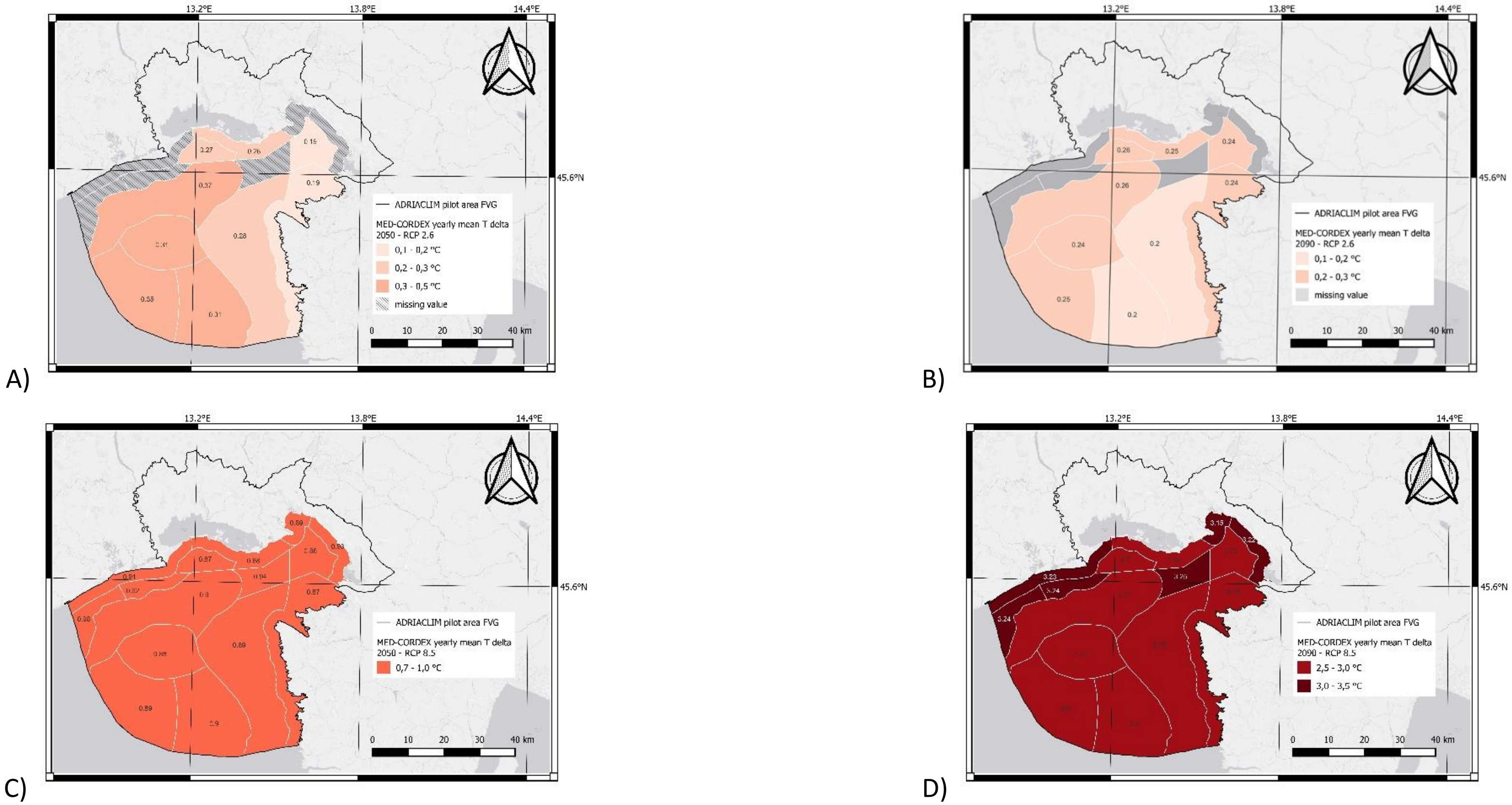


Figure 71 A-D. *Annual average temperature differences from reference decade 2010-2020 for RCP2.6 -2050 (A) and 2100 (B) and RCP8.5-2050 (C) and 2100 (D)*

Sea Level Rise projections

In terms of sea level rise at the FVG Pilot Site, modelling activities from WP3 will be implemented. However, in order to insert in the present document projections regarding the increase of the sea level, we used the Sea Level Projection NASA tool, as mentioned in the previous chapter (see Chapter 3 – FVG Pilot Site identification).

In **Table 17** are shown the sea level rise (SLR) values for Trieste at mid-century and end-of-century scenario according to RCP2.6 and RCP8.5. As already explained in Chapter 3, we preferred to round up or down values in our further elaborations.

Sea level rise is of primary importance in coastal areas, also depending on coastal morphology. In the FVG Pilot Site there are mainly two types of coastal morphology: the low, sandy coast from the mouth of the Tagliamento River to the mouth of the Timavo River and the high, rocky coast from Duino to Muggia (the so-called *Costiera triestina* also seen in the delimitation of the pilot area).

The low, sandy coastline is, of course, the type of coastline most vulnerable to rising sea level and, together with subsidence and the depressed nature of the area, makes this area particularly exposed. What is unfavourable to the lagoon and *Bassa friulana*[87] area, in fact, is not only subsidence, but also the nature of the territory, which underwent intensive land reclamation in the first half of the last century and is still below the mean sea level. To keep the soil dry, the *Consorzio di Bonifica*[88] (Land Reclamation Consortium) operates several drainage pumps distributed throughout the area and a system of embankment surrounds the lagoon area to prevent storm surges and erosion. The coastal defence system includes embankments, groynes and walls, the total height of which varies from a few tens of centimetres to a few metres.

The following figures show the possible flooding situation of the lagoon and *Bassa Friulana* area in the event that the SLR reaches an increase of 20 cm in 2050 for both RCP2.6 and RCP8.5 (**Figure 72**) and an increase of 40 cm and 70 cm in 2100 (**Figure 73**) for RCP2.6 and RCP8.5 respectively.

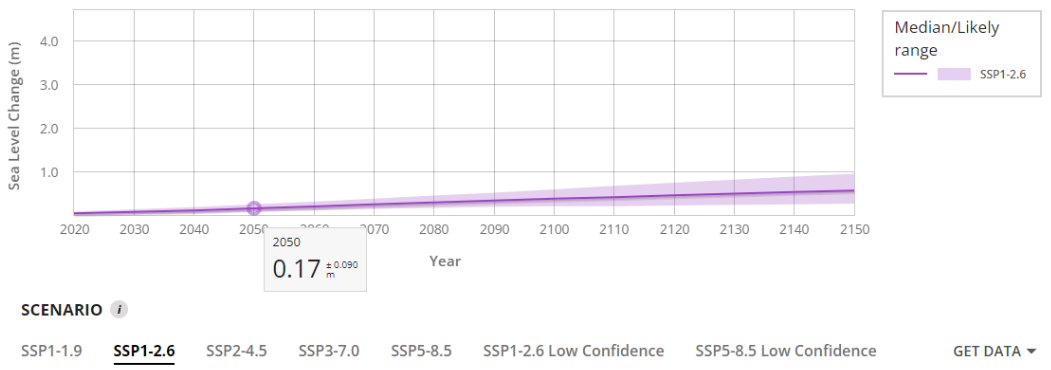
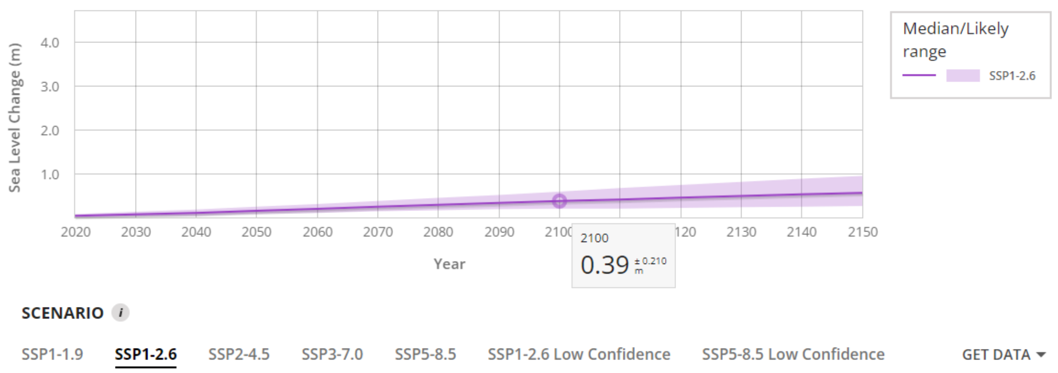
However, it is important to note that not only the Friuli coast is vulnerable to rising sea levels, but also the cities of Trieste and Muggia located along the *Costiera triestina*. In fact, despite the high karst formation behind the urban settlements, Trieste and Muggia are built on the Flysch formation, where the coast descends toward the sea. As evidenced by several flooding events in recent years (one example above all: the flood of November 2019), the waterfront areas of the city can also be affected by storm surges, causing flooding of squares, marinas and the historic centre in general.

[87] The *Bassa friulana* area is the Friuli lowland area under the "line of springs" that separates the high and low plains. Here, the waters meet the impermeable subsoil and come to the surface, forming broad flowing water courses.
[88] https://www.bonificafriulana.it/

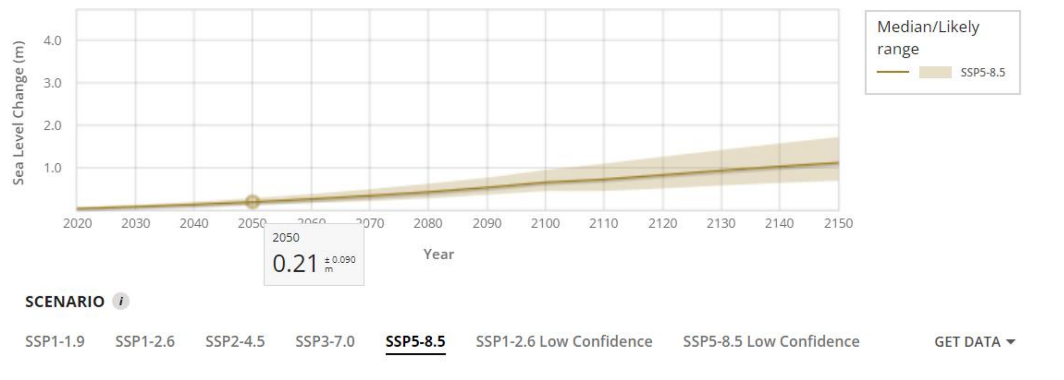
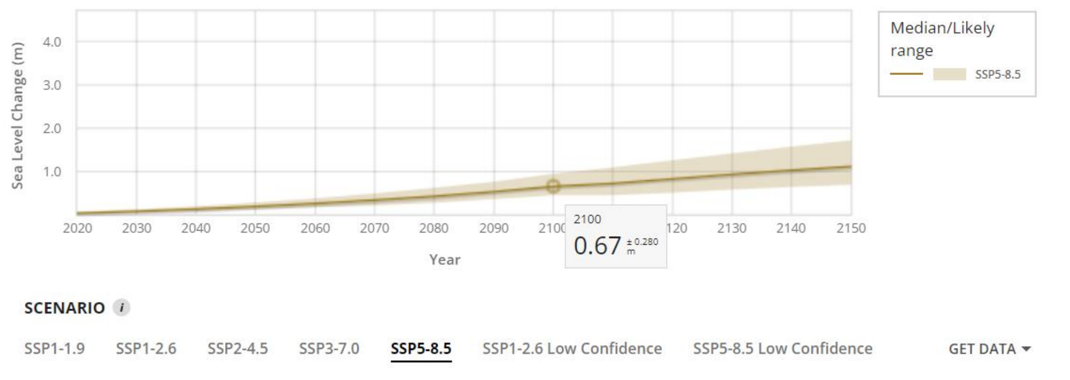
The study of seawater entry points due to storm surges or SLR was the subject of a dissertation conducted at the Department of Mathematics and Geosciences at the University of Trieste (2021-2022) (please refer to Coastal Group)[89].

Finally, SLR is linked to several impacts. Indeed, it is not only the loss of land (agricultural crops, urban settlements and infrastructure), but also the marinisation of lagoons and wetlands (loss of biodiversity), erosion and salt-wedge intrusion. The rise in mean sea level affects several impacts distributed over different impact sectors, as described in Chapter 6**.**

Table 17. *SLR values (median) for RCP 2.6 and RCP 8.5 in 2050 and 2100 according to the NASA tool (screenshots from the Sea Level Projection NASA tool).*

Original values	IPCC-NASA: Sea level projections – TRIESTE (https://sealevel.nasa.gov/ipcc-ar6-sea-level-projection-tool?psmsl_id=154)
Values rounded up or down	
RCP2.6 2050 0.17 ±0.090 m	
20 cm	
RCP2.6 2100 0.39 ±0.210 m	
40 cm	

[89] https://coastalgroup.units.it/

RCP8.5 2050 0.21 ±0.090 m	
20	
RCP8.5 2100 0.67 ±0.280 m	
70	

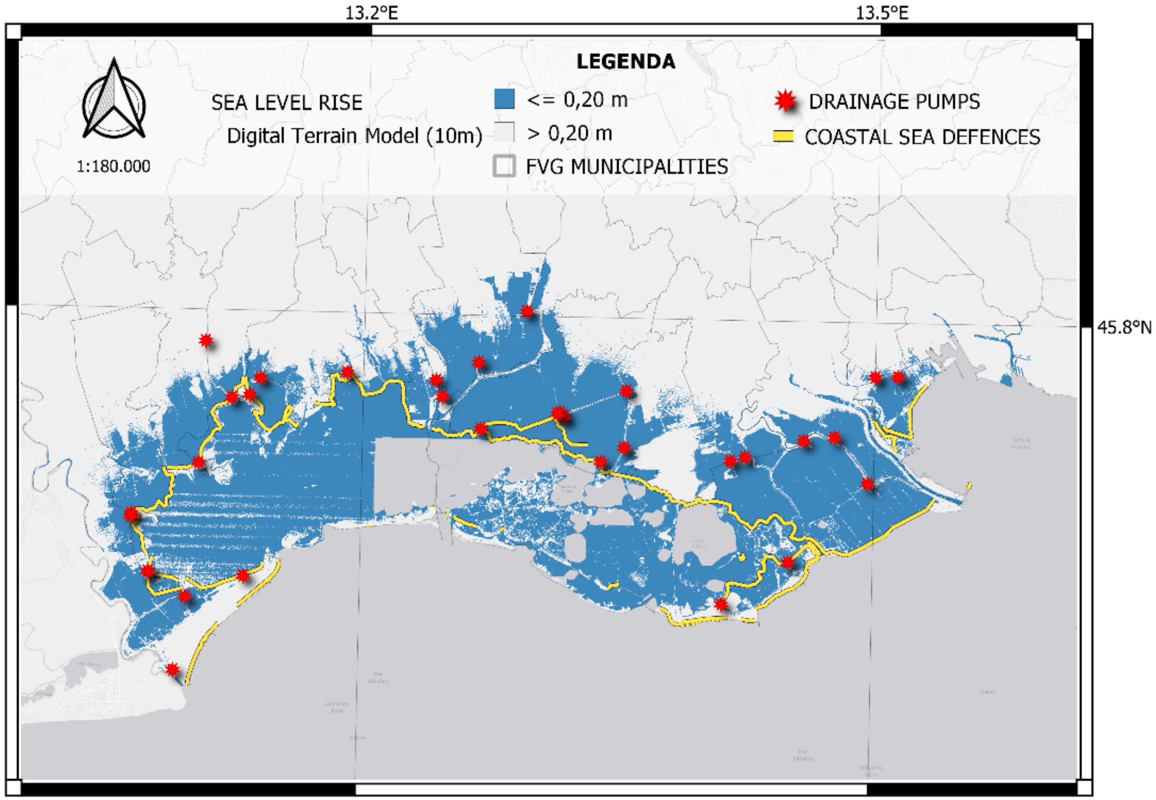


Figure 72*. SLR: +0.20m in mid-term scenario (2050) according to RCP 2.6 and 8.5. The Digital Terrain Model used for this elaboration comes from IRDAT, the regional catalogue of geographical data of the Regione Autonoma Friuli Venezia Giulia.*

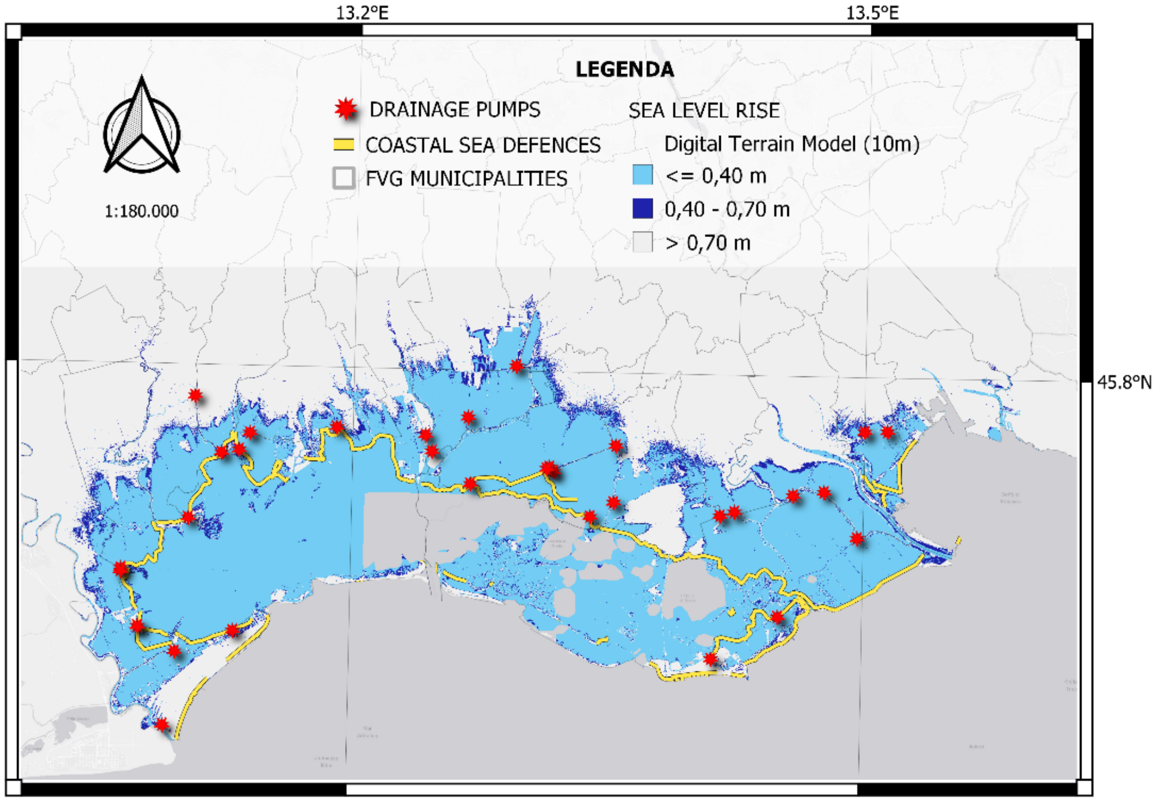


Figure 73*: SLR: +0.40m in RCP2.6 and +0.70m in RCP8.5 in the end-of-century scenario. The Digital Terrain Model used for this elaboration comes from IRDAT, the regional catalogue of geographical data of the Regione Autonoma Friuli Venezia Giulia.*

Chapter 5 – Exposure and vulnerability context analysis

In this section we briefly describe the FVG Pilot Site context in which climate change adaptation policies could be implement in order to provide a general framework and useful elements for a Risk Vulnerability Assessment. In fact, when talking about the vulnerability of a certain territory, an inventory of exposed elements is necessary, as well as information on the sensitivity, adaptive capacity and impacts that have already occurred on that area.

Here, brief information is provided on the geography, natural environments, cultural heritage, economic and production activities and a general description of the social characteristics of the Pilot Site.

Most of the information comes from the Regional Landscape Plan (PPR-*Piano Paesaggistico Regionale*) of the Friuli Venezia Giulia Region, in which the region has been divided into different areas based on standard criteria. As mentioned in Chapter 3 – FVG Pilot Site identification, the territorial subdivision found in the PPR was useful to identify the FVG pilot area in the context of the AdriaClim project. The Regional Government Plan (PGT - *Piano di Governo del Territorio*) was also taken into account, especially in terms of economic and productive activities.

5.1 – Context analysis

Friuli Venezia Giulia is the most north-easterly region of Italy. It covers an area of 7856 square kilometres and is the fourth smallest region of the country with about 1.2 million inhabitants. The main cities are Trieste, Udine, Pordenone, Gorizia. The regional capital is Trieste.

It is bordered by Austria to the north and Slovenia to the east. The south coast of the region faces the Adriatic Sea and to the west Friuli-Venezia Giulia borders the Veneto region.

Located at a crossroads of different areas – the Mediterranean, the Balkans, the Alps, the northern Italy plain – Friuli Venezia Giulia is a meeting point between various natural and human elements, resulting in a remarkable high diversity from many points of view: geology, climate, ecosystems, human cultures and languages, production activities. As the Alps and the Mediterranean area are both "hotspots" being extremely affected by climate change, the region is particularly exposed to it and its impacts.

Physical geography

The FVG Pilot Site encompasses the southern part of the Friuli Venezia Giulia region, i.e. the coastal area that directly faces the Adriatic Sea, and a portion of the territory behind it. As far as the orographic units (**Figure 74**), the PS includes the "*Bassa pianura friulana*" and the "*Carso goriziano e triestino*" units (RAFVG 2006 and reference therein)[90].

***Figure 74**. Orographic units of the Friuli Venezia Giulia Region (from: RAFVG 2006).*

The Friuli plain is the eastward continuation of the Venetian plain, and extends from the pre-Alps in the north to the sea in the south. It's transversally divided into high and low plain by the "resurgence line" that runs from west to east and corresponds to the outcrop of the shallowest water table. South of the resurgence line (lower plain) are sandy-silty and silty-clay alluvial deposits, which are not very permeable to the passage of water. At the southern edge of the *Bassa pianura friulana* lies the lagoon of Marano and Grado separated from the Adriatic Sea by a long shore bar, composed by isles and sandbanks, and interrupted by a system of inlets connecting the lagoon to the sea. The lagoon lies between the mouth of the Tagliamento River to the west and the mouth of the Isonzo River to the east. The latter is the main contributor of freshwater in the Gulf of Trieste. As far as freshwater supply is concerned, some rivers flow directly into the lagoon of Marano-Grado, such as the Stella, the Aussa-Corno and the Natissa, contributing to maintain the salinity gradient in the lagoon system. It's important to remember that in the Northern Adriatic one of the widest tidal ranges of the Mediterranean occurs and during the syzygies the tidal amplitude can exceed 100 cm.

With regard to the Karst, the lower course of the River Isonzo marks its north-western border, while the central-southern sector lies between the *Costiera triestina* and the Italian-Slovenian border. At

[90] Regione Autonoma Friuli Venezia Giulia (2006). *Carta Geologica del Friuli Venezia Giulia – Note Illustrative*. Edited by Carulli GB. S.EL.CA. srl – Firenze, 48 pp.

the lithological level, the Karst consists of Cretaceous and Palaeocene platform limestones with patches of Eocene flysch cover. The Karst sees the near absence of surface watercourses, given the dissolution to which the limestone rock is exposed when it encounters water. Some rare cases of surface water presence are mainly represented by the karstic lakes of Doberdò and Pietrarossa, the Rosandra and Ospo streams and the mouths of the Timavo river.

Natural vulnerabilities

With regard to the natural vulnerabilities that characterise these territories, for the Friuli plain and the Marano-Grado lagoon, subsidence is of primary importance. This natural phenomenon is exacerbated by the extraction of fluids from the subsoil, which in recent decades has accelerated the processes of soil compaction, as well as the land reclamation that has taken place in recent centuries.

Another aspect that affects the vulnerability of the lagoon area and the plain behind it are the areas below hydrometric zero, which consist mainly of the areas affected by the previous land reclamation. The entire area is therefore more susceptible to flooding, which is exacerbated by coastal erosion due to surface water, inundation by rivers and the sea, and the rise in groundwater levels. Regarding beach erosion, a case study is presented in D5.3.2-*FVG Pilot Site insights from case studies*.

The lagoon area, in particular, is vulnerable to sea flooding mainly due to natural phenomena such as violent sea storms associated with exceptional high tide events. The latter are due to the synergic action of syzygy tides, wave motion and low atmospheric pressure, often in combination with the strong sirocco wind.

In addition, the lagoon of Marano-Grado is facing a reduction in the surface area of salt marshes due to the deficit of the sedimentary balance, exacerbated by subsidence and sea level rise. In addition, is the increase in salinity and the intrusion of the salt wedge along the freshwater channels up to 5 km from the lagoon boundary, together with the infiltration of salt water into the surface water table near the embankment system, with the risk of making the agricultural crops behind it unproductive.

The Friulian Plain, on the other hand, is affected by hydraulic instability phenomena, in which areas face flooding (river flooding, water stagnation, rising water tables) and exceptional high tide events. One of the main causes of instability is urbanisation, which leads to a reduction in the size of river basins and an increase in extreme weather events. In addition, it is difficult to estimate the extent of groundwater flowing along river relics and palaeoalvements outside the official hydrographic network, transporting significant volumes of water. These conditions complicate the removal of water introduced by flood events.

Finally, as far as karst is concerned, the risk of flooding by rivers is not so great, since the high permeability of the carbonate rock means that there are virtually no surface waters. Flooding is mainly due to storm surges, which involve various factors such as rainfall, high tides, and southerly winds. These events occur mainly in the urban areas of Trieste and Muggia, due to the low elevation of the city centre combined with excessive soil sealing as a result of extreme urbanisation.

Flysch-covered areas are prone to hydrogeological instability phenomena, especially landslides and surface slides; these events are quite frequent given the level of urbanisation and land use. In karst areas, on the other hand, landslides in the steepest areas and sinkhole collapses are common.

Regarding sinkholes, weather conditions are one of the main triggers for sinkhole collapse, especially due to the succession of long droughts and extreme weather events. Climate change plays a role in groundwater resource availability and can lead to significant movements in groundwater levels. Its change can lead to an increase in the solubility of evaporite and carbonate rocks, which in turn favours the triggering of sinkholes (UNITS 2015 and reference therein)[91].

Natural environment: habitats, ecosystems, biodiversity

Due to climate, geology, geomorphology, and hydrography, different natural environments coexist in the FVG pilot area. In general, the FVG region lies at the intersection of three biogeographic regions: the Alpine, the Continental, and the Mediterranean (**Figure 75**). Thus, the FVG pilot site is influenced by the characteristics of each of the three sites.

Each of the sectors of the pilot area has natural characteristics in terms of habitat, flora and fauna and hosts several endemic species.

The Marano and Grado Lagoon is the largest and most attractive wetland in the Friuli Venezia Giulia region, where typical transitional habitats such as coastal lagoons, grey and white dunes, mud and sand areas cover about 85% of the basin. Other typical transitional habitats, such as Mediterranean salt marshes and seagrass beds, are also well represented. Several estuaries overlook the lagoon basin, such as the mouth of the Stella River, where a nature reserve is located. The lagoon hosts a large number of bird species, and bird communities are well represented in terms of richness and diversity (more than 300 species are observed). For example, it is the most important migratory and wintering area in Italy and Europe for Eurasian curlew (*Numenius arquata*), the Grey plover (*Pluvialis squatarola*), the Great scaup (*Aythya marila*) and the Bar-tailed godwit (*Limosa lapponica*) (Cosolo et al. 2015)[92].

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[91] Università degli Studi di Trieste (2015). *Impatti dei cambiamenti climatici sul territorio fisico regionale – Relazione di sintesi*. Edited by: Department of Mathematics and Geosciences with the support of Regione Autonoma Friuli Venezia Giulia, 160 pp.

[92] Cosolo M, Sponza S & Fattori U (2015). *La laguna di Marano e Grado: un mosaico di biodiversità – un patrimonio da preservare*. Regione Autonoma Friuli Venezia Giulia, Udine, 52 pp.

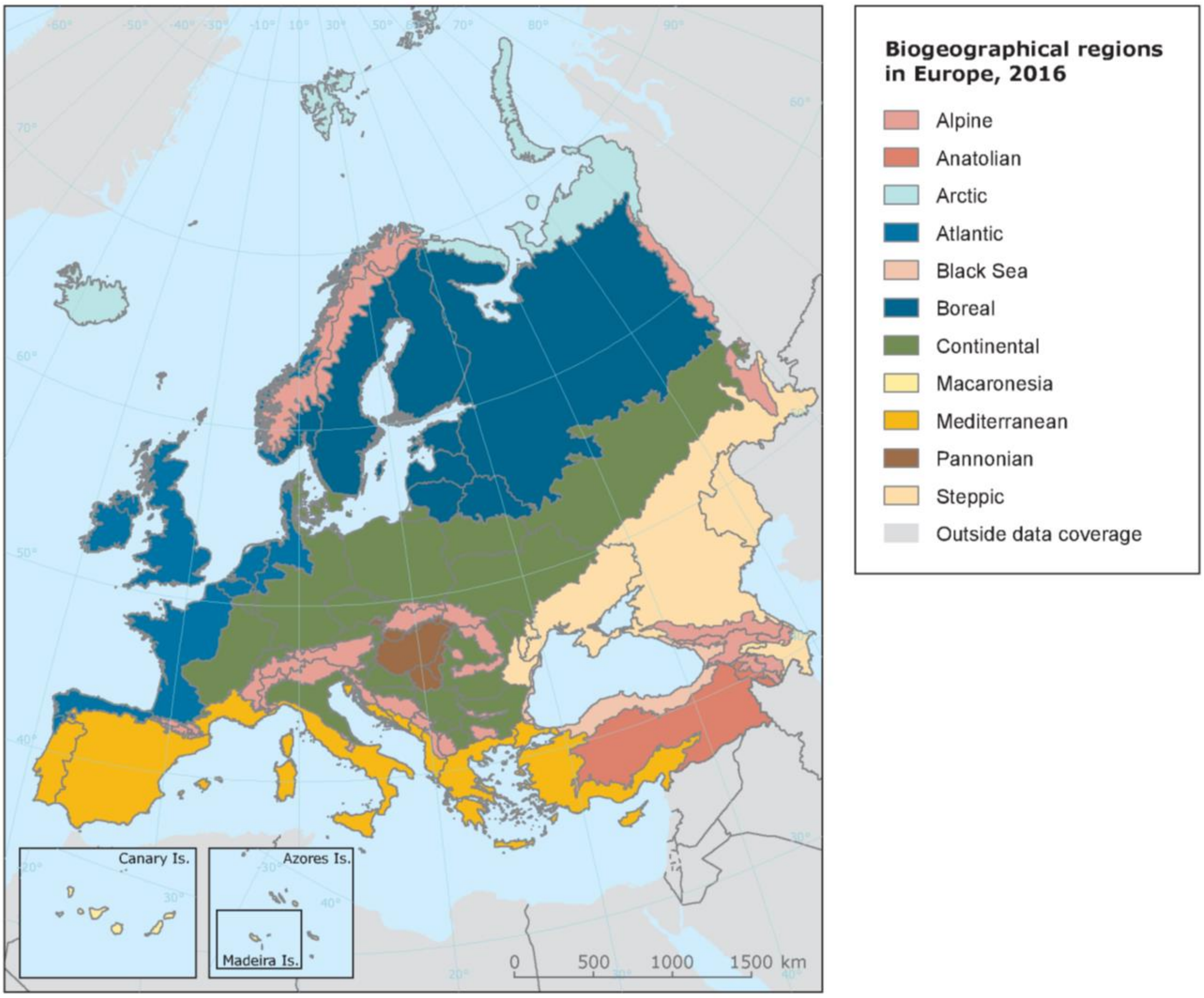

Figure 75. *Biogeographical Regions in Europe from 2016 onwards (from: https://www.eea.europa.eu/data-and-maps/figures/biogeographical-regions-in-europe-2).*

Although traditional productive activities (fishing and extensive aquaculture, known as "*vallicultura*") are still practised, the lagoon is subject to a high degree of anthropization due to the expansion of economic, tourist and industrial services. As a result, the lagoon area is now a mosaic of well-preserved areas alternating with other areas that have been severely affected.

The Karst and the *Costiera triestina* host a high biodiversity with numerous endemics that reflect the particular geomorphology of the Karst area. The karst phenomenon manifests itself here in numerous hypogean and epigean forms. The plant communities are the result of the millenary balance between man and nature, which has led to the preservation of the so-called "*landa carsica*". This is the habitat most threatened by land abandonment and the resulting natural process of vegetation succession by native and exotic, sometimes invasive, shrub and tree species such as ailanthus. The *landa* is an environment of anthropogenic origin, enriched with sometimes endemic herbaceous species (*Gentiana tergestina, Iris illyrica* and *Crocus variegatus*). It has been created by the deforestation of the original Mediterranean oak forest and the subsequent grazing by sheep and goats.

A mosaic of plant communities can also be seen in this area. Thus, dry grasslands and pastures alternate with forests of heat-loving species such as the holm oak (*Quercus ilex*), artificial black pine forests (*Pinus nigra*) and Mediterranean scrublands, such as on the steep cliffs of Duino above the sea, where the endemic species *Centaurea kartschiana* occurs. In any case, the entire Karst and the *Costiera triestina* are severely threatened by numerous and widespread anthropogenic influences.

As for *the Bassa pianura friulana*, flora and fauna represent the meeting point between the Po Valley and the Illyrian area, since for several species this area represents the limit of their own spatial distribution. The biocenoses are the result of the mixing of elements belonging to the two areas, and they are of utmost importance for conservation. The natural elements have been greatly reduced over time by intensive and semi-intensive agricultural activities, and the area has been greatly modified by the presence of man. However, there are still valuable natural elements such as the spring mosaic with base-poor peat bogs, wet meadows, hygrophilous forests and the floodplain forests.

The communities most threatened are those of the spring system, which has been severely damaged and fragmented by land reclamation in the last century. These fresh and wet habitats, characterised by oligothrophic waters and soils, harbour highly specialised plants and animals. As for the floodplain forests, Roman testimonies report the presence of the so-called "*selva lupanica*" throughout the Po Valley, i.e. an extensive oak-hornbeam forest that today is present only in rare and fragmented patches in a total area of 645 hectares.

As for the rare animal species, the fauna tied to the spring system is in danger. Thus, typical species of the open spring area are threatened by the fragmentation of their habitat, such as the marsh harrier and Lepidoptera species, as well as the adder (*Aspis francisciredi*) and the carniolica lizard (*Zootoca carniolica*). Species tied to the wet headwaters, such as amphibians and reptiles (*Emys orbicularis*), fish, and invertebrates like the native crayfish (*Austropotamobius italicus meridionalis*), are also threatened by water pollution and land reclamation.

Regarding protected areas, there are several Natura 2000 sites in the FVG pilot area. In the lagoon area, the main protected area is SPA-SAC IT3320037 *Laguna di Marano e Grado* (16363 ha), while in the karst area SPA IT3341002 *Aree carsiche della Venezia Giulia* (12,002 ha) and SAC IT3340006 *Carso triestino e goriziano* (9648 ha) cover a large part of the karst plateau. On the other hand, due to the fragmentation of natural habitats, there are no large protected areas in the Friulian Plain, the largest being SAC IT3320034 *Boschi di Muzzana* (350 ha).

There are not only Natura 2000 sites, but also regional nature reserves, biotopes and Ramsar wetlands. The coastal area has a dense network in which, from the low sandy coast of Friuli to the high rocky coast of Trieste, the continuity of natural areas is well guaranteed. In the rear part of the coastal area (Friulian Plain), on the other hand, there are no large protected areas due to the anthropogenic pressure to which the area is subjected. The protected areas are less widespread and when they are present, they are small patches.

Demography and society

As can be seen from the previous paragraph, the land part of the FVG Pilot Site is divided into 3 macro areas: the lagoon area and the Friulian coast, the Karst and the coast of Trieste, and the Friulian plain behind the lagoon area. Each of these 3 areas has different characteristics in terms of demographic structure and society (**Figure 76**).

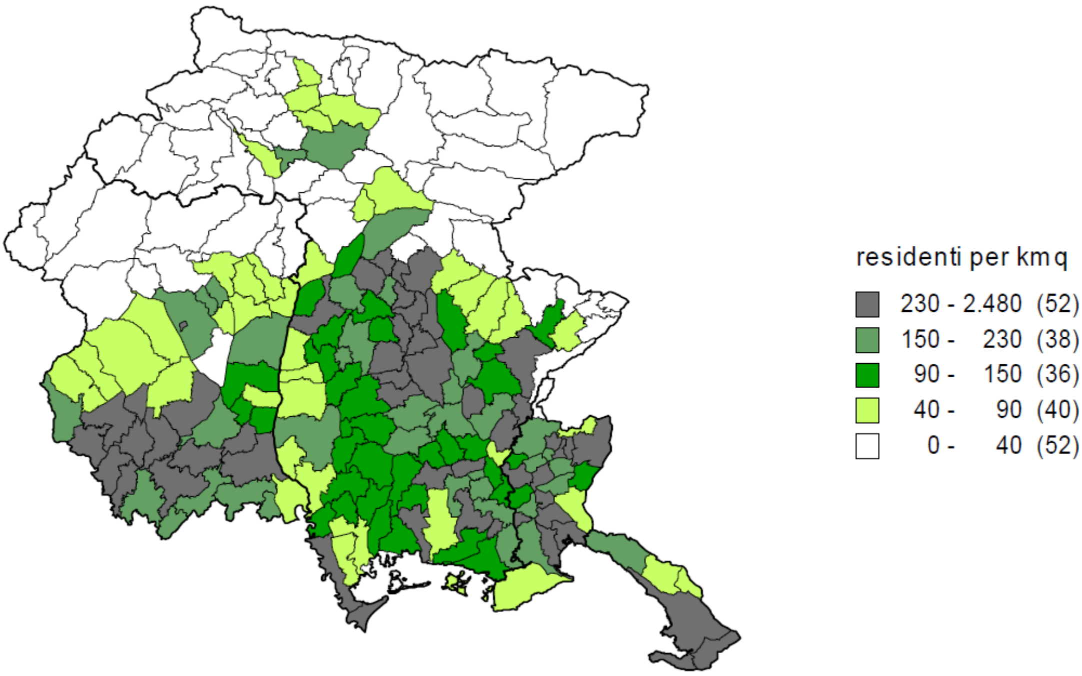

Figure 76. *Resident population density per km² in 2009 (from: Piano di Governo del Territorio, RAFVG 2013)*[93].

The lagoon area has only one important urban center, namely the city of Monfalcone (Gorizia-GO), where the resident population in 2011 was more than 25000 inhabitants. Then there is only one municipality with more than 10˙000 inhabitants (Latisana, Udine-UD) and 7 with more than 5000. Lignano Sabbiadoro (UD) has large tourist flows and its resident population is subject to large

[93] Regione Autonoma Friuli Venezia Giulia (2013). *Piano di Governo del Territorio. Relazione di analisi del territorio regionale*. Edited by Direzione centrale Infrastrutture, mobilità, pianificazione territoriale e lavori pubblici.

seasonal increases. Nevertheless, in the lagoon area the population has grown by almost 18% between 1951 and 2011.

The total population density has a median value of almost 109 inhabitants per km^2 (minimum 23, maximum 1370 in the municipality of Monfalcone). As for the demographic structure, the median number of elderly persons per child is 5.1.

Regarding education and employment, 7% of the population in the Lagoon and Friuli Coast has a university degree or a non-university degree. Unemployment, on the other hand, reaches a median value of almost 8%. As for the primary sector, the territory has a median value of almost 20 employees per 1000 inhabitants, with an agricultural area of 58% in relation to the municipal area. The median value of employees in the industrial and tertiary sectors is 67 and 111 per 1000 inhabitants, respectively. The median industrial density, on the other hand, is 2.1 enterprises per km^2.

In contrast, in the Karst and coastal area of Trieste, the resident population in 2011 was 282077, of which almost 72 percent resided in the city of Trieste, which at the same time also experienced the largest population loss. Indeed, since the post-war period (1951), Trieste has lost about 70000 inhabitants. The population density of the area has a median value of almost 224 inhabitants per km^2, twice the regional value of 111 inhabitants/ km^2. With regard to the demographic structure, on the other hand, the median value is 5.4 elderly people per child.

The indicator for the possession of university and polytechnic degrees is 9.4%, with Trieste standing out with a value of 15.3%. The median unemployment rate, on the other hand, is just over 6%. At 37%, this area also has the highest percentage of the resident population that travels outside the municipal boundaries on a daily basis.

The median number of persons employed in agriculture is almost 10 persons per 1000 inhabitants, while the median value of the area used for agriculture is 13.6%. The median employment in the industrial and tertiary sectors is 78 and 117 persons employed per 1000 inhabitants, respectively. Moreover, the median industrial density is 3.4 enterprises per km^2, which is significantly higher than the regional median.

In 2011, a total of 177˙096 people lived in the Friulian Plain. Since 1951, the population of the area has increased by almost 7%. The population density is 146 inhabitants per km^2, with a population structure of 4.9 elderly people per child.

Both the median university and non-university tertiary level graduates and the unemployment rate are close to 7%. On the other hand, the median agricultural workforce is 22.5 per 1000 inhabitants. For the secondary and tertiary sectors, the median is 93 and 90 employees per 1000 inhabitants, respectively. The agricultural area in relation to the municipal area is 59%, and the industrial density is 3.5 enterprises per km^2.

Economy and productive sectors

According to the latest available version of the Regional Territory Government Plan, dating back to 2013, in 2008 there were 98˙281 business locations in Friuli Venezia Giulia employing 411653 people. 36% of the local units operated in the tertiary sectors of trade, transport and hotels and 38% in other services. 11% of the units belonged to industry in the narrow sense, and the remaining 14% to construction. In terms of employees, however, the secondary sector absorbed 42% (industry and construction together), while the tertiary sector employed 58% of the total, in particular 31% in trade, transport and hotels and 28% in other tertiary services.

With respect to the regional distribution of employment, this was more concentrated in industry in the narrow sense, which alone absorbed 32% of the workforce, exceeding the average for the North-East. This is due to the larger size of the local units of manufacturing companies in the region compared to the rest of the country. In fact, the average number of employees per location was almost 12 units in FVG, compared to 10.5 units in the North-East and almost 9 units in Italy.

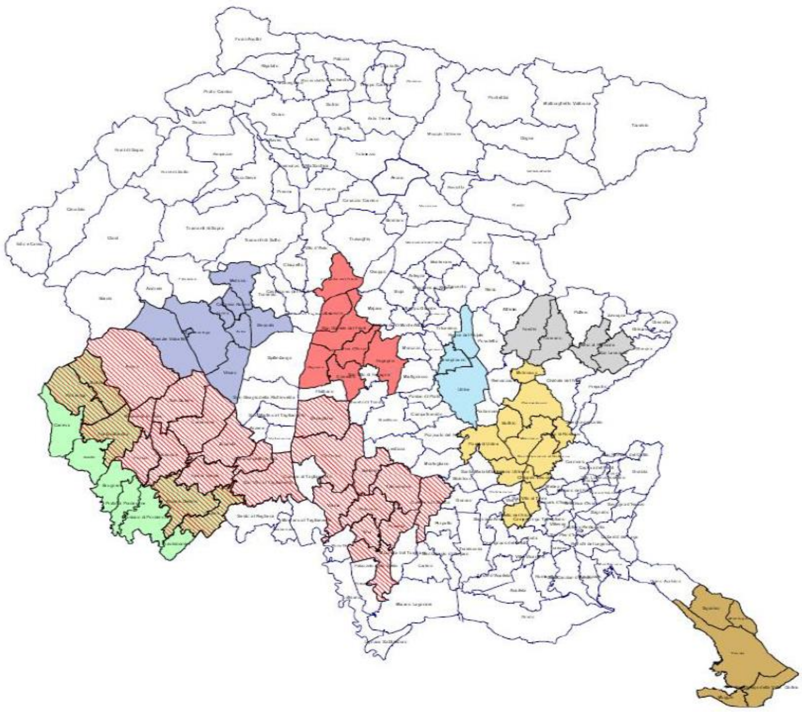

Figure 77*. Distribution of industrial districts in the FVG region (from: Piano di Governo del Territorio, RAFVG 2013). The brown coloured (Industrial District of Coffee) and red-striped (Industrial District of Components and Thermoelectromechanics) ones are those affected by the FVG Pilot Site.*

As regards the provinces involved in the Pilot Site, 47% of local production units were located in the province of Udine, 18% in the province of Trieste and 11% in the province of Gorizia. There are two industrial districts affecting the regional coastal strip, the first fully falling within the Pilot Site and located in the province of Trieste, the second marginally falling within the Pilot Site and affecting the province of Udine (**Figure 77**).

As far as the province of Trieste is concerned, the Coffee Industrial District includes all the municipalities in the province of Trieste with the exception of Duino Aurisina. Although there are only 16 companies, they generate 635 jobs, with exports of 106 million euros and an added value of 25 million. The District that falls partially within the province of Udine is that of Components and Thermoelectromechanics, and involves the municipalities of Palazzolo dello Stella, Pocenia and Rivignano Teor. The number of registered companies in 2010 was 2994, with a total of 33005 employees. The added value amounted to 1385 million euros, while exports exceeded 3610 million euros.

In addition to the Industrial Districts, the regional industrial fabric locally hosts several consortia. The Pilot Site includes the Consortium for the Industrial Development of the Monfalcone Municipality, the Consortium for the Industrial Development of the Aussa-Corno Area and the Ente Zona Industriale di Trieste (EZIT).

Finally, the Region hosts several poles dedicated to technical and scientific research that aim at innovation, competitiveness and excellence. Those that fall within the Pilot Site are the AREA Science Park (province of Trieste) and the DITENAVE Naval Technology District in Monfalcone (province of Gorizia).

Cultural heritage and landscape

As far as the cultural heritage within the Pilot Site is concerned, it is particularly rich and varied, starting from the Marano and Grado Lagoon where there are fishing valleys and traditional settlement architectures such as the "*casoni*". Those located near the mouths of the Stella River are particularly valuable. In addition, there are submerged archaeological areas in the lagoon area, of which, however, an up-to-date archaeological map is lacking.

As for the settlements, the historic centre of Grado is recognisable by its ancient bell tower, alleys and squares, waterfront, pine forests and beaches, together with Marano Lagunare, shaped by its ancient vocation as a fishing village. The island of Barbana, moreover, represents both a site of natural and religious value, together with the island of San Zulian, an ancient Roman port, lazaret and monastery. Not to mention the very high naturalistic value that the lagoon itself and the surrounding wetlands present in terms of biodiversity and naturalness of the landscape, where preserved.

There are many significant archaeological remains in the Karst and the Trieste coastline, such as the network of "*castellieri"*, ancient prehistoric settlements, as well as the rural buildings of the Karst plateau and its well-preserved villages and fortresses. In addition to these, there are the typical "*muretti a secco*", rural artefacts that served to demarcate landed estates.

Moreover, in this area, there are numerous testimonies from the Great War and the wartime and post-World War II period, such as trenches, shrines, museums and memorial sites. The close relationship of the cities of Trieste and Muggia with the sea and the numerous visual openings on the Gulf of Trieste, such as those located along the "*Strada Costiera*", are also worth mentioning.

Regarding the urban context, Trieste offers a great deal of industrial sector architecture to be restored, recalling the importance of the city at the time of the Austro-Hungarian Empire, as well as the network of castles of San Giusto, Duino and Miramare, from the medieval period to the 19th century.

Finally, the Friulian plain area includes well-preserved historical villages such as Strassoldo, historical structures linked to the anthropic use of water such as mills and sawmills, and the large archaeological area of Aquileia, which has become a UNESCO site (see D5.3.2-*FVG Pilot Site insights from case studies*). In addition, the cultural heritage system of the Stella River represents an exceptional landscape and environmental value, rich in villas, mills, and archaeological evidence from the protohistoric and Roman periods related to river navigation (landing places, wrecks) representative of an almost completely disappeared vegetation and rural landscape that affects a highly transformed plain territory.

5.2 – Exposure maps examples: Sea Level Rise

The regional territory is exposed to climate hazards at different levels. As seen above, the coastal area of the FVG region differs for geology, geomorphology, urban settlements, productive sectors, population composition, natural environments, cultural heritage etc.

In the following maps, we present some elements exposed to different categories of climate hazards, such as sea level rise, one of the major risks for coastal areas that are below zero level and affected by subsidence.

In **Figure 78** it shown the possible submersion of coastal protected areas and wetlands on the basis of a sea level rise from 0.4 m up to 0.7 m in accordance with data from the NASA-Sea Level Projection Tool (see 3.1 – Identification of the FVG coastal pilot area). Same data were used to overlap the Cultural heritage (**Figure 79**) and Infrastructure (**Figure 80**) networks within the FVG Pilot Site with the possible submerged areas. In **Figure 81** are shown the sites in which marineculture and "*vallicoltura*" (traditional lagoon fish farming) are practised in coastal and lagoon areas, while **Figure 82**, as far for the tourism context, represents the slow mobility routes identified by the Regional landscape Plan (PPR), together with the bathing waters. With regard to the urban and industrial context, **Figure 83** shows cities and urban settlements, together with industrial sites and porta areas.

As one can see, the most exposed elements are those in the lagoon area and Friuli lowland since, as mentioned before (see 5.1 – Context analysis), it is an area currently below the hydrometric zero and also affected by the subsidence phenomenon.

It is worth noting that in these digital elaborations are not considered the embankment system surrounding the lagoon areas as well as the drainage pumps system, which together contribute to maintain the area in dry conditions. However, it will be necessary to study how these systems will respond to the effects and impacts of climate change.

As explained in detail in the following section, the main source we consulted and from which we downloaded geographical and spatial data was the IRDAT regional catalogue. Another source we consulted was the National Geoportal, the national access point to environmental and spatial information. As already mentioned (see "Sea Level Rise projections" in 4.5 – Sea climate change: projections), the Digital Terrain Model used for the elaboration on sea level rise comes from IRDAT.

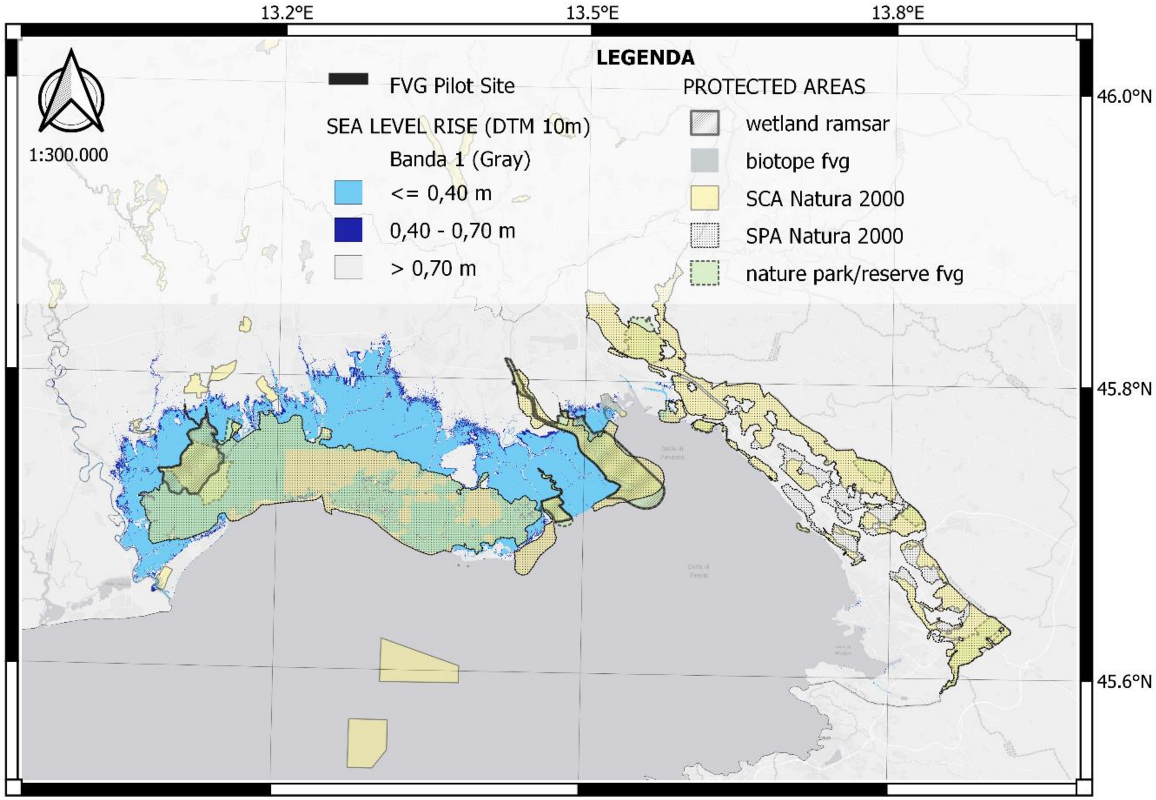

***Figure 78**. Protected areas (from IRDAT) within the FVG Pilot Site that could be submerged by rising sea levels in 2100 according to RCP2.6 (+0.4 m, light blue) and RCP8.5 (+0.7 m, blue).*

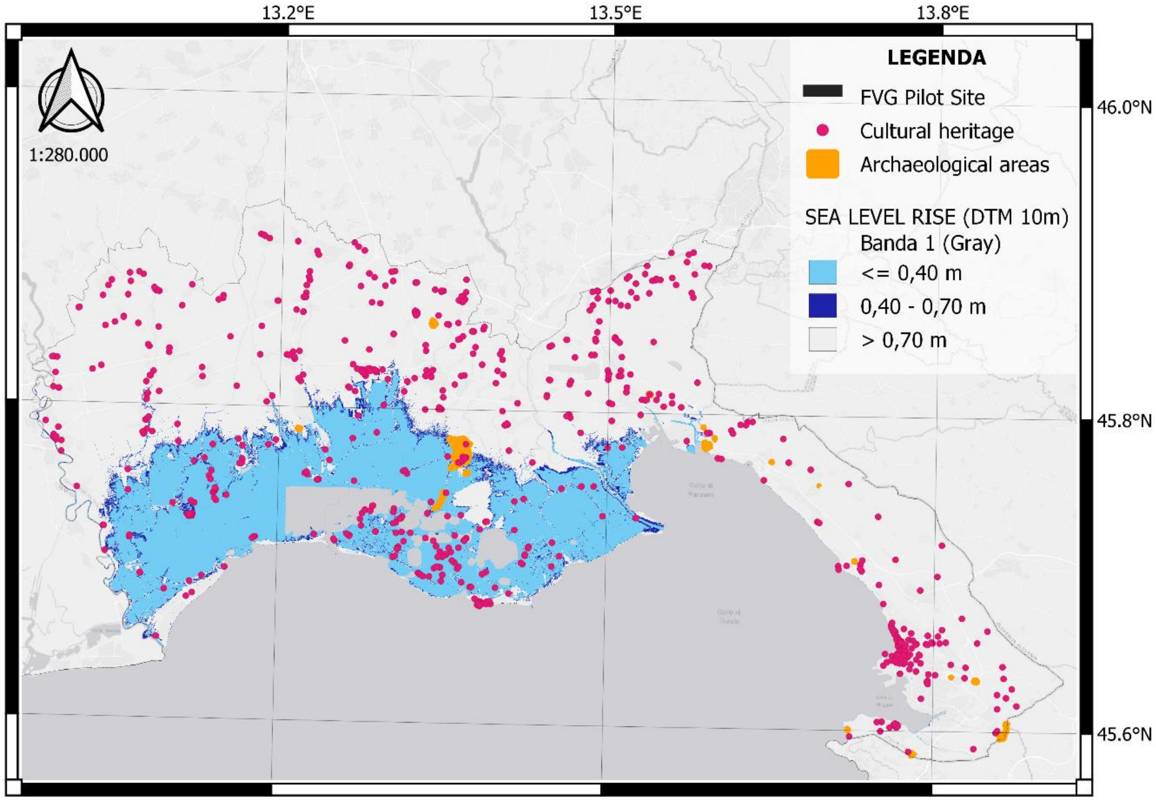

***Figure 79**. Cultural heritage network (from PPR) within the FVG Pilot Site that could be submerged by rising sea levels in 2100 according to RCP2.6 (+0.4 m, light blue) and RCP8.5 (+0.7 m, blue).*

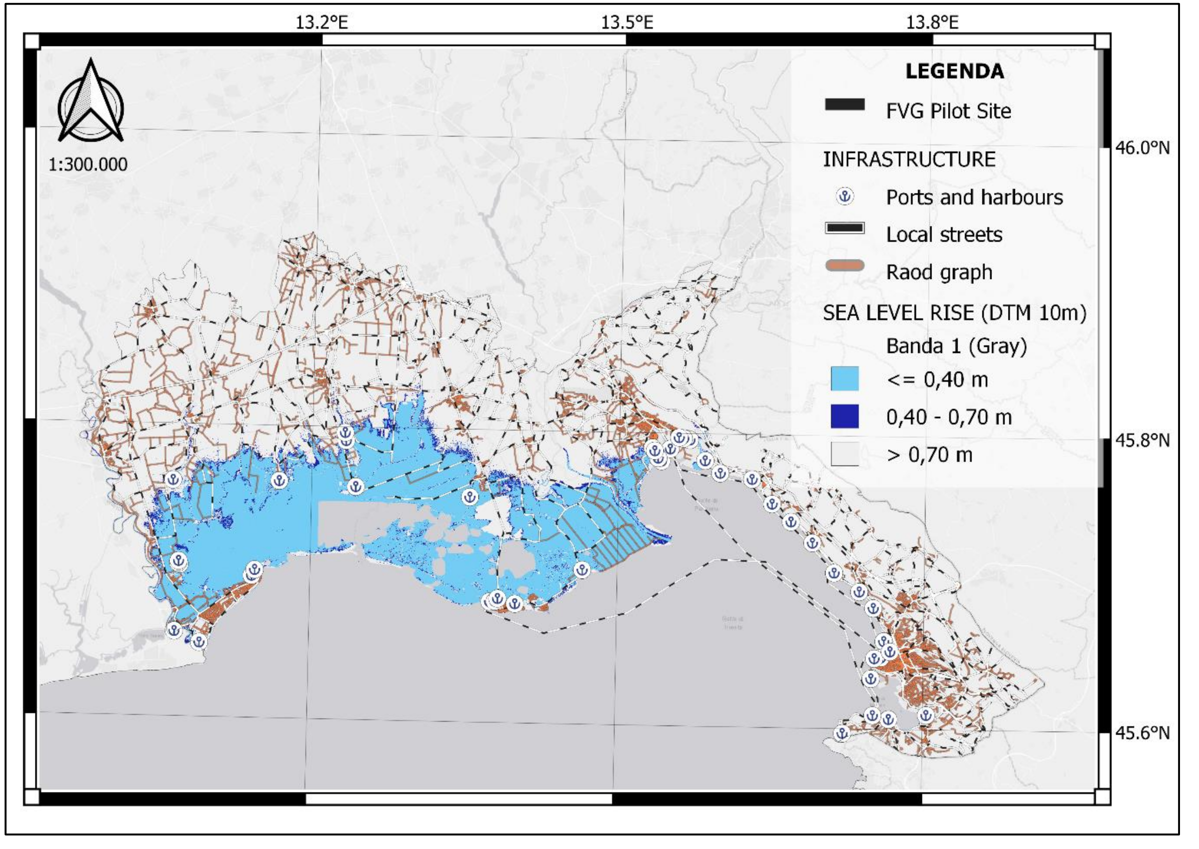

***Figure 80**. Infrastructure (from IRDAT) within the FVG Pilot Site that could be submerged by rising sea levels in 2100 according to RCP2.6 (+0.4 m, light blue) and RCP8.5 (+0.7 m, blue).*

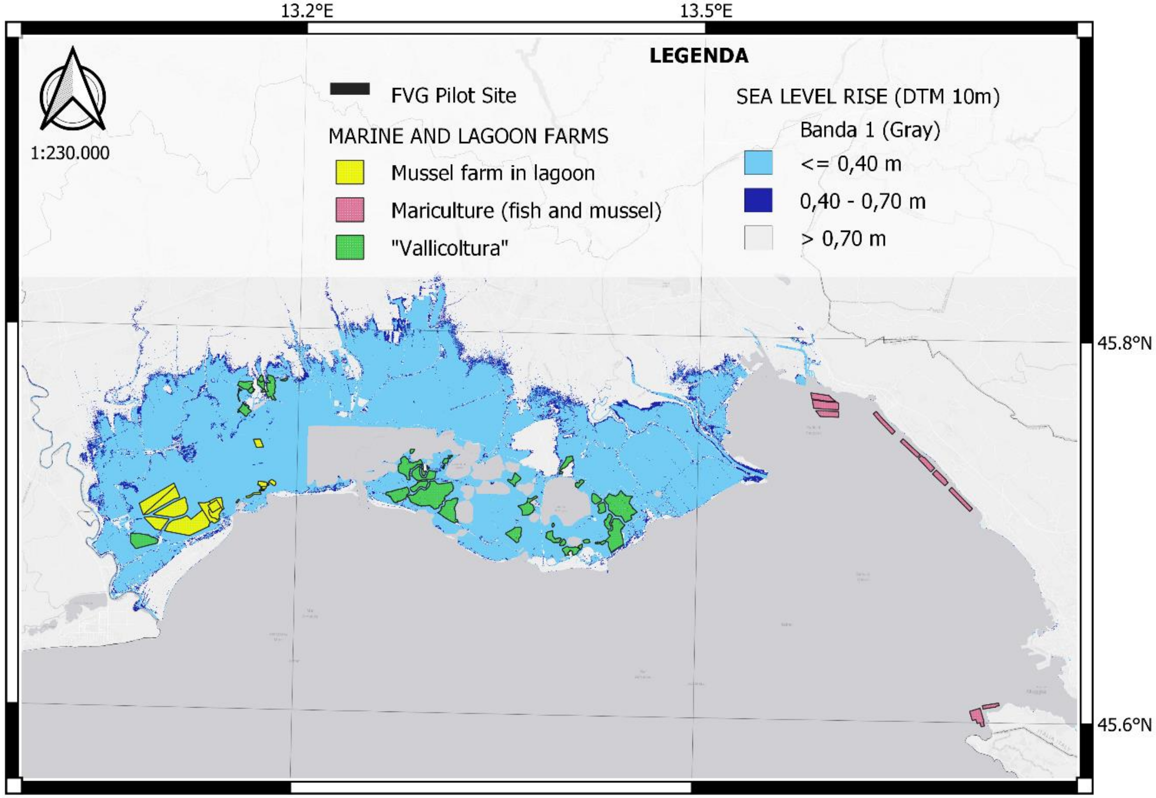

Figure 81. *Marineculture and "valliculture"areas (from IRDAT) within the FVG Pilot Site that could be submerged by rising sea levels in 2100 according to RCP2.6 (+0.4 m, light blue) and RCP8.5 (+0.7 m, blue).*

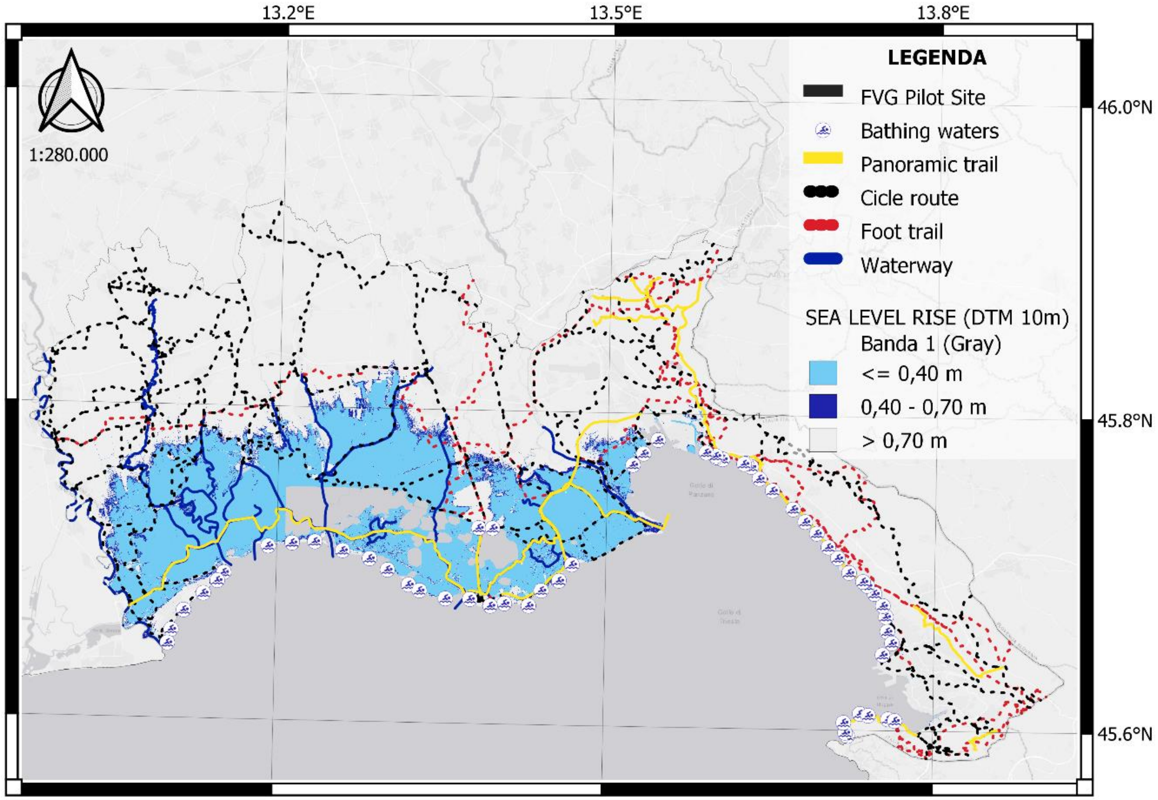

Figure 82. *Slow mobility pathways (from PPR) and bathing waters (from IRDAT) within the FVG Pilot Site that could be submerged by rising sea levels in 2100 according to RCP2.6 (+0.4 m, light blue) and RCP8.5 (+0.7 m, blue).*

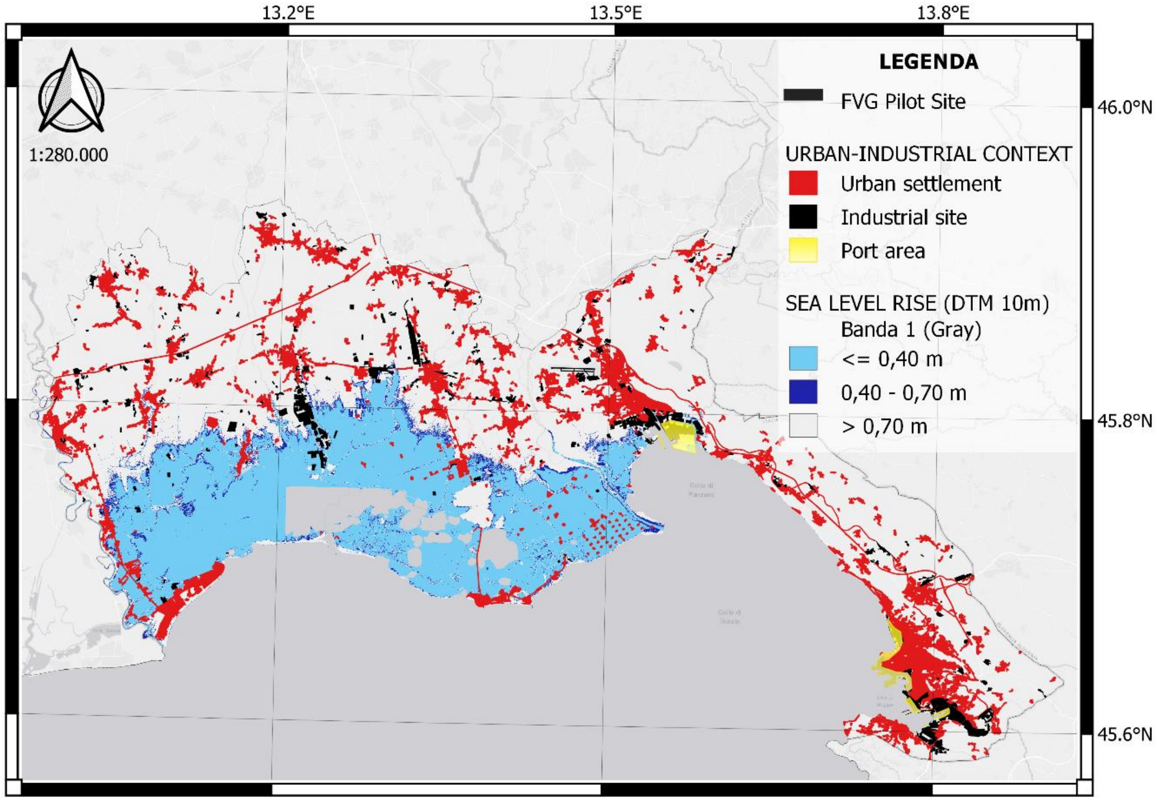

Figure 83. *Urban settlements, industrial sites (from IRDAT) and port areas (from Geoportale Nazionale) within the FVG Pilot Site that could be submerged by rising sea levels in 2100 according to RCP2.6 (+0.4 m, light blue) and RCP8.5 (+0.7 m, blue).*

5.3 – Preliminary survey of possible receptors based on geographic data

Thanks to the IRDAT service, a survey of possible receptors was created. IRDAT, the Regional Infrastructure for Environmental and Territorial Data, is a freely accessible open source catalogue where to find and download a large amount of georeferenced data produced by the departments and services of the Autonomous Region of Friuli Venezia Giulia. In some cases, other data portals were consulted, such as Adriplan[94], especially in relation to marine spatial data.

For our purpose, we looked for data that could gave information on exposed elements and possible impacts in the FVG Pilot Site, following the distribution of SNAC impact sectors (see 1.2 – Regional plans mapping). This effort represents a preliminary attempt to quantify the exposed elements in order to provide useful information for adaptation planning activities.

The information is presented in the table below (**Table 18**), in which an overall quantification of the receptor's presence in the Pilot Site is included, as well as whether it falls within Zone A (directly facing marine or transitional waters) or Zone B (backshore territories) of the Pilot Site. Where a link is present, an example of an impact that could occur involving that element has been assigned to the receptor.

As can be seen, there are some impact sectors where no receptors have been assigned to them. This is because our survey found no georeferenced receptor matching this impact sector (such as “Energy”, “Desertification, land degradation and droughts” and “Health”). However, in the case of the impact sector "Tourism", it has many links with other sectors such as "Coastal areas", "Biodiversity" or "Critical infrastructure". Therefore, in order to avoid duplication, it was decided to leave it blank.

As the 2030 Agenda points out, climate change has many links with sustainable development. To highlight these linkages, we report on the Sustainable Development Goals (SDGs) that intersect with climate change, particularly in terms of adaptation, as the CReIAMO PA project does in its fifth line of action, “*Strengthening administrative capacity for adaptation to climate change*”. In the document “*Methodologies for defining regional climate change adaptation strategies and plans*”[95], 7 SDGs are pointed out:

- SDG 1 on vulnerable people aims to reduce their exposure and vulnerability to extreme climatic events → *Health* impact sector;
- SDG 2 promotes sustainable agriculture → *Agriculture, aquaculture and fishing* impact sector;

[94] http://data.tools4msp.eu/

[95] CReIAMO PA (2017-2023) - *Competenze e Reti per l’Integrazione Ambientale e per il Miglioramento delle Organizzazioni della Pubblica Amministrazione*, funded in the context of PON - Axis 1 “*Governance e Capacità Istituzionale*” 2014-2020.

- SDG 6 relates to the sustainable management of water resources → *Water resources* impact sector;
- SDG 7 is concerned with access to sustainable sources of energy → *Energy* impact sector;
- SDG 9 on resilient infrastructure → C*ritical infrastructure* impact sector;
- SDG 11 covers policies and urban plans for mitigation and adaptation → *Urban settlements* impact sector;
- SDG 15 concerns forestry and how it interacts with LULUCF[96] provisions → *Forests* impact sector.

Furthermore, according to Climate-ADAPT, the European Climate Adaptation Platform[97], in its assessment of the national circumstances relevant for adaptation, the key sectors concerned for Italy are:

- AGRICULTURE AND FOOD

"In Italy water shortages during specific crop development stages may reduce the productivity of most crops (e.g. corn, soybeans and wheat). The decline in agricultural productivity could especially concern wheat yield and fruit and vegetables production, as a consequence of water scarcity, pathogens species increasing and soil degradation. Conversely olive, citrus, wine and durum wheat cultivation could become possible in the North of Italy. Wine production, an activity of particular economic relevance in Italy, could undergo major changes too. The suitability of cultivation areas for specific crops might modify, which could lead to displacements of agricultural productions. In addition, the future temperature increase (2-5°C) could reduce further the crop productivity. Climate change is expected to affect the livestock by increasing the risk of heat stress. Moreover, climate change is expected to reduce the quality of agricultural products, especially for the most vulnerable regions, characterized by a widespread use of traditional cultivation methods for quality food production. A particular attention should be paid to the risk posed by temperature and precipitation change to the different Protected Designation of Origin (PDO), the Protected Geographical Indication (PGI) and the Typical Geographical Indication (TGI), which are a significant element of the Italian agriculture."

- COASTAL AREAS

"Over 7.500 km of Italian coasts, 47% is represented by high or rocky shores and 53% are beaches. About 42% of the beaches is currently undergoing erosion processes. The rate of coastal erosion varies between 13% in Friuli Venezia Giulia and 91% in Molise. Saltwater intrusion in the coastal groundwater is already occurring in many coastal areas and will be aggravated by the sea level

[96] Land use, land-use change, and forestry, see the Regulation (EU) 2018/841 of the European Parliament and of the Council of 30 May 2018 on the inclusion of greenhouse gas emissions and removals from land use, land use change and forestry in the 2030 climate and energy framework, and amending Regulation (EU) No 525/2013 and Decision No 529/2013/EU (http://data.europa.eu/eli/reg/2018/841/oj).

[97] https://climate-adapt.eea.europa.eu/en/countries-regions/countries/italy

rise and the precipitation reduction, causing new potential problems to water supply. Future scenarios of climate change impacts on Italian coastal areas include: increase in coastal erosion and instability; loss of coastal land and related economic activities, infrastructures, urban settlements, recreational areas and natural heritage sites; reduction and loss of biodiversity and ecosystems (especially wetlands), and decrease of marine life caused by the combined effect of climate change and anthropogenic stress; damages to coastal rural economy, due to saltwater intrusion; negative impacts on tourism and possible displacement of tourist flows; possible threat to human health posed by flood events. About 4500 km of Italian coastal areas are at risk of sea flooding from sea level rise by the next 100 years. The Northern Adriatic coast, characterized by the Po river delta and the Venice lagoon, is at high risk, as this area lies below sea level and hosts many residential settlements, cultural heritage sites as well as industrial establishments."

- FORESTRY

"The effects of climate change on forest ecosystems are already significant so as to endanger the Italian forestry heritage, thus compromising the functionality and the ecosystem services it offers and are intended to increase as a consequence to future climate scenarios. The impact of climate change is causing changes in growth rates and productivity, in the composition of existing species and altitudinal and latitudinal displacement of forest habitats resulting in local biodiversity loss and increased risk of fire and damages from insects and pathogens, as well as alteration of the water cycle and carbon. The actual possibilities for the forest ecosystems to shift are scarce because climate change rate far exceeds the rate of colonization of new areas and the potential corridors are often obstructed by territorial fragmentation. Climate change could induce overall changes in the composition of species and habitats of Italian forests, resulting in local losses of biodiversity. Potential impacts of climate change include: northwards and altitudinal shift of the range of climatic and environmental conditions typical of the Mediterranean area; reduction of growth and productivity rates in Central-Southern Italy; changes in the distribution of main tree forest species in central Italy mostly located in the central Apennines, over 1500 m, in 2080; higher risk of forest fires and droughts, with possible extension of burned areas, more ignitions and longer fire seasons."

- HEALTH

"In addition to the direct effects of climate change due to heat and frost waves, with a consequent excess of mortality and morbidity and further socio-economic impacts such as damages to infrastructure and settlements, deaths, psychological and physical pathologies, resulting from increasingly frequent weather events, indirect health risks are mediated by the impacts of meteoclimatic factors on ecosystems, biodiversity, drinking and bathing water, soil, and outdoor and indoor air. Vector-borne diseases are already occurring in Italy. Even tick-borne infectious diseases have increased over the past decades in Italy. The consequences of hydrogeological occurrences have caused between 2002 and 2012 direct damages to population (128 dead due to floodings and 165 due to landslide). Expected impacts of climate change include: increased heat-related mortality and morbidity related to summer heat waves; slight reduction of cold-related mortality, linked to expected milder winter temperatures; increased risk of injuries, morbidity and

deaths from floods, heavy precipitation and fires events; increased respiratory diseases and allergic disorders as a result of the effects of changes in air pollution concentrations; adverse consequences of potentially more frequent and prolonged extreme ozone events and increasing toxicity of pollutants particularly in summertime; possible increase of vector borne diseases.”

- WATER MANAGEMENT

“Climate change is already affecting the hydrological cycle, with observed consequences on soil moisture, runoff, groundwater recharge. The existing conditions of high stress on water resources and hydro-geologic disturbance in some Italian regions could be exacerbated by projected climate change, with the following effects: reduced water availability and quality and increases in frequency and intensity of droughts especially in summer; increases in frequency and severity of river summer flows reductions and annual river flow decline and limited groundwater recharge; increased seasonal water deficit due to significant pressure of summer tourism peaks in small Italian islands. All these pressures will reduce the capability regenerate reservoirs, increasing, especially in summer and in southern regions, the competition among the different water uses. The systems that have the highest risks are those that use water resources from alluvial aquifers that are characterized by a large storage capacity coupled with long recharging times. Systems dependent on small-sized karst aquifers are particularly vulnerable to possible deficits, requiring the use of alternative resources (usually alluvial aquifers), with the consequent risk of overexploitation in case of prolonged drought. Systems less exposed to the risk of deficit, due to a variation in the climatic regime, are the interconnected ones that use different types of resources with different charging times and storage capacities.”

Climate change thus affects various sectors that directly or indirectly affect the population and the economy. Health is directly at risk, given that Italy and Friuli Venezia Giulia have an increasingly elderly population, the citizens most exposed to heat waves. Not only physical health is affected, but also mental health, with a general and widespread decline in well-being.

Agriculture and water management are also linked, affecting the primary production of food, which in turn affects other sectors such as exports, agriculture and viticulture, with a general decline in product quality. Changes in the hydrological cycle also endanger the population in terms of flooding and landslides, with the number of deaths due to these phenomena increasing in recent decades.

In addition, the loss of biodiversity and the reduction of ecosystem services, the increased risk of fire and damage from insects and pathogens, as well as the alteration of the water and carbon cycle, are affecting forests, which in Italy will cover up to 31% of the national territory by 2015 and are part of the national natural heritage.

Finally, coastal areas are exposed to mean sea level rise, erosion and saline intrusion, with a cascading effect on other related sectors such as tourism, land degradation, agriculture, cultural heritage, health, urban settlements, infrastructure, hydrogeological risk, biodiversity and ecosystems.

Table 18. Survey on possible receptors to adaptation policies in the FVG Pilot Site.

SNAC impact sector	Possible receptor	Quantified presence in the FVG Pilot Site	UoM	Source	PS zone	Data format	Edition	Scale	Other main available info	Link with a possible impact
WATER RESOURCES										
RI	Drainage pumps	34	Units	IRDAT	A-B	Vector – point	2008	25000	Maximum flow rate	Increase in flood events and consequent disruptions to services
	Spring uptakes	13	Units	IRDAT	A-B	Vector – point	2015	5000	Average and maximum flow rate; volume of the concession; drinkable y/n; destination use	Changes in water quality
	Surface uptakes	149	Units	IRDAT	A-B	Vector – point	2015	5000	Average and maximum flow rate; volume of the concession; drinkable y/n; destination use; what stream	Changes in the availability of renewable water sources
	Ground water uptakes	2332	Units	IRDAT	A-B	Vector – point	2015	5000	Average and maximum flow rate; volume of the concession; drinkable	

									y/n; depth; pump diameter	Changes in groundwater resource availability
	Declared wells	8679	Units	IRDAT	A-B	Vector – point	2010	5000	Prevalent destination use	
	Drinking water extraction	42	Units	IRDAT	A-B	Vector – point	2010	10000	Geographic evidence on drinking waters protected areas	
	Water bodies classification for management	2252.45	Km	IRDAT	A-B	Vector – line	2015	5000	Natural/modified	Increased problems for water and energy supply
	Surface water bodies	195.24	Km	IRDAT	A-B	Vector – line	2021	5000	Chemical and biological status; natural/modified	Changes in the hydrological cycle
DESERTIFICATION, LAND DEGRADATION AND DROUGHTS										
HYDROGEOLOGICAL RISK										
DI	Elements at risk of landslides	106	Units	IRDAT	A-B	Vector – line	2013	5000	Risk classification; type and perimeter of element	
	High risk of soil compaction	44	%	IRDAT	A-B	Vector – polygon	2014	100000	Risk classification; area	
	Flooded areas	250.28	Ha	IRDAT	A-B	Vector – polygon	2007	5000	Historical flooded area y/n; province	Increasing of damage to urban centres and their elements

	Events of hydraulic instability	10	Units	IRDAT	A-B	Vector – point, line, polygon	2006	5000	Municipality; land use in which the damage occurs; damage type and description; date; province	(infrastructure, cultural and landscape heritage, settlements)
	Landslide events	18	Units	IRDAT	A-B	Vector - polygon	2006	5000	Municipality; type of landslide movement; area; damage type and description	Reduction of frost-thaw landslides
	Landslides boundaries	265.14	Ha	IRDAT	A-B	Vector - polygon	2013	5000	Frequency of data updating; date of the event; competent authority; province; municipality; landslide status; type of landslide movement	Change in frequency and spatial distribution of landslide events
BIODIVERSITY AND ECOSYSTEMS (Terrestrial ecosystems; Marine ecosystems; Freshwater and transitional ecosystems)										
ET EM EA	*Carta Natura*	PS area fully covered	Km^2	IRDAT	A-B	Vector - polygon	2021	25000	Land use; environmental fragility; anthropic disturbance; ecological sensitivity and value; Corine biotopes code; degree of habitat fragmentation by the	Habitat alteration and loss

									road network; Natura 2000 priority habitat y/n	
	Biotopes	424.60	Ha	IRDAT	A-B	Vector - polygon	2020	5000	Municipality; date and founding law	
	Natura 2000 SPA-Special Protection Areas	320.94	Km^2	IRDAT	A-B	Vector - polygon	2018	5000	Type of site; altitude	
	Natura 2000 SAC-Special Areas of Conservation	332.96	Km^2	IRDAT	A-B	Vector - polygon	2018	5000	Type of site; biogeographical region	
	Natura 2000 habitats	35427.46	Ha	IRDAT	A-B	Vector - polygon	2020	10000	Type of site; biogeographical region; code and label compared to the regional habitats classification	
	Regional parks and reserves	62.36	Km^2	IRDAT	A-B	Vector - polygon	2018	5000	Founding law	
	Ramsar wetlands	40.04	Km^2	IRDAT	A	Vector - polygon	2018	5000	Municipality; founding law	Changes in the wintering/summering areas of birds
	Marine environments Eunis	3352.39	Km^2	Adriplan	A	Vector - polygon	2016		Benthic and littoral zonation; substrate; Eunis category and code	Changes in marine plant communities

	Transitional waters	174.17	Km^2	IRDAT	A	Vector - polygon	2021	5000	Chemical and ecological status	Alteration of transitional water habitats
	Marine-coastal waters	415.87	Km^2	IRDAT	A	Vector - polygon	2021	5000	Chemical and ecological status	Alteration of marine-coastal water habitats
FORESTS										
FO	Forest fire	1768	Units	IRDAT	A-B	Vector - polygon	2015	5000	Competent forestry station; province; location and date of the event; duration; vegetation status; causes	Increasing of drought risk in natural environments
AGRICULTURE, AQUACULTURE AND FISHING (Agriculture and food production; Aquaculture; Sea fishing)										
AG PM AC	Intensive and continuous arable crops	55399.83	Ha	*Carta Natura* (IRDAT)	A-B	Vector - polygon	2021	25000	Land use; environmental fragility; anthropic disturbance; ecological sensitivity and value; Corine biotopes code; degree of habitat fragmentation by the road network; Natura 2000 priority habitat y/n	Variation in the cultivation landscape and/or decrease in productivity
	Extensive crops and complex farming systems	1397.57								
	Vineyards	4344.62								Increasing of damage from atmospheric events

	Mussel farming, mariculture, *vallicoltura*	26.72	Km^2	IRDAT	A	Vector – polygon	2009	5000	Name of the farm; description; classification	Damage from extreme meteo-marine phenomena (storm surges and heat waves)
	Marine farms	121	Units	Adriplan	A	Vector – polygon	2015		Type of farm; location	Reduction of natural recruitment of molluscs and juveniles of fish species
	MBV areas (live bivalve molluscs)	567.05	Km^2	IRDAT	A	Vector – polygon	2010	10000	Area classification	Modification of growth and growth rate of farmed species, their survival, disease susceptibility and resistance to harmful/toxic organisms
COASTAL AREAS										
ZC	Lagoon inlets	10	Units	IRDAT	A	Vector – point	2007	5000		Modification of the landscape value of the territory
ZC	Bathing water	57	Units	IRDAT	A	Vector – point	2010	10000		Changing the summer bathing season in time and space and

										favourable conditions for certain activities
	Maritime works (breakwaters, outer dams, groynes, piers)	273	Units	IRDAT	A	Vector – line	2016	5000	Type of work; length (obtainable from GIS tools)	Landscape alterations due to semi-natural and artificial changes
	Jetties	22	Units	IRDAT	A	Vector – line	2007	5000	Length (obtainable from GIS tools)	
	Coastal defence works (embankments, seawalls, groynes)	224	Units	IRDAT	A	Vector – line	2007	5000	Type of work; length (obtainable from GIS tools)	Flooding events in urban areas
	Coastal dynamics	147	Units	IRDAT	A	Vector – line	2007	5000	Type of dynamics (accumulation/erosion); length (obtainable from GIS tools)	Geomorphological changes in coastal zones
	Lagoon coastline	1	Units	IRDAT	A	Vector – line	2018	5000	Length (obtainable from GIS tools)	
	Sea coastline	1	Units	IRDAT	A	Vector – line	2018	50000	Length (obtainable from GIS tools)	
	Regional coastline	261	Units	IRDAT	A	Vector – line	2016	5000	Length; type and subtype of coastal morphology	
TOURISM										
HEALTH										

URBAN SETTLEMENTS										
IU	Cities and urban settlements	1358.24	Ha	*Carta Natura* (IRDAT)	A-B	Vector - polygon	2021	25000	Land use; Corine biotopes code	Worsening of the population's physical, physiological, mental and social well-being and health
CRITICAL INFRASTRUCTURE (Cultural Heritage; Transportation and infrastructure; Industry and dangerous infrastructure)										
IP	Cultural heritage	700	Units	*Regional Landscape Plan* (IRDAT)	A-B	Vector – point	2018	5000	Identification and category; type; location (province, municipality, hamlet); historical dating; date of last intervention; landscape context	Rising costs of cultural heritage management
	Degraded areas (photovoltaic fields; quarries; dumps; military disposal in border areas)	321.35	Ha	*Regional Landscape Plan* (IRDAT)	A-B	Vector - polygon	2018	5000	Degree of impairment; type of alteration; land use; area (obtainable from GIS tools); location	Increasing the yield of photovoltaic systems
	Protected archaeological areas	282.79	Ha	*Regional Landscape Plan* (IRDAT)	A-B	Vector - polygon	2018	5000	Category and identification; location; historical dating	Submergence of archaeological sites and artistic heritage
	Ports and harbours	44	Units	Adriplan	A	Vector – point	2013		Denomination; location; type	Reducing accessibility to coastal infrastructure

	Road graph	2810.02	Km	IRDAT	A-B	Vector – line	2014	5000	Denomination and code; classification; length; body of management; number of lanes	Increased infrastructure damage from extreme weather and climate events and their consequences
	Regional and provincial roads	1274.76	Km	IRDAT	A-B	Vector – line	2006	5000	Denomination and code; classification; length; body of management	
	Coastal navigation	102.91	Km	*Regional and provincial roads* (IRDAT)	A	Vector – line	2006	5000	Denomination and code; classification; length; body of management	Increased difficulty and inconvenience in navigating inland and coastal waters
	Active industrial sites	3553.28	Ha	*Carta Natura* (IRDAT)	A-B	Vector - polygon	2021	25000	Land use; Corine biotopes code	Increased risks and consequent damage from extreme weather events to coastal industries and infrastructure
ENERGY										

Chapter 6 – Climate change impacts

6.1 – Potential impacts in FVG Pilot Site

An effort has been made to produce a synoptic table of the potential impacts that could affect the pilot area. Impacts were sorted according to the 18 impact sectors as classified by the Italian National Climate Change Adaptation Strategy and Plan. 4 impact sectors (Terrestrial ecosystems, Marine ecosystems, Freshwater and transitional ecosystems, Forests) were removed from the synoptic table, as they are analysed in more depth and detail in Deliverable 5.3.2. A fifth one - "Coastal areas" - was not included as a stand-alone sector because the related impacts are already included in other impact sectors. Therefore, the synoptic table includes 13 impact sectors.

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 content of the checklist of impacts, we focused only on those that could interest the Pilot Site, i.e., those affecting the coastal area of Friuli Venezia Giulia and the lowlands behind. We started from the *Climate change in FVG, first study* (ARPA 2018), then we considered the *Report on climate change impact indicators* by SNPA (2021)[98], i.e. the Italian National System for the Environmental Protection, and the *Climate-related hazard indices for Europe* edited by the European Environmental Agency (Crespi et al. 2020)[99]. In addition, we consulted also the *Italian National Climate Change Adaptation Strategy* (the so-called SNAC, MATTM 2015)[100], i.e. the reference document at national scale for planning local adaptations measurements.

With regard to drawing up of the synoptic table, the following bullet points summarize the steps we followed to harmonize the different sources we consulted:

- firstly, we adopted the same classification of impact sectors that had been established by the SNAC, which we also used in the mapping of regional plans (see 1.2 – Regional plans mapping): that allowed us to establish a first order in the synoptic table;
- starting from the *First study on climate change in FVG*, which considered the impacts potentially affecting the Friuli Venezia Giulia Region (thus already set at a regional scale), we checked if there were other impacts listed in the SNAC (set at national scale) that could fit for the FVG region, provided that the impact occurred on the territory. Therefore, we implemented the list of impacts initially only from the *First study* with some other SNAC impacts that had not yet been considered;

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[98] SNPA (2021). *Rapporto sugli indicatori d'impatto dei cambiamenti climatici – Edizione 2021*. Report SNPA 21/2021.
[99] 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.
[100] Ministero dell'Ambiente e della Tutela del Territorio e del Mare (2015). *Strategia Nazionale di Adattamento ai Cambiamenti Climatici*.

- we also reviewed the impacts of the *First study* to update their naming, reporting in the table if the name was modified;
- subsequently, we also included in the synoptic table the impacts of the SNPA Report that did not appear in either the *First Study* or the SNAC, or that had some differences with those already present. Therefore, for each impact in the checklist we reported the source from which it came;
- with regard to climate hazards linked to climate change impacts, the main sources from which to retrieve information were the *First study* and the SNPA Report. There was inhomogeneity among the sources consulted, as there were different wording depending on the document considered. In the end, we chose to refer to the hazard categories in the EEA Report with minor modifications explained as follows;
- we matched the different climate hazard wording found in the *First study* and SNPA Report, with the categories identified in the EEA report (**Table 19**). In addition, we made a small change to the name of the EEA categories to give them a meaning related to the change in the current situation. For example, the EEA category "Extreme heat" was changed to "Increase in extreme heat events";
- in the presence of climatic hazards found in the *First study* and SNPA Report that did not correspond to any EEA category, we reported the original wording found in the document considered (grey colour in **Table 19**);
- to attribute one or more climate hazards to each impact, we cross-referenced them to obtain a matrix, where in the first column we placed the impacts and in the first row the climate hazards. Where impacts and climate hazards were connected, a "Y" (YES) was inserted in the cell that crossed the row with the corresponding column;
- since climate hazards were reported as a variation of a current situation, we added the nature of this variation next to the cell marked "Y", where appropriate. In detail, for climate hazards *Air temperature variation*, *Variation in precipitation*, *Mean sea temperature variation*, we reported whether an increase or decrease is expected, as well as other available information such as season, type of precipitation, change in surface or deep water etc.;

***Table 19**. Climate hazard categories. On the left, the original categories found in the EEA Report (Crespi et al. 2020). On the right, the EEA climate hazard categories modified in order to give them a meaning related to the change in the current situation. In grey there are the categories found in other sources (Firs study, SNPA Report) that did not match with those in the EEA Report.*

Hazard category	Hazard type
Heat and cold	Mean temperature
	Extreme heat
	Cold spells and frost *
Wet and dry	Mean precipitation
	Extreme precipitation *
	River flooding
	Aridity
	Drought
	Wildfire
Wind	Mean wind speed
	Severe windstorm
Snow and ice	Snow and land ice
Coastal	Relative sea level
	Coastal flooding
Oceanic	Ocean temperature *
	Biochemical ocean properties *

Atmosphere	Climate conditions variation	Increase in solar radiant energy	Increase in CO_2 atmospheric level	Increase in UVB rays intensity			
Heat and cold	Air temperature variation	Increase in extreme heat events					
Wet and dry	Relative humidity variation	Variation in precipitation	Increase in heavy precipitation events	Increase in river flood events	Increase in aridity	Increase in drought events	Increase in wildfire events
Wind	Mean wind speed variation	Increase in severe windstorm events					
Coast	Increase in storm surges (mareggiata)	Increase in relative sea level rise	Increase in coastal flood events (acqua alta)				
Sea	Mean sea temperature variation	Increase in marine heatwaves	DO level variation	pH level variation	Salinity variation	Currents regime variation	

The synoptic table includes a list of 117 potential impacts distributed in 13 impact sectors. Impacts are cross-referenced with an overall of 23 climate hazards, distributed in 6 categories which fit with the FVG Pilot Site. Therefore, we excluded climate hazards of alpine origin, such as the category "Snow and ice". As previously stated, impacts on Ecosystems and Forests are treated in D5.3.2-FVG Pilot Site insights from case studies as case study and they are not included in this checklist.

It is worth noting that our impacts checklist represents the result of a preliminary survey: subjective choices have been made regarding the definition and clustering of impacts and their cross-referencing with hazards. There may be other impacts and/or intersections to be included on the basis of new evidence or methodologies. Our intention was to assemble an up-to-date and possibly comprehensive framework that would serve as a common basis for policy and decision makers, as well as local and regional stakeholders, to help them navigate the complex issue of adaptation.

More specifically, this synoptic "Potential impacts table" provides a basis for drawing up the inventory of previous events (occurred impacts) which have had significant effects in the planning area: one of the first steps to be carried out in the outlining of impact chains and in the risk and vulnerability assessment process, as explained in chapter *2.3 – Conceptual framework, methodologies and guidelines for adaptation planning*.

The impacts synoptic table in excel format is digitally attached to the present document as an annex. The language in which the table is written is Italian, as this is a product intended for and aimed at local policy makers.

Chapter 7 - Participatory process

7.1 – Potential SHs identification on the basis of "Pilot area features"

To involve stakeholders who are interested in adaptation measures and policies, a pooling exercise has been carried out within the framework of the AdriaClim project. Furthermore, a number of experts from different disciplines were approached to gather more information about the current and future situation of different areas.

The table below lists stakeholders and experts with whom we have interacted (**Table 20**, **Figure 84 A-F**). Many of these stakeholders and experts have provided us with information and points of view that have been useful in understanding the needs of a territory for the preparation of Deliverable 5.3.2, which focuses on case studies.

With regard to the case study on cultural heritage, a workshop was held by ARPA FVG in Aquileia on the 5th of December 2022[101]. The workshop was an opportunity to bring together a pool of experts and representatives of the local authorities. Participants were drawn from various disciplines, including archaeologists, architects, geologists, regional and local administrators, as well as those responsible for managing archaeological sites. On this occasion, an overview of climate change and its consequences on a regional scale was presented by experts from the ARPA FVG. The experts then looked at the impact on the cultural heritage, particularly in archaeological areas. The UNESCO site of Aquileia, with its Romanesque buildings and Roman mosaics, is a particular case in point.

***Table 20**. List of stakeholders (SH) and experts involved in the AdriaClim project.*

SH/Expert	Denomination	Institution	Area of influence	What
SH	Department of *Urban planning - Private building*	Municipality of Lignano Sabbiadoro	Local	Focus on beach erosion from a management perspective
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 a workshop
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

[101] https://www.arpa.fvg.it/temi/progetti/progetti-europei/news/cambiamenti-climatici-e-beni-culturali-ad-aquileia-il-workshop-adriaclim-per-costruire-conoscenze-condivise-1/

SH/Expert	Denomination	Institution	Area of influence	What
Expert	Department of *Mathematics and Geosciences* - Coastal Group	University of Trieste	Sub-regional	Focus on beach erosion from a scientific perspective and trends related to climate change
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)
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
SH	Comunità Riviera Friulana	Supra-municipal Entity (Municipalities of Carlino, Latisana, Lignano Sabbiadoro, Marano Lagunare, Muzzana del Turgnano, Palazzolo dello Stella, Pocenia, Porpetto, Precenicco, Rivignano-Teor, Ronchis, San Giorgio di Nogaro)	Local	Interest in the products of AdriaClim for the general planning with special reference to the impact on the ecosystems.

Figure 84 A-F. *Some moments of the participatory process: (A) Superintendence of Archaeology, Fine Arts and Landscape for Friuli Venezia Giulia; (B, C, D) Fondazione Aquileia; (E, F) Department of Life Sciences-University of Trieste.*

In addition, a webinars series was organized in 2021 introducing the AdriaClim project (**Figure 85**), in collaboration with the RESPONSe Italy-Croatia Interreg project (2019-2022). The event was coordinated by ARPA FVG (AdriaClim), APE FVG[102] and Informest[103] (RESPONSe), with the participation of several experts, which took part as speakers, from Regione Friuli Venezia Giulia, University of Trieste, Civil Protection, CReIAMO PA and Area Science Park.

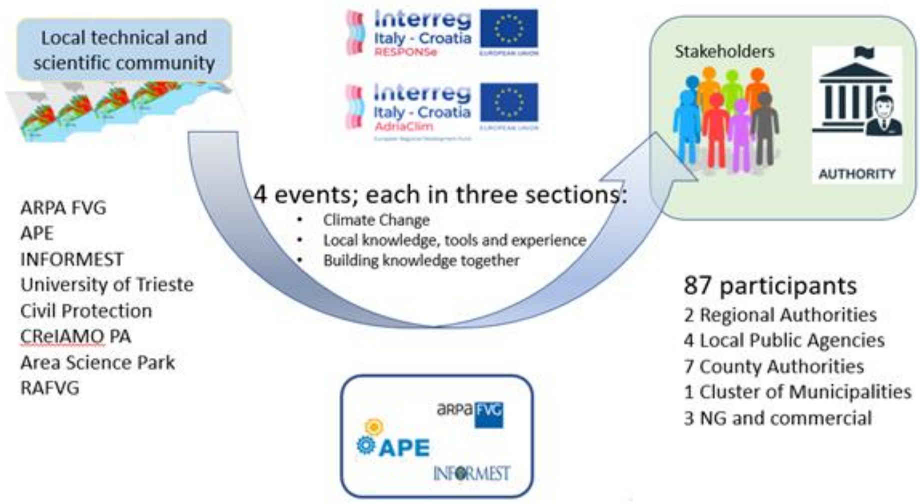

***Figure 85**. "Climate change and local adaptation in coastal and lagoon areas of Friuli Venezia Giulia" webinars organized by ARPA FVG, APE and Informest in 2021, in the context of AdriaClim and RESPONSe Interreg projects.*

The meetings had a dual purpose, informative and participatory:

1. provide participants with a knowledge base on climate change, its impacts and the actions authorities can take to address them, with particular reference to the local context and adaptation, but also to the national guidelines and methodologies for adaptation planning;
2. offer participants an opportunity to point out the critical issues that climate change is causing in their territories, the solutions that are being hypothesised or experimented with, and the support needs for effective adaptation planning.

A total of 87 people participated in the webinars, among which were represented 2 Regional Authorities, 4 Local Public Agencies, 7 County Authorities, 1 Cluster of Municipalities and 3 NG and commercial organisations.

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[102] Agenzia per l'Energia del Friuli Venezia Giulia - Friuli Venezia Giulia Energy Agency.

[103] Agenzia per lo sviluppo e la cooperazione economica internazionale - Agency for International Economic Development and Cooperation of Friuli Venezia Giulia.

Four appointments were organized to discuss on “Climate change and local adaptation in coastal and lagoon areas of Friuli Venezia Giulia”:

1. “Knowing and managing climate hazard”, 1st webinar on 13 May 2021 (**Figure 86**), available on YouTube at the following shortened link: https://rb.gy/0wmg2;
2. “Identify impacts with a view to assessing vulnerabilities and risks”, 2nd webinar on 21 May 2021 (**Figure 87**), available on YouTube at the following shortened link: https://rb.gy/da00r;
3. “Climate policies: building the basis for adaptation planning”, 3rd webinar on 4 June 2021 (**Figure 88**), available on YouTube at the following shortened link: https://rb.gy/ymddn;
4. “Planning and implementing adaptation”, 4th webinar on 18 June 2021 (**Figure 89**), available on YouTube at the following shortened link: https://rb.gy/0olx9.

This was the opportunity to establish initial contacts with some stakeholders on which we based subsequent interactions, as mentioned above.

13 maggio 2021
CONOSCERE E GESTIRE IL PERICOLO CLIMATICO

Introduzione e avvio lavori	**INFORMEST**
Il percorso dei 4 incontri e il quadro concettuale di riferimento	**ARPA FVG** Federica Flapp
L'ABC DEL CAMBIAMENTO CLIMATICO	
Intervista doppia: meteo vs clima	**ARPA FVG** Sergio Nordio e Andrea Cicogna
Dal meteo alle criticità al suolo. La risposta immediata agli eventi estremi.	**Protezione Civile Regionale FVG** Riccardo Ravalli
I cambiamenti climatici in Friuli Venezia Giulia: dalle evidenze agli scenari futuri	**ARPA FVG** Federica Flapp
CONOSCENZA LOCALE, STRUMENTI, ESPERIENZE	
Nuovi sviluppi per la conoscenza e la "previsione" dei pericoli climatici che interessano e interesseranno la costa del Friuli Venezia Giulia: • il progetto RESPONSe • il progetto AdriaClim	 **APE FVG -** Giulia Pederiva **ARPA FVG -** Dario Giaiotti
COSTRUIRE INSIEME LA CONOSCENZA	
Sessione interattiva: primi riscontri e avvio dell'inventario degli impatti dei cambiamenti climatici nelle aree costiere e lagunari del Friuli Venezia Giulia.	**APE FVG & ARPA FVG**
Conclusioni e prossimi appuntamenti	**INFORMEST**

Figure 86. *1st webinar Agenda "Knowing and managing climate hazard", on 13 May 2021.*

21 maggio 2021
INDIVIDUARE GLI IMPATTI NELL'OTTICA DELLA VALUTAZIONE DELLE VULNERABILITÀ E DEI RISCHI

Introduzione e avvio lavori	**INFORMEST**
L'ABC DEL CAMBIAMENTO CLIMATICO	
Valutare le vulnerabilità agli impatti e il rischio climatico: metodologie e strumenti	**PON Governance CReIAMO PA L5 - Cambiamenti climatici, presso MiTE** Antonio Carbone
CONOSCENZA LOCALE, STRUMENTI, ESPERIENZE	
Gli impatti dei cambiamenti climatici sull'ambiente fisico di coste e lagune del Friuli Venezia Giulia	**Università di Trieste, Dipartimento di Matematica e Geoscienze** Giorgio Fontolan
L'inventario degli impatti avvenuti: gli eventi estremi e i danni documentati dalla PCR	**Protezione Civile Regionale FVG** Riccardo Ravalli
COSTRUIRE INSIEME LA CONOSCENZA	
Sessione interattiva: l'inventario degli impatti dei cambiamenti climatici sull'ambiente e sui diversi settori socio-economici; conoscenze ed esperienze dei partecipanti. Avvio della ricognizione delle esperienze di adattamento locali	**APE FVG & ARPA FVG**
Conclusioni e prossimi appuntamenti	**INFORMEST**

Figure 87*. 2nd webinar Agenda "Identify impacts with a view to assessing vulnerabilities and risks", on 21 May 2021.*

4 giugno 2021

LE POLITICHE CLIMATICHE; COSTRUIRE LE BASI PER PIANIFICARE L'ADATTAMENTO

Introduzione e avvio lavori	**INFORMEST**
L'ABC DEL CAMBIAMENTO CLIMATICO	
Le politiche climatiche, dal globale al locale	**PON Governance CReIAMO PA L5 presso MiTE** Ferdinando Franceschelli
CONOSCENZA LOCALE, STRUMENTI, ESPERIENZE	
Il Patto dei Sindaci e la pianificazione climatica locale	**APE FVG** Daniele Barbieri
Pianificare la mitigazione e l'adattamento a scala locale e transfrontaliera: il progetto SECAP	**Regione Autonoma Friuli Venezia Giulia - Direzione centrale difesa dell'ambiente, energia e sviluppo sostenibile** Nicolò Tudorov **Area Science Park -Ufficio Studi, Struttura Innovazione e Sistemi Complessi** Stefano Alessandrini
COSTRUIRE INSIEME LA CONOSCENZA	
Sessione interattiva: ricognizione delle esperienze di adattamento locale già progettate e/o realizzate; conoscenze ed esperienze dei partecipanti.	**APE FVG & ARPA FVG**
Conclusioni e prossimi appuntamenti	**INFORMEST**

***Figure 88**. 3rd webinar Agenda "Climate policies: building the basis for adaptation planning", on 4 June 2021.*

18 giugno 2021
PIANIFICARE E IMPLEMENTARE L'ADATTAMENTO

Introduzione e avvio lavori	**INFORMEST**
L'ABC DEL CAMBIAMENTO CLIMATICO	
Strumenti per la pianificazione, il finanziamento e la governance dell'adattamento a scala locale o di area vasta	**PON Governance CReIAMO PA L5 presso MiTE** Elisa Anna Di Palma
Partecipazione e governance multi-livello: il Contratto di Area Umida della Laguna di Marano e il progetto INTERREG Italia-Croazia CREW	**Comunità Riviera Friulana - INTERREG Italia-Croazia CREW** Gabriele Pitacco
CONOSCENZA LOCALE, STRUMENTI, ESPERIENZE	
Climate Menu per le regioni adriatiche	**APE FVG**
Sinergie e continuità tra progetti Interreg a supporto dei percorsi di adattamento locale	**APE FVG & ARPA FVG**
SESSIONE INTERATTIVA	
Adaptation game	**APE FVG & ARPA FVG**
Conclusioni	**INFORMEST & ARPA FVG**

***Figure 89**. 4th webinar Agenda "Planning and implementing adaptation", on 18 June 2021.*

FVG Pilot Area: D5.3.2 - *FVG Pilot Site insights from case studies*

1) Impacts on cultural heritage in the UNESCO archaeological site of Aquileia
2) Impacts on ecosystems and biodiversity
3) Coastal erosion and beach drowning

Annexes

1. Regional plans mapping
2. Potential impacts table
3. Digital cartographic elaborations

3.1 SHYFEM simulation comparison respect to 2018 (benchmark year) series - Annual average sea surface temperature difference from the benchmark in the FVG Pilot Site

a. RCP2.6 - Decade 2025-2035
b. RCP2.6 - Decade 2045-2055
c. RCP2.6 - Decade 2085-2095
d. RCP4.5 - Decade 2025-2035
e. RCP4.5 - Decade 2045-2055
f. RCP4.5 - Decade 2085-2095
g. RCP8.5 – Decade 2025-2035
h. RCP8.5 - Decade 2045-2055
i. RCP8.5 - Decade 2085-2095

3.2 Sea Level Rise – Areas that could potentially be submerged by rising mean sea level according to RCP2.6 and RCP8.5 at different time scales (2050 and 2100)

a. SLR +0.2 m in 2050 (both RCP2.6 and RCP8.5)
b. SLR +0.4 (RCP2.6) and +0.7 m (RCP8.5) in 2100

3.3 Exposure maps examples: Sea Level Rise – Receptors within the FVG Pilot Site that could be submerged by rising sea levels in 2100 according to RCP2.6 (+0.4 m) and RCP8.5 (+0.7 m)

a. Protected areas
b. Cultural Heritage Network
c. Infrastructures (roads and ports)
d. Marine and lagoon farms
e. Tourism (slow mobility pathways and bathing waters)
f. Urban settlements and industrial sites

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Sitography

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