In-between waters.
Italian coastal landscape in Mediterranean Sea Level Rise scenarios: restoration of adaptive ecosystems in the 2100 Agro Pontino.

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IN-BETWEEN WATERS

Italian coastal landscape in Mediterranean Sea Level Rise scenarios:
restoration of adaptive ecosystems in the 2100 Agro Pontino.

In meno di pochi anni il terreno fangoso e irregolare della foresta fu trasformato in terreno pianeggiante da coltivare e in una superficie solida dove furono costruite tre nuove città. (...) La palude e la sua torbida fluidità, simbolo di primitività e natura, si contrappone al paesaggio costruito dalle forme solide, simbolo di civiltà, cultura e progresso (...) noto come Bonifica Integrale (...). Immaginate una vasta pianura, delimitata da un lato dal mare e dall'altro da una catena di montagne pittoresche. (...) Le pendici più basse sono ricoperte da boschetti di aranci rigogliosi. Foreste, prati e campi coltivati dividono la pianura.

In less than a fewyears the muddy and uneven ground of the forest was transformed into flat land to be cultivated and into solid surface where three new towns were built. (...) The marshland and its murky fluidity, as a symbol of primitiveness andnature, is opposed to the built landscape of solid forms, symbolizing civilization, culture, and progress (...) known as the Bonifica Integrale (Integral Reclamation)(...). Imagine an extendedplain, bounded on one side by the sea, on the other by a range of picturesque mountains. (...) The lower slopes are planted with groves of well-bearing orange-trees. Forests, meadows, and cultivated fields divide the plain.

"In-between Solidity and Fluidity: The Reclaimed Marshlands of Agro Pontino" Gruppuso, 2022.

TABLE OF CONTENTS

4 WATER RETURN

A. SCENARIO BUILDING PROCESS

ABSTRACT

Il bacino del Mediterraneo è sempre più riconosciuto come un'area a rischio climatico: secondo l'IPCC AR6, l'innalzamento del livello del mare dovrebbe superare 0,43-0,84 m entro il 2100 in scenari ad alte emissioni. Si prevede che circa 38.500 km² di territorio costiero mediterraneo saranno esposti a inondazioni marine entro la metà del secolo, con gravi conseguenze ecologiche e socioeconomiche.

Nel contesto italiano, le zone umide costiere hanno storicamente funzionato come un buffer dinamico, un paesaggio in grado di adattarsi naturalmente alle fluttuazioni del livello del mare e alle intrusioni saline. Tuttavia, secoli di bonifiche hanno sistematicamente sostituito questi ecosistemi adattivi con rigide griglie agricole e urbane, alterando in modo fondamentale il metabolismo paesaggistico del territorio e privandolo della sua intrinseca resilienza. Questa cancellazione ecologica è aggravata da una storia di eccessivo sviluppo costiero e di edilizia abusiva, che ha popolato le fragili coste con "città vuote" di residenze stagionali e contesti urbani con scarsi servizi. Di conseguenza, la costa italiana contemporanea si trova in uno stato di elevata vulnerabilità; la rimozione delle spugne naturali (le zone umide) combinata con insediamenti umani pesanti e rigidi rende il territorio incapace di assorbire i futuri rischi di innalzamento del livello del mare, trasformando un paesaggio adattivo in uno statico e indifeso.

L'Agro Pontino costituisce un caso di studio fondamentale per questa trasformazione del paesaggio.Un tempo un complesso sistema di paludi e lagune, il suo stato attuale riflette un cambiamento nel metabolismo del paesaggio che ha lasciato il territorio impreparato a gestire i rischi legati all'innalzamento del livello del mare che dovrà presto affrontare.

La tesi indaga come le zone umide costiere italiane possano essere ripensate attraverso l'architettura del paesaggio come infrastrutture resilienti in grado di rispondere ai futuri cambiamenti climatici, utilizzando un approccio di costruzione di scenari. Identificando le attuali vulnerabilità e le aree a rischio di futuro innalzamento del livello del mare, il progetto affronta sia la condizione attuale (2026) - caratterizzata da infrastrutture insufficienti e accesso limitato al mare - sia il paesaggio futuro (2100), modellato da nuove dinamiche ecologiche e idrologiche.

Anziché opporsi alla trasformazione, la tesi abbraccia l'innalzamento del livello del mare attraverso il concetto di "ritorno": ritorno alle condizioni precedenti alla bonifica e a un paesaggio in cui l'acqua è un elemento integrato piuttosto che una minaccia. Attraverso il caso studio dell'Agro Pontino, la tesi sostiene che le soluzioni alle sfide attuali e future risiedono nel recupero della memoria ecologica del passato e nella valorizzazione del carattere ibrido degli ecosistemi.

IT

The Mediterranean basin is increasingly recognized as a climate-risk hotspot: according to the IPCC AR6, sea-level rise is projected to exceed 0.43 0.84 m by 2100 under high-emission scenarios. Approximately 38,500 km² of Mediterranean coastal land are projected to be exposed to marine flooding by mid-century, leading to severe ecological and socio-economic consequences.

In the Italian context, coastal wetlands historically functioned as a dynamic buffer—a landscape capable of naturally adapting to fluctuating sea levels and saline intrusions. However, centuries of land reclamation (bonifiche) have systematically replaced these adaptive ecosystems with rigid agricultural and urban grids, fundamentally altering the territory's landscape metabolism and stripping it of its inherent resilience. This ecological erasure is compounded by a history of coastal over-development and illegal building (abusivismo), which has populated fragile shorelines with "empty cities" of seasonal residences and service-poor urban contexts. Consequently, the contemporary Italian coastline exists in a state of heightened vulnerability; the removal of natural sponges (the wetlands) combined with heavy, inflexible human settlements makes the territory incapable of absorbing future sea-level rise hazards, turning an adaptive landscape into a static and defenseless one.

The Agro Pontino serves as a critical case study for this landscape transformation. Once a complex system of marshes and lagoons, its current state reflects a changed landscape metabolism that left the territory ill-equipped to manage the hazards related to sea-level rise it will soon face.

The thesis investigates how Italian coastal wetlands can be reimagined through landscape architecture as resilient infrastructures capable of responding to future climate change, using a scenario building approach. By identifying current vulnerabilities and areas at risk from future sea level rise, the project addresses both the present condition (2026)—marked by insufficient infrastructures and limited access to the sea—and the future landscape (2100), shaped by new ecological and hydrological dynamics.

Rather than resisting transformation, the thesis embraces sea level rise through the concept of "returning": returning to pre reclamation conditions and to a landscape in which water is an integrated element rather than a threat.

Through the case study of the Agro Pontino, the thesis argues that solutions to both current and future challenges lie in recovering the ecological memory of the past and enhancing the hybrid character of ecosystems

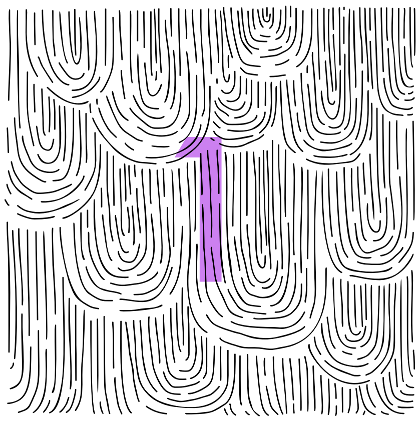
EN

RESEARCH TOPIC AND APPROACH

The thesis aims to deal with climate change and its implications within coastal ecosystems, taking into consideration the role of wetlands and marshlands in adapting the territories to future conditions.
Human pressure and tourism infrastructures are affecting the coasts, both at the global and Italian scale, inhibiting the capacity to deal with the projected Sea Level Rise and exacerbating impacts of climate change affecting the Cryosphere.

The thesis selected a scenario approach, drawn from IPCC reports, using RCPs 2.6 and 8.5 (representative trend in greenhouse gas and aerosol concentrations) to determine future possible trends (H. Lee & J. Romero, 2023b). The Sea Level Rise is defined as the key factor to be observed in coastal ecosystems: the historical and projected trends were studied as well as its consequences and impacts, defining possible responses and measurers for driven hazard *(Board 02, Section A.1).*
Mediterranean Sea is then observed, studying the specific Italian coastal context: climate drivers defining Sea Level Rise and coastal hazards affecting to current situation *(Board 01, Board A, Section A.2).*
Following a scientific approach (F. Antonioli et al., 2017; Mastrocicco et al., 2019; K. Lambeck et al., 2011) a 90m Digital Terrain Model is used to model the areas potentially covered by Sea: in 2050, with 0,24 m SLR for scenario RCP 2.6 and 0,32 m SLR for scenario RCP 8.5, and 2100, with 0,43 and 0,84 m (H.-O. Pörtner et al., 2019) *(Board 02, Section 4).*
The Argo Pontino is chosen, by the thesis, as the ground to test the scientific approach in developing project responses: in the territories coexist both protected coastal wetlands and an area of former marshland that have been reclaimed. The sharp contrast provide the perfect example to study the effects of the changing in territorial metabolism operated by the reclamation process: the Sea Level Rise scenario fits in a chronological horizon where areas, once existing as marshland, now areaffected by the most severe hazard and may observe, in future, sea cover phenomena *(Board B, Board 03, Section 2).*
The use of more detailed Digital Terrain Models (with 30 m and 5 m detail) makes possible

to investigate in detail the Sea Level Rise scenarios for Agro Pontino and builds solid base for the development of the design *(Board C, Section 4)*.
The approach guides the thesis into proposing a project that stretches in time. A masterplan for present day deals with current issues, with the illegal development being the most prominent one together with the lack of infrastructures: a design for a more clear dialogue with the cost, with public and mobility spaces, and the restoration of an adaptive landscape, as wetlands used to be before reclamation process *(Board 04, Board 06, Section 3)*.
The project, reaching 2100 horizon, decides to use projected SLR (as locally modelled) as a liquid ground that needs to be enhanced: together with the water, the adaptive landscape comes back in the territory bringing back the situation prior to the land reclamation massive works *(Board 05, Board 07)*.
The wetlands and the transitional waters represent, per se, a possible solution to climate change impacts and their possible arrival can be seen as an opportunity to develop projects that do not "reconstruct a landscape" but embrace transition allowing for a fully functional adaptation of the natural metabolism *(Section 1)*.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TRANSITIONAL WATERS

f.1

2025

Si diceva che le bombe sganciate nelle valli avessero scosso dal loro letargo esseri dormienti da secoli, da chissà quando. Ma ci fu chi riferí di avvistamenti già prima della guerra. Addirittura, gli uomini pesce erano apparsi per la prima volta vent'anni prima, durante le bonifiche di alcune valli di Comacchio: le valli Trebba, Ponti e Oppio. Le voci si tinsero di soprannaturale: la bonifica aveva destato quegli esseri da una millenaria catalessi e li aveva sloggiati, spingendoli nelle zone non ancora prosciugate. dove forse si erano riaddormentati. (...) Ma chi erano? Cosa erano? Sul fondo della valle Trebba si era scoperta la necropoli etrusca di Spina, forse c'era un nesso? Erano spiriti di Etruschi? Creature ferine dei tempi degli Etruschi? Divinità o, piú «plausibile», demoni della religione etrusca?(...)Com'erano fatti? Se qualcuno li avesse detti lunghi e scuri e viscidi come anguille, ma con braccia di uomini, gambe che si piegava ho in avanti come quelle degli uccelli, occhi neri privi di espressione, labbra enormi e pallide e barbigli di storione, barbigli che fremevano quando con un balzo quegli esseri arrivavano di fronte ai tedeschi, avrebbe reso bene parte dell'Impressione che suscitavano.Se qualcun altro li avesse descritti come grandi pesci con zampette da baco e teste di uomini, teste calve, o con radi capelli, che parevano prigioniere di quei corpi, volti di cui si distinguevano solo nasi ruscellanti muco verde.

The rumors took on a supernatural tone: the reclamation had awakened these beings from a thousand-year cataleptic sleep and displaced them, pushing them into areas that had not yet been drained, where they had perhaps fallen back asleep. (...) But who were they? What were they? At the bottom of the Trebba valley, the Etruscan necropolis of Spina had been discovered. Perhaps there was a connection? Were they spirits of the Etruscans? Wild creatures from Etruscan times? Gods or, more plausibly, demons of the Etruscan religion? (...) What did they look like? If someone had described them as long and dark and slimy like eels, but with human arms, legs that bent forward like those of birds, expressionless black eyes, enormous pale lips, and sturgeon barbels, barbels that quivered when those beings leaped in front of the Germans, it would have conveyed well the impression they made. If someone else had described them as large fish with silkworm legs and human heads, bald heads, or with sparse hair, which seemed imprisoned in those bodies, faces distinguished only by noses dripping with green mucus.

"Uomini Pesce" Wu Ming 1, 2022.

COASTAL WETLAND AS COMPLEX ECOSYSTEMS

Transitional waters are places of meeting and motion where land and sea negotiate their boundaries. Salt marshes, estuaries, tidal flats, and lagoons form dynamic mosaics shaped by tides, freshwater inflows, sediments, and organisms; here, sea rhythms mingle with terrestrial processes to create gradients of salinity, inundation, and nutrient exchange (Mitsch & Gosselink, 2015).
These zones act as thresholds and buffers—absorbing storm energy, filtering nutrients, and supporting rich productivity—yet remain highly sensitive to sealevel rise, sediment supply, and human pressure(Mitsch & Gosselink, 2015).
Wetlands can be defined, in their simplest form, as “lands with soils that are periodically flooded” by Michael Williams(Williams, 1993). They can be found in every climatic zone and rarely cover large areas, as they are normally intermittent and scattered in distribution.
Occupying the porous border between land and water and combining tidal and terrestrial rhythms, variable hydrology, and a mosaic of soils and vegetation, they have been described through multiple historical labels—marsh, swamp, bog, fen—each capturing different expressions of the same continuum (Mitsch & Gosselink, 2015).
For decades these areas were considered “wastelands” with no productive value, but they are now increasingly appreciated for their “natural functions” and the ecological benefits they provide(Williams, 1993). The scientific challenge lies less in naming than in recognising their roles: filters and transformers of nutrients, buffers against storms, and hotspots of biological activity whose productivity and connectivity vary widely(Mitsch & Gosselink, 2015).
Three attributes can be identified: hydrology (surface water or saturated root zones), soils (hydric properties formed by prolonged wetness), and biota (hydrophytes and the absence of floodintolerant species) (Azous & Horner, 2000; Mitsch & Gosselink, 2015).
Climate and geomorphology set the broader context for wetland formation, but hydrology remains the primary driver shaping the physicochemical environment, soil development, and the types and abundance of organisms (Mitsch & Gosselink, 2015).
According to researchers, multiple natural features make wetlands particularly difficult to identify: water levels fluctuate widely across seasons and years; wetlands occupy the shifting margin between uplands and open water; and their biota includes facultative species tolerant of both wet and dry conditions, complicating the use of vegetation as a clear indicator. Lastly, wetlands vary enormously in scale, structure, and processes, differing greatly across locations—from inland marshes to coastal salt marshes.
Coastal wetlands—salt marshes, mangroves, tidal flats, and seagrass meadows—occupy the shifting boundary between land and sea, and their history is inseparable from the long oscillations of global mean sea level (GMSL) (H.-O. Pörtner et al., 2019; Perillo, 2009).
Over the last 120,000 years, global sea level has undergone three major phases. During the last interglacial, sea level stood close to its present position. This was followed by a 100,000year glacial period in which

vast ice sheets stored ocean water on land, lowering sea level by roughly 120 m and exposing large portions of the continental shelves. Beginning around 20,000 years ago, sea level rose rapidly as the ice melted, eventually stabilising near modern values about 6,000 years ago, accompanied by isostatic rebound in formerly glaciated regions (Perillo, 2009).

These shifts profoundly shaped coastal wetlands. They likely expanded during the interglacial high stand, contracted to a fraction of their former extent during the glacial low stand—surviving mainly in sheltered estuaries—and reestablished widely as postglacial sealevel rise recreated intertidal zones. The relative stability reached in the midHolocene set the foundation for the coastal wetland configurations we recognise today (Perillo, 2009).

Coastal wetlands are not simply opportunistic colonisers of intertidal mudflats. Their development depends on crossing key elevation thresholds: below mean sea level, mudflats remain flat and inactive, but once they rise above it, tidal flows intensify, carve channels, and reorganise sediments and vegetation. These feedbacks show how sealevel fluctuations continually reshape coastal wetland states, and how accelerating sealevel rise may push even stable systems into new trajectories of adjustment (Perillo, 2009).

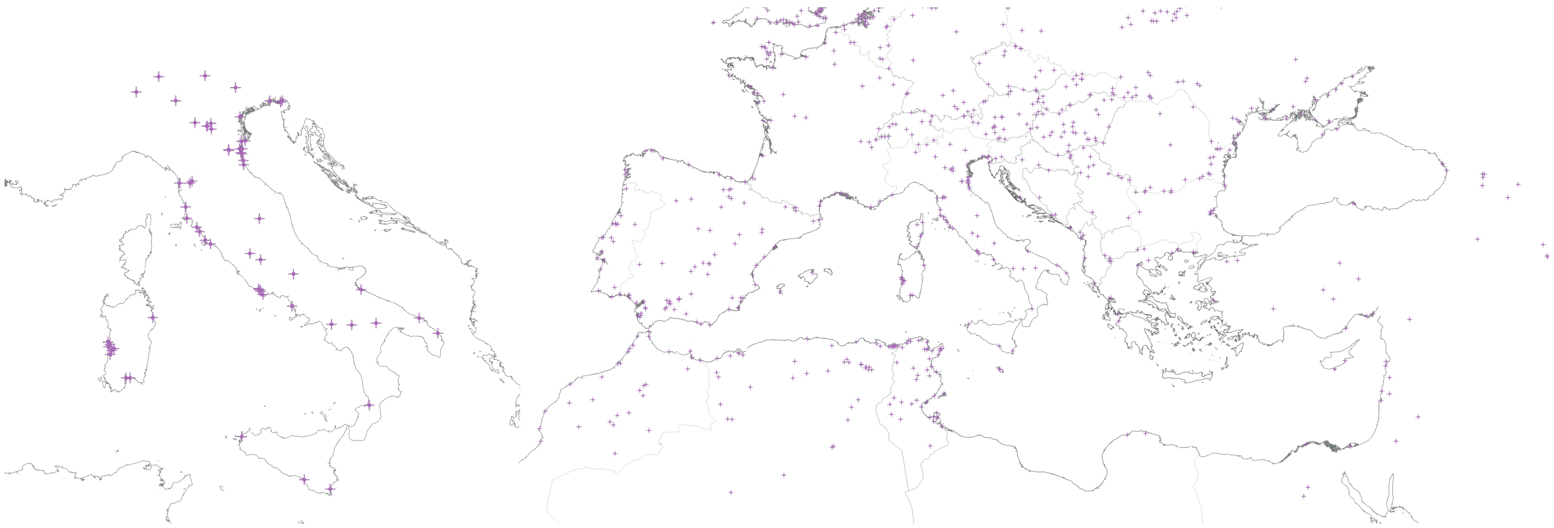
Sediment processes add another essential layer to coastal wetlands. Surface and subsurface water circulation regulate how sediments are deposited, mobilised, and transformed, creating tight feedbacks between hydrodynamics, geomorphology, and biological activity(Perillo, 2009)

f.2

RAMSAR CONVENTION AND PROTECTION IT ITALY

The global framework for wetland protection is founded on the Ramsar Convention, signed in 1971 in Ramsar, Iran, during the International Conference on the Conservation of Wetlands and Waterfowl (Convention on Wetlands of International Importance Especially as Waterfowl Habitat, 1971).
Promoted by the IWRB, with the support of IUCN and the ICBP, the Convention marked the first international commitment to safeguarding wetlands as critical ecological systems (Official Documents | The Convention on Wetlands, n.d.).
Ramsar adopts a broad definition of wetlands, including marshes, swamps, peatlands, and natural or artificial water bodies—fresh, brackish, or saline—as well as shallow marine areas up to six metres deep. Adjacent riparian and coastal zones, islands, and deeper waters are also included when ecologically linked to wetland habitats, especially for waterbirds (Zone Umide Di Importanza Internazionale Ai Sensi Della Convenzione Di Ramsar - Ministero Dell'Ambiente e Della Sicurezza Energetica, n.d.).
Its objective is the conservation and wise use of wetlands through site designation, habitat protection, research, and coordinated management (Zone Umide Di Importanza Internazionale Ai Sensi Della Convenzione Di Ramsar - Ministero Dell'Ambiente e Della Sicurezza Energetica, n.d.).
In Italy, the Ramsar Convention has been formally implemented through national legislation, leading to the designation of numerous wetlands of international importance (Elenco Delle Zone Umide - Ministero Dell'Ambiente e Della Sicurezza Energetica, n.d.).
Over time, these sites have come to overlap with other conservation frameworks—most notably the Natura 2000 network established under the EU Birds and Habitats Directives (DIRECTIVE 92/43/CEE "Habitat," 1992; DIRECTIVE 2009/147/EC "Birds," 2009).
As a result, many Italian Ramsar sites now coincide with Special Protection Areas (SPAs) and Special Areas of Conservation (SACs), creating a multilayered system of protection that reinforces the ecological value of wetlands and strengthens their role within broader landscapescale conservation strategies (Rete Natura 2000 - Ministero Dell'Ambiente e Della Sicurezza Energetica, n.d.).

RAMSAR Convention areas



f.3

NATURA 2000 areas

f.4

COASTAL PRESSURE AND CLIMATE CHANGE ADAPTATION

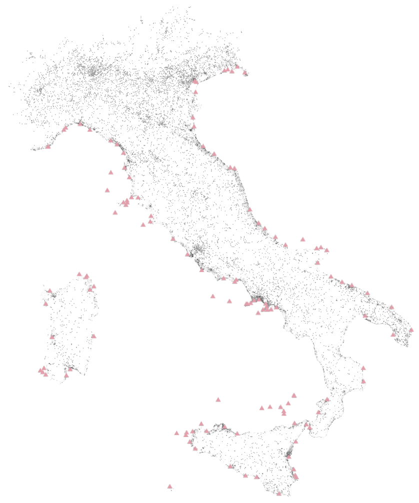
Human alteration—urbanisation above all—profoundly reshapes wetland conditions. Drainage, pollution, land conversion, and especially modified hydrology increase runoff volumes and peak flows, transporting sediments and pollutants that degrade water quality, alter soils, and disrupt vegetation and habitat structure. These pressures act at multiple scales, from the loss of entire wetland areas to the fragmentation of individual sites (Azous & Horner, 2000).
Because hydrology governs inundation patterns and underpins all other wetland processes, changes driven by urban runoff often exert the most immediate and decisive influence on a wetland's condition (Azous & Horner, 2000).
Building on these pressures, Italy's coastal zone adds another layer of complexity.
The Italian situation presents an exceptionally heterogeneous coastline—alternating rocky headlands, sandy littorals, pebble and boulder shores, and deeply indented gulfs and embayments—each with distinct geomorphological behaviours and sensitivities.
This physical diversity intersects with uneven patterns of urbanisation, port infrastructure, and reclaimed lowlands, creating a mosaic of coastal segments that respond very differently to erosion, storm exposure, and sealevel rise.
Coastal erosion exemplifies this tension. Disruptions to the sediment cycle—driven increasingly by human interventions—have reduced sediment supply and rigidified shorelines, triggering significant changes in both emerged and submerged beach morphology (Direzione generale per la salvaguardia del territorio e delle acque, 2017).
As natural buffers diminish, beaches become unstable and retreat landward, threatening settlements and infrastructure. Storm events, once absorbed by more resilient sedimentary systems, now reveal heightened vulnerability: in many stretches, a single storm can cause tens of metres of shoreline retreat. This accelerated erosion reflects the loss of natural coastal defences, particularly submerged beach platforms, which once acted as the primary buffer and structural support for sandy shores.
In many areas, the combination of fragile coastal types and intense human occupation amplifies hydrological stress, constrains natural sediment dynamics, and reduces the space available for inland migration, making the Italian coast a critical frontier where climate pressures and territorial adaptation must be addressed together(Direzione generale per la salvaguardia del territorio e delle acque, 2017).
Alongside these geomorphological and hydrological pressures, Italy's coastal territories are further shaped by intense human concentration.
Large stretches of the shoreline coincide with continuous urban fabric, dense transport infrastructures, and some of the country's highest tourism loads—factors that amplify environmental stress and reduce the system's capacity to absorb change.

Infrastructure and lithology

1

2

3



1. Physipgraphic units
- Ridge
- Embayment
- Gulf
- Bay
- Alluvional plain

2. Coast lithology
- Pebble
- Pebble with boulders
- Rocky
- Sandy
- Sandy with boulders

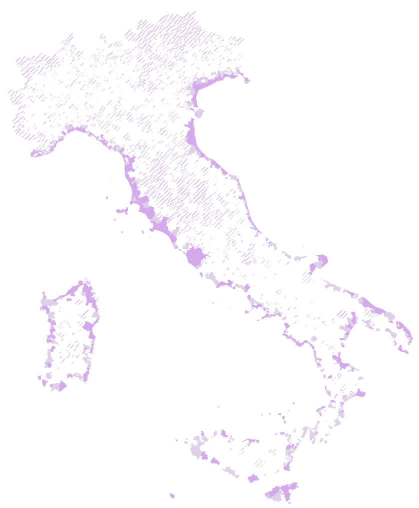
3. Coast infrastructure
- Ports

Land cover
- Coastal urban fabric
- Continuous urban fabric

Anthropic pressure

4

5



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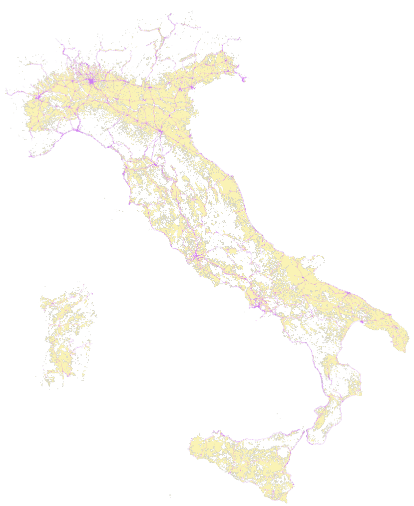


4. Polluted areas

PM10 Annual Average Concentration
42
2

5. Touristic pressure

Tourism-Based Classification

Synthetic Tourism Density Index
- High
- Really high

Index in Coastal municipality
- High
- Really high

6. Productive and mobility system
- Crop fields
- Railways

Hydrogeologic risk

7

8

9

7. Natural subsidence phenomena

Sinkholes location

Soil permeability velocity

Combined porosity, fracturing and karst
- High (M3)
- Really high (M4)

8. Flooding hazard areas
- High (HPH)
- Medium (MPH)
- Low (LPH)

9. Landslide Hazard areas
- High (P3)
- Really high (P4)

f.5

These overlapping pressures increase exposure to air pollution, constrain ecological processes, and limit the spatial flexibility needed for coastal adaptation. The result is a coastal landscape where environmental vulnerability and socioeconomic intensity converge, making climateresilient planning both more urgent and more complex.

Since the 1950s, global climate systems have undergone unprecedented change, with each of the past three decades warmer than the one before. Rising temperatures and altered hydrological regimes affect wetlands directly by modifying water levels, biogeochemical cycles, and the balance of greenhouse gases they exchange with the atmosphere (Borchert et al., 2018; Salimi et al., 2021a).

Because wetlands modulate methane, carbon dioxide, and nitrous oxide—three of the most influential greenhouse gases—they play a significant role in climate regulation while simultaneously being threatened by the very changes they help buffer. Climate change alters temperature, precipitation, and hydrology, reshaping wetland functioning and, in many cases, destabilising the ecological processes that sustain them (Salimi et al., 2021a).

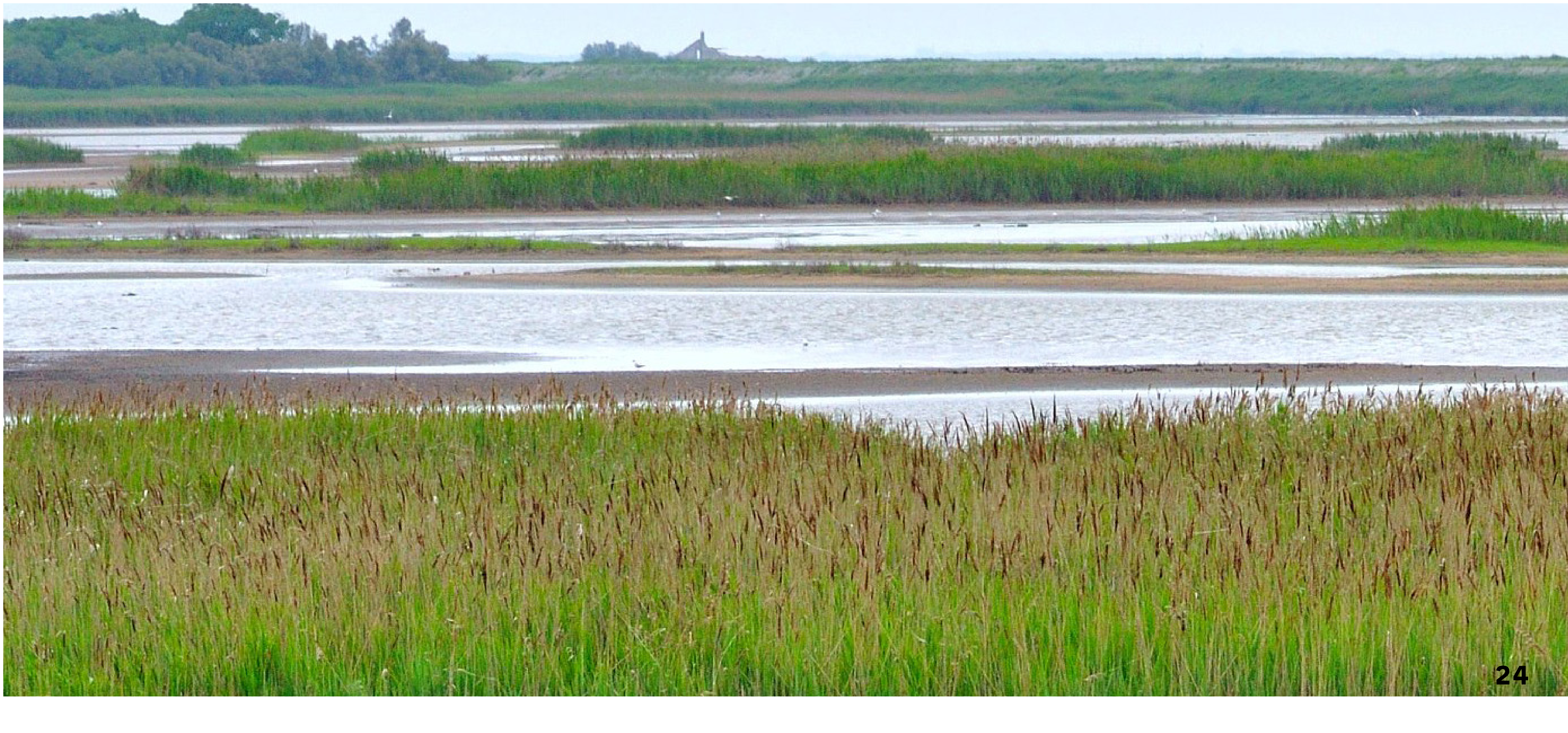
The influence of sealevel change emerges most clearly in coastal wetlands, where geomorphology and hydrodynamics respond to millennialscale shifts in ocean height, offering a compelling lens on how adaptive territories form and transform under accelerating climate pressures.

In this context, we can understand why coastal wetlands embody a dual condition: they are among the most adaptive territories in the face of environmental change, yet also among the most exposed.

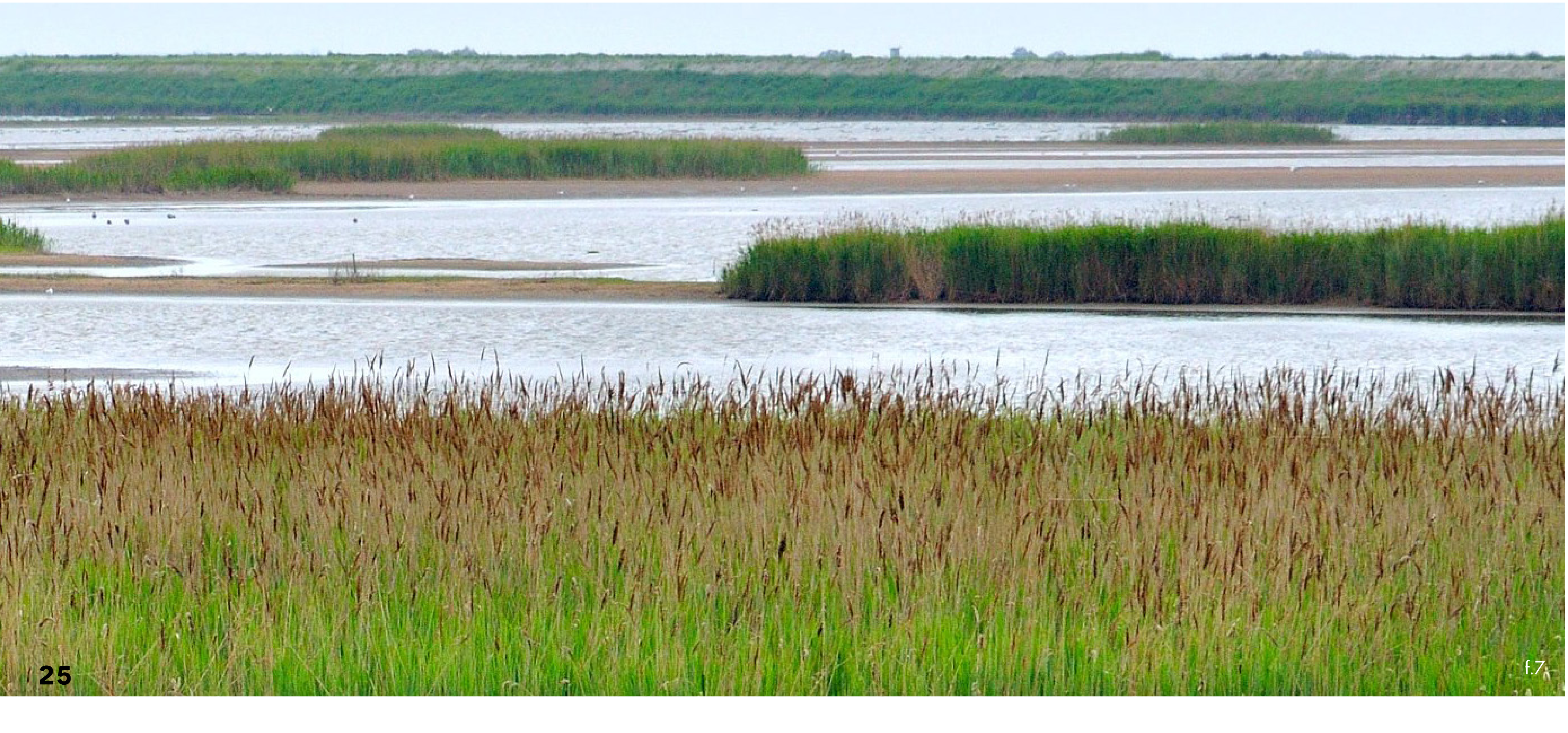
Their very structure depends on the shifting balance between land, sea, sediments, and hydrodynamics, making them capable of reorganising in response to disturbance but also vulnerable to any acceleration in the processes that shape them (Borchert et al., 2018; IPCC, 2023; Salimi et al., 2021b, 2021c).

f. 6

Despite these vulnerabilities, coastal wetlands remain profoundly adaptive systems. Their structure and functioning are shaped by continuous adjustments to water levels, sediment supply, and hydrodynamic forces, allowing them to reorganise in response to disturbance rather than simply degrade.
Yet this adaptive capacity is uneven: topography, sediment supply, and especially coastal urbanisation can restrict landward movement, producing "coastal squeeze," where wetlands are trapped between rising seas and fixed human infrastructure. In such settings, wetlands may drown if they cannot accrete vertically at a pace that matches sealevel rise. Identifying potential migration corridors and assessing where coastal squeeze is likely to occur have therefore become urgent tasks for many estuaries (Xiong et al., 2023).
Coastal wetlands provide erosion control, storm protection, water filtration, flood mitigation, carbon sequestration, and support for productive fisheries—services that depend on their ability to adjust to changing water levels.Despite their sensitivity, many coastal wetlands can keep pace with rising seas through two primary mechanisms. The first is vertical adjustment, driven by feedbacks between plant growth, inundation,



and sediment deposition, which allow wetlands to build elevation as water levels rise. The second is landward migration, whereby wetlands shift upslope or upriver into adjacent ecosystems when space and topography permit (Borchert et al., 2018).
These mechanisms, however, have limits. If sealevel rise outpaces vertical accretion, wetlands may drown and transition into subtidal habitats. And where urbanisation or steep topography block landward retreat, wetlands become trapped in a condition of coastal squeeze, losing the very space required for adaptation(Borchert et al., 2018; H.-O. Pörtner et al., 2019).
Under higher rates of sea level rise, landward migration is expected to become the dominant pathway for wetland persistence—yet it is precisely the pathway most constrained by human development.(Borchert et al., 2018; H.-O. Pörtner et al., 2019).
In conclusion, understanding sea level rise is crucial for anticipating how climate change will reshape coastal wetlands. As ocean levels climb and hydrological regimes shift, these ecosystems must either migrate landwards or vertically adjust—processes increasingly constrained by human development and accelerating environmental pressures.



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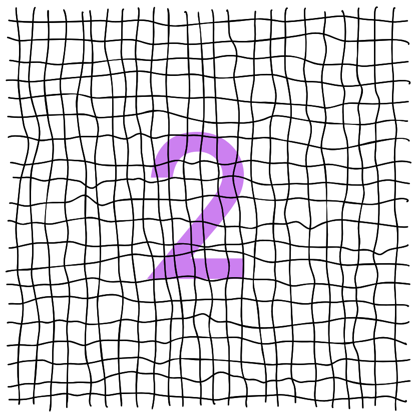
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LOST LANDSCAPE


f.8

1936

L'unico modo che aveva per andare a mare era quindi prendere la via più lunga, quella longitudinale verso Terracina. Essendo però questa di quaranta chilometri e tutta in piano – con un leggerissimo dislivello di soli due metri – lei capisce che non poteva quella povera acqua che perdere ogni idea d'abbrivio, ogni sogno di velocità e rassegnarsi buona buona a ristagnare. (...)
E così i miei zii sono arrivati a Littoria di notte. O meglio, non era ancora Littoria, era solo Littoria in costruzione, però era sempre Littoria. Le luci si vedevano già da Borgo Piave e lì - a Borgo Piave che ancora si chiamava Passo Barabino e c'erano un sacco di baracche anche lì, e pure baracche che vendevano vino e le impalcature del cantiere al centro della rotonda, dove stavano costruendo la torre serbatoio dell'acquedotto - i miei zii vedendo sullo sfondo le luci di Littoria hanno calcato sui pedali: «Forza tosi, vedém chi riva primo», per uno sprint di quattro chilometri.A Littoria cantieri dappertutto. Lampade. Cellule fotoelettriche. Viavai come se fosse giorno. Migliaia di persone - tutti maschi - a lavorare per le strade e per i fossi.

The only way she could get to the sea was therefore to take the longest route, the longitudinal one towards Terracina. However, as this was forty kilometers long and completely flat—with a very slight difference in height of only two meters—you can understand that the poor water could not help but lose all momentum, all dreams of speed, and resign itself to stagnating. (...)
And so my uncles arrived in Littoria at night. Or rather, it wasn't Littoria yet, it was just Littoria under construction, but it was still Littoria. The lights could already be seen from Borgo Piave and there – in Borgo Piave, which was still called Passo Barabino and where there were also lots of shacks, and even shacks selling wine and the scaffolding of the construction site in the center of the roundabout, where they were building the aqueduct's water tower—my uncles, seeing the lights of Littoria in the background, pedaled hard: "Come on kids, let's see who gets there first," for a four-kilometer sprint. In Littoria, there were construction sites everywhere. Lamps. Photoelectric cells. People coming and going as if it were daytime. Thousands of people - all men - working on the streets and in the ditches.

"Canale Mussolini" Pennacchi, 2010.

ITALIAN WETLANDS AND RECLAMATION THROUGH HISTORY

Water has always played a decisive role in Italian history, and across centuries its use, control, and transformation have been central forces in shaping landscapes, territories, and human settlements (Gruppuso, 2022).
The very idea of wetlands—paludi in Italian—becomes fully intelligible only when placed in relation to the long and complex history of land reclamation (bonifica) and hydraulic works that took place throughout centuries (Gruppuso, 2022).
For many centuries, large portions of Italy's lowlands, river valleys, and coastal margins were dominated by stagnant waters. Shortly after national unification, an approximate survey by engineer Raffaele Pareto identified over 1,068,000 hectares of marshland across the peninsula, nearly half of which lay in the former Kingdom of Naples and in the provinces of Bologna, Modena, Ferrara, and Ravenna—areas where water often prevailed over dry land (Bevilacqua, 2023; Biasillo, 2023).
Outside the Po Valley, most of these wetlands resulted from processes that nineteenthcentury hydraulic engineers had come to understand clearly. Rivers and torrents descending from the deforested Apennines carried heavy loads of eroded material, which accumulated in the lowlands and obstructed the natural outflow of waters to the sea.
Depressions, lowlying coastal plains, and the presence of springs or resurgence zones further contributed to the persistence of marshes. Ultimately, the formation of these stagnant waters was rooted in the distinctive relationship between the peninsula's coastal areas and the geomorphological dynamics of the Apennine chain(Bevilacqua, 2023; Biasillo, 2023). From the fifteenth century to the end of the nineteenth, the primary purpose of water use in Italy was irrigation, which—then as now—was expected to increase agricultural productivity. Along natural and artificial waterways, however, it was also common to divert water to power mills, fulling machines, presses, and a wide range of early industrial devices. River navigation was equally widespread, enabling the movement of goods and people (Isenbrug, 1981).
Yet in many parts of Italy, the existing legal framework created endless obstacles to a rational distribution of water uses, and only a few regions achieved an early and coherent hydraulic organization, as in the case of the Venetian Republic where the main concern was to regulate the rivers diverting them away from the lagoon to prevent its silting (Isenbrug, 1981).
In the eighteenth and nineteenth centuries, land reclamation gained prominence alongside irrigation, as new agricultural surfaces were created through drainage and the consolidation of marshes using sediment-rich river deposits (Isenbrug, 1981).
The fragmented pre-unification states produced regulatory frameworks adapted to diverse regional conditions, but national unification later imposed uniform directives that often deepened existing territorial imbalances, an effect reinforced by the laws of 1865 and 1882 (Biasillo, 2023; Isenbrug, 1981).
By the late nineteenth century, industrial expansion reshaped the entire system of water management, marking Italy's uneven transition into a capitalist economy (Isenbrug, 1981).

Between 1900 and 1950, water underwent a decisive shift in status: from a private resource to one formally declared public (and then redistributed through state concessions). So the State assumed a central role beetween 1916 and 1920, in determining who would be entrusted with hydraulic interventions.
From 1922 to 1940, and again in the early republican years up to 1950–52, the themes of reclamation, colonization, and irrigation dominated public discourse. These terms were repeated relentlessly in both technical literature and opinion journalism, becoming key slogans in the political and ideological narrative of the period (Gruppuso, 2022; Isenbrug, 1981). Reclamation and colonization became central ideological tools in mobilizing rural populations, consolidating alliances among agrarian elites, and attracting financial capital to modernize marginal territories and integrate them into the market economy, including in colonial contexts. This framework also contributed to the roots of today's hydrogeological instability since from the 1920s onward state services for monitoring water systems expanded while structures for environmental protection did not.
The modern history of reclamation in Italy begins with the 1882 Baccarini Law, which defined reclamation primarily as hydraulic reordering (Legge n.269, 1882). A qualitative shift occurred after 1924 with Serpieri's first governmental mandate, when public funding was increasingly used as a tool for land transformation in the plains. This trajectory culminated in the Testo Unico 1933, whose first article introduced the notion of "bonifica integrale", uniting public works and land improvements within a single plan aimed at a "radical transformation of the productive system" (Isenbrug, 1981; Regio Decreto n. 215, 1933).


f.11


f.10

CONSTRUCTION OF "PALUDI PONTINE" IMAGINARY

"Civilization, however, comes to a halt at Nettuno, for immediately beyond the town begins the solitude of the Pontine forest, stretching all the way to Terracina. Along the coast there is no settlement to be found; only a few isolated towers, standing about two miles apart, rise from the romantic and melancholy solitude of these shores, whose charm is truly wonderful." (Gregorovius, 1995).

The recent history and geography of the Agro Pontino—today a highly urbanized corridor seventy kilometres south of Rome—cannot be understood without considering the interpretive frame that has long shaped its representation(Gruppuso, 2022).

In the 1930s the fascist regime subjected the area to an unprecedented experiment in ecological and social engineering, the Bonifica Integrale: the drainage of one of Italy's largest forested wetlands, the reorganization of land tenure, and the construction of new towns designed to embody the regime's agrarian modernity(Gruppuso, 2022). Within dominant historiography, the Pontine Marshes appear as a primordial, disorderly landscape, and reclamation is cast as the act that finally imposed a stable frontier between land and water, enabling agriculture and settlement (Gruppuso, 2022).

Yet wetlands resist such clarity. The Pontine Marshes were shaped by overlapping, often conflicting regimes of management: drainage and conservation, agricultural ambitions and reluctance to cultivate, speculation and informal uses of the forest commons. Ecologically, too, the area eluded binary categories. Contemporary accounts describe a semi-liquid terrain where fields emerged and disappeared with seasons and weather, a shifting mosaic of water, meadows, and arable patches (Bevilacqua, 2023).

The marsh was not a void awaiting order, but a dynamic equilibrium in which land and water continually redefined each other (Bevilacqua, 2023).

From the late nineteenth century onward, new qualitative and quantitative readings of the Pontine landscape began to circulate, challenging earlier depictions of the marshes as either an empty, hostile void or, conversely, an untouched pastoral nature.

The first systematic knowledge of the area had in fact emerged only with the reclamation works promoted by Pope Pius VI at the end of the eighteenth century; through those partial hydraulic interventions, it became possible to explore and document a territory that had until then remained largely inaccessible (Biasillo, 2023). Terracina was among a small group of municipalities in the Roman province to possess substantial communal lands. A 1910 inspection by the Ministry of Agriculture, Industry and Commerce estimated its collective estate at roughly 20,000 hectares, with largest tracts as the "Selva marittima" and the "Selva montuosa", with additional lands for grazing and seasonal cultivation. The Selva marittima, one of the most extensive lowland forests in Italy, was around 14,500 hectares during this period (Biasillo, 2023).

The marshes also contained extensive dry areas where seasonally for grazing (often by shepherds arriving from neighbouring town) and cultivated plots were present as well.

Population was unstable. Agriculture on these large estates relied on seasonal labour for the harvest of wheat and maize (migrant workers primarily from Sora, Frosinone, and Cassino) (Biasillo, 2023).

Their cyclical presence shaped the settlement patterns of the forest clearings: the "lestra"—a temporary hut built in open glades—remained the characteristic dwelling of Terracina's flatland woods. These structure were noted by Goethe in the late eighteenth century and later photographed by geographer Elio Migliorini (Biasillo, 2023).
Alongside instability, poverty was defining the agricultural fluctuating population(Biasillo, 2023).
Fishermen, however, played a distinctive role in the wettest zones: their livelihood depended on maintaining closed-water systems, an interest that frequently clashed with the aims of reclamation. They openly opposed the expansion of dry land, and contemporary observers noted their deliberate efforts to preserve or even extend lacustrine water (Biasillo, 2023).


f.11

f.12

f.13

f.14

f.15


f.16


f.17


f.18


f.19

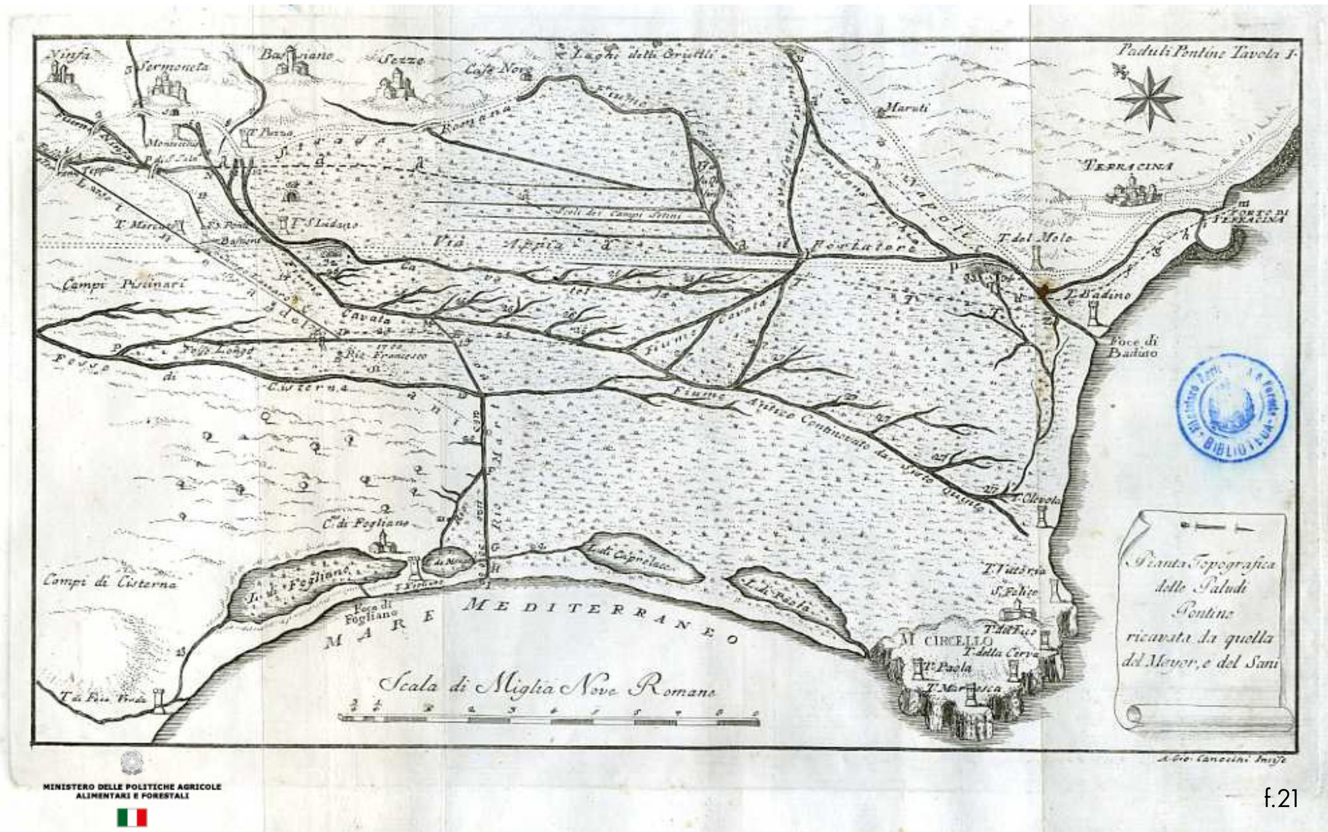

f.20

THE RECONFIGURATION OF TERRITORIAL METABOLISM

The transformation of the Pontine Marshes was carried out by the fascist regime, which in the 1930s concentrated major resources and political attention on this vast landscape just south of Rome. The socalled "bonifica integrale" was envisioned not merely as the drainage of marshes and ponds, but as the comprehensive construction of a new territory: agricultural modernization, permanent settlement, rural housing, and a network of roads linking the reclaimed land to regional markets (Biasillo, 2023).
For the regime, the Pontine project became the most ambitious territorial intervention of fascism and a privileged stage for its propaganda. Mussolini and the ruling elites could present the successful drainage of the marshes as an achievement where centuries of papal attempts had failed becaming the regime's most dazzling showcase, feeding an imperial rhetoric of the Roman city-founding legacy with the creation of entirely new towns as Littoria, Sabaudia, Aprilia, Pomezia (Bevilacqua, 2023).
Early drainage attempts in the Pontine region date back to ancient Rome and the Ostrogothic kingdom, though little survives beyond a few inscriptions and the line of the Appian Way. The first sustained phase of reclamation began only at the end of the eighteenth century with Pope Pius VI, who inherited two earlier works—the Terracina canal (Portatore) and the Sisto River—and entrusted engineer Gaetano Rappini with a comprehensive plan (Vöchting, 1990). Rappini envisioned a major canal capable of collecting both surface and groundwater, but the Linea Pia, running along the Appian Way, could not satisfy both functions. If raised to carry surface waters, it failed to drain the deeper aquifers; if lowered for groundwater, it caused renewed flooding. This structural flaw, rooted in limited knowledge of water levels, meant that the marsh persisted.
One element of his design proved more durable: the geometric grid of transverse ditches, still functioning today, though altered from the original plan, the so-called "traversa". It soon became clear that natural outflow alone could not drain the Pontine plain (Vöchting, 1990). Even so, Pius VI's works improved groundwater conditions, opened new areas to cultivation, and protected the Appian Way with the iconic elevated embankment lined with elm trees. The struggle over maintenance continued into the nineteenth century, as Pius IX confronted landowners who resisted the costs required to keep the system functioning.
The law of 18 June 1899 introduced a new classification of reclamation works, dividing them into first- and secondcategory projects with the Pontine area being placed in the first category,for the first time together with coastal sand belt. The inconsistencies of earlier interventions, with technical miscalculations and the need for financial support, meant that hydraulic results in the Pontine plain remained largely unsatisfactory. A few privately installed pumps achieved only limited, local drainage and did nothing to alter the overall water level: in the large marsh basin the ground had even subsided since the eighteenth century due to peat shrinkage. Even the area along the Appian Way continued to flood,, roughly 14,000 hectares of submerged each year, but by the end of 1918 the consortium of Pontine landowners obtained authorization for a drainage plan including four pumping stations (Vöchting, 1990).

Between 1926 and 1930, while surveys were underway, the regime built the basic infrastructure needed for reclamation: roads, rail and telephone lines, electricity, storage facilities, workers' housing, and a quarry. Farmsteads were replaced by small service villages that first hosted labourers and later served as administrative outposts. Migration of workers involved in the land reclamation peaked between 1932 and 1933, with about 8,000 monthly movements; between 1931 and 1935, roughly 230,000 workers passed through the area. Prampolini's drainage plan rested on a strict separation of waters.
High waters from the mountains were intercepted by two major canal belts forming a protective arc around the plain: the first completed section being the 37kilometre Mussolini Canal. Medium waters required separate collectors: in the Piscinara basin, flows from Ninfa were channeled through a new canal cutting across the coastal dunes, while in the central plain the old Linea Pia was reassigned a more modest but workable role.
Groundwater drainage in the twelve polder basins was ensured by an equal number of pumping stations. Along the dune belt, persistent marsh depressions were reclaimed through a mix of embankments, infilling, and pumping; numerous ponds in the coastal forest were drained and levelled where possible. To irrigate this sandy soils, water from the Ninfa springs was diverted into two longitudinal canals, supplemented by additional supplies lifted from the Linea Pia (Vöchting, 1990). By 1919, agrarian reclamation was still largely unsuccessful: only 120 hectares had been cultivated, and even these suffered from bad weather, the sudden withdrawal of prisonerofwar labour, and the damage caused by rodents and wild boar inhabiting the remaining marshy, reedcovered areas (Biasillo, 2023).
In the lower Po Valley, long a center of social unrest, the economic crisis had triggered protests that mere wage labour could not appease. This pressure pushed the government to accelerate settlement plans even before full hydraulic reclamation was completed. The coastal dune belt—still uncultivated and sparsely inhabited—was therefore selected for rapid colonization, which required only minimal and fast hydraulic adjustments. The task was entrusted to the Opera Nazionale Combattenti (Vöchting, 1990).
A decree of 28 August 1931 assigned the ONC 17,680 hectares of lowvalue woodland and pasture. On 10,000 of these hectares, immediate colonial settlements were to be established and, since then, additional neighbouring lands of better quality were soon incorporated through purchases and further expropriations, allowing the colonization to expand from the dune belt into the pantani and the marshland.

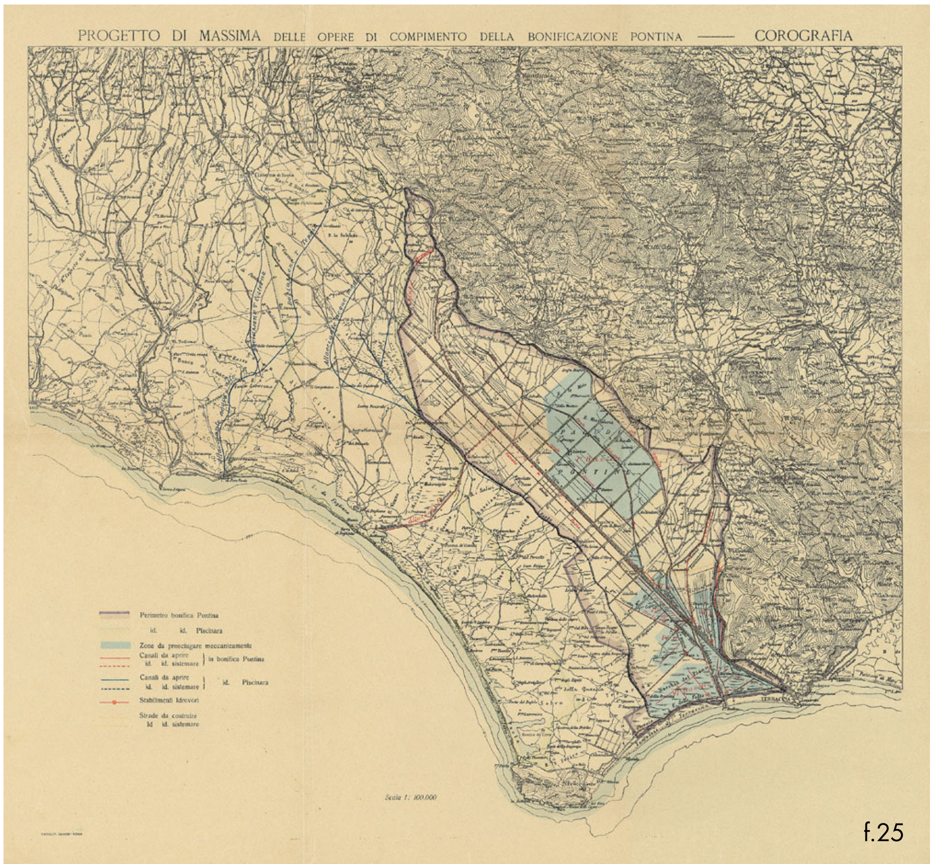
1759



f.21

f.24

1914



f.25

1918

1778

f.22

1800

f.23

f.26

1939

(3)

Franc.º de Capo dis. — C. Antonini inc.

Veduta dei Granari della R. C. Ap.ca al Porto di Terracina

1. Estremità del Porto di Terracina 2. Nuovi Granari della R. C. Ap.ca 3. Sbocco del nuovo Canale di Navigazione
4. R.R. P.P. di S. Francesco 5. Magazeni delle Mastre Pie 6. Posta
7. Novine detto di S. Angelo 8. Pisco Montano

Franc.º de Capo dis. — Carlo Antonini inc.

Veduta di Terracina

1. Granari della R. C. A 2. Palazzo Braschi 3. Casa della Bonificazione 4. Fortezza di Terracina 5. Nuova Strada Pia

Carlo Antonini inc.

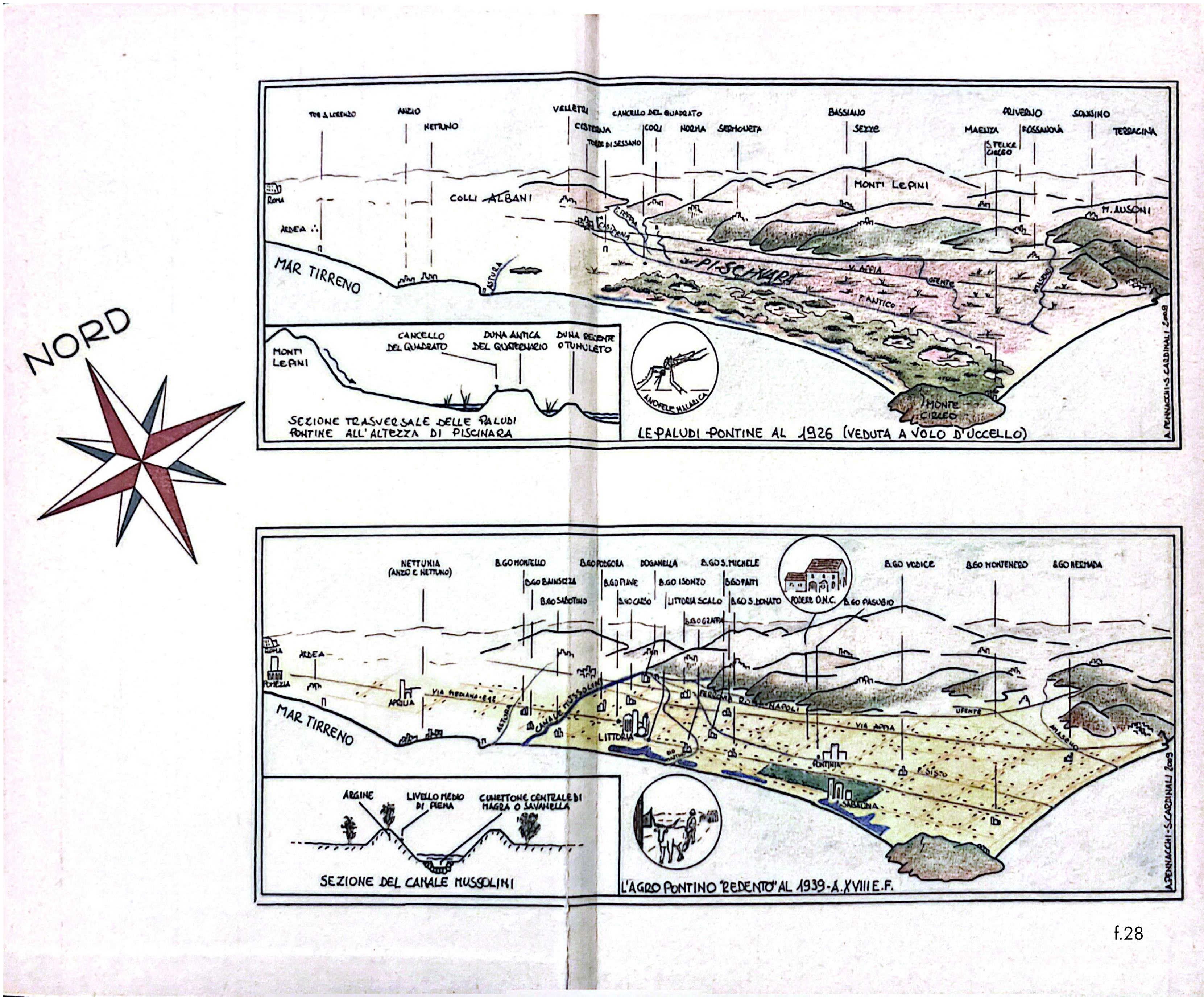
Veduta della Dogana, e Posta in Terracina

Carlo Antonini inc.

Palazzo Braschi in Terracina

1718

f.27

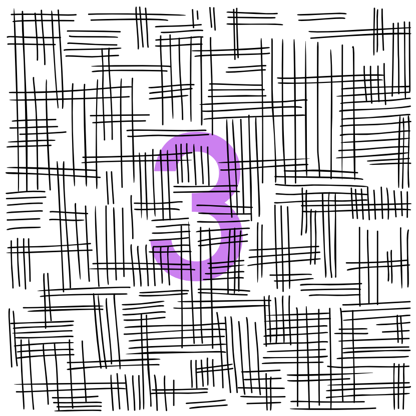

NORD
MAR TIRRENO
COLLI ALBANI
MONTI LEPINI
M. AUSONI
PISCINARA
SEZIONE TRASVERSALE DELLE PALUDI PONTINE ALL'ALTEZZA DI PISCINARA
LE PALUDI PONTINE AL 1926 (VEDUTA A VOLO D'UCCELLO)
MAR TIRRENO
LITTORIA
SEZIONE DEL CANALE MUSSOLINI
L'AGRO PONTINO "REDENTO" AL 1939-A.XVIII E.F.

f.28

SOLIDIFYING THE MARSH AND ERASING LANDSCAPE

For much of the past, marshlands and their opaque, shifting materiality were interpreted as symbols of primitiveness and untamed nature, standing in contrast to the built landscape of solid forms that came to represent civilization, culture, and progress.
Within this cultural framework, the drainage of wetlands and the broader project of reclamation were framed as engines of social, economic, and moral advancement: the act of solidifying unstable ground was seen as a prerequisite for the construction of cities and the emergence of ordered societies (Gruppuso, 2022).
Marshlands were thus imagined as the realm of fluid indeterminacy, while cities embodied the domain of solidity, clarity, and distinction—paved surfaces where class-based social structures could take shape alongside military, political, and religious elites.
From this perspective, "humankind is imagined as having evolved along a linear trajectory, from marshlands to cities, following the capacity to abstract land from water and to make this separation durable, thereby exerting control over the fluid and ephemeral materials of nature" (Gruppuso, 2022).
Reclamation, in this sense, became a material and symbolic act of exerting control over the fluid, ephemeral substances of nature.
Historians have likewise used reclamation as the main lens for reconstructing the evolution of Italy's wetlands. From the 1960s onward, however, growing awareness of the ecological value of these environments broadened the range of possible management strategies, prompting a critical reassessment of hydraulic and agricultural reclamation(Gruppuso, 2022).
The rise of environmental thinking within the humanities has reshaped how reclamation is interpreted. What was once celebrated as the conquest of unhealthy marshlands is now seen as the destruction of an ancient and distinctive ecosystem (Bevilacqua, 2023).
Despite the presence of malaria and poor sanitary conditions, these wetlands hosted an exceptional biodiversity shaped over millennia. Much of this richness—and the unique landscapes that sustained it—has been irreversibly lost, a reality still evident in the surviving Circeo National Park (Bevilacqua, 2023).

f.29


3

STOLEN SEA


f.30

1960

L'abusivismo edilizio dell'Italia povera del dopoguerra che migrava e si urbanizzava, però, si è esaurito nel corso di pochi decenni – grazie sia allo sviluppo economico del paese. (...)Per quanto sia una nozione caratterizzata da svariati angoli di vaghezza e problematicità, «abusivismo di convenienza» indica genericamente il fatto che non si è spinti a costruire irregolarmente dal bisogno urgente di un tetto, ma si è attratti dai vantaggi che ciò comporta. (...)È questo abusivismo di convenienza e speculazione ad aver fatto, negli ultimi quarant'anni in Italia, la parte del leone: la colata illegale di cemento che ha sfigurato molte aree turistiche, soprattutto costiere, ne è la rappresentazione plastica. Non è povera gente che ha auto-costruito la propria casa per dare un modesto riparo ai propri figli. Sono seconde e terze case, usate per le vacanze in famiglia oppure messe a reddito all'interno del mercato degli affitti turistici. (...) Quanto ciò sia vero è tornato sotto gli occhi di tutti, per qualche giorno, nel novembre del 2022, quando, a seguito di piogge troppo intense, una porzione di una collina a Casamicciola, sull'isola di Ischia, ha ceduto, generando un'enorme frana che ha travolto tutto: alberi, auto, abitazioni. Dodici persone, tra cui tre bambini, hanno perso la vita. Così, per qualche giorno, si è tornato a parlare dell'abusivismo edilizio che devasta l'isola, di quelle case travolte che lì non dovevano essere costruite, delle demolizioni mai eseguite, di quelle 27000 domande di condono presentate, di cui solo 1300 esaminate. E sull'isola di Ischia, con i suoi quasi tre milioni di turisti all'anno a fronte di 62000 abitanti, le case abusive non vengono di certo costruite per i poveri.

However, illegal building in post-war Italy, which was poor and undergoing migration and urbanization, came to an end within a few decades, thanks in part to the country's economic development. (...) Although it is a concept characterized by various degrees of vagueness and complexity, "illegal construction for convenience" generally refers to the fact that people are not driven to build illegally by an urgent need for shelter, but are attracted by the advantages that this entails. (...)It is this illegal building for convenience and speculation that has played the lion's share in Italy over the last forty years: the illegal pouring of concrete that has disfigured many tourist areas, especially coastal ones, is a clear example of this. It is not poor people who have built their own homes to provide modest shelter for their children. These are second and third homes, used for family vacations or rented out on the tourist rental market. (...)
Just how true this is was brought back into the spotlight for a few days in November 2022, when, following heavy rainfall, part of a hill in Casamicciola, on the island of Ischia, collapsed, causing a huge landslide that swept away everything in its path: trees, cars, houses. Twelve people, including three children, lost their lives. So, for a few days, there was renewed talk of the illegal construction that is devastating the island, of those houses that should never have been built there, of the demolitions that were never carried out, of the 27,000 applications for amnesty that were submitted, of which only 1,300 were examined. And on the island of Ischia, with its nearly three million tourists a year compared to 62,000 inhabitants, illegal houses are certainly not built for the poor.

"Cemento armato: la politica dell'illegalità nelle città italiane" Chiodelli, 2023.

ILLEGAL COASTAL DEVELOPMENT IN ITALY

Unauthorized construction (abusivismo edilizio) constitutes a parallel modality through which a significant portion of the Italian territory has been urbanized. This phenomenon extends beyond episodic instances involving individual structures or interventions on existing buildings (Chiapperino, 2021). This process of territorial transformation, occurring in open contradiction to urban planning norms, spatial regulations, and established practices, has been particularly concentrated within the specific geographical context of Southern and Central Italy (Chiapperino, 2021).
To frame the origins of this phenomenon, one must examine the evolving relationship between population growth and housing provision throughout Italy's post-unification history. During the first century following unification (1861 – 1951), the Italian population increased from 26 to 47 million, while the total number of rooms rose from 18 to 37 million (Cremaschi, 2002). Throughout this extensive interval, despite the doubling of both demographic and building mass, the absolute gap between population and housing remained substantially constant, maintaining a deficit of approximately ten million rooms relative to the standard parity of one occupant per room (Cremaschi, 2002). A definitive rupture occurred after 1951: in the face of a demographic increase of only 9 million inhabitants, construction growth became remarkably conspicuous, reaching 88.6 million rooms by 1981 (Cremaschi, 2002). The fact that the volume of residential construction in the post-war period was triple that of the preceding century suggests that such growth was not entirely "physiological"; this is further evidenced by the rise in unoccupied dwellings, which increased from 6% to approximately 20% of the total stock (Cremaschi, 2002). While unauthorized construction was initially linked to a genuine lack of space, the advent of the economic boom and the proliferation of secondary homes caused the motivations for extra-legal building to shift radically (Cremaschi, 2002).
In this context, between the 1960s and the 1980s, a strategy of "individualistic mobilization" unfolded to address demands for residential, occupational, and recreational space that found no resonance within the institutional mechanisms of land rent distribution (Zanfi, Curci, & Formato, 2015). The flight from overcrowding and the inadequate hygenic-sanitary conditions characterizing historic centers and rural settlements well into the 1970s, coupled with the pursuit of new models of domestic consumption, culminated in forms of unauthorized building that became intertwined with territorial governance in a complex "contributory negligence" (concorso di colpa) (Zanfi, Curci, & Formato, 2015). This dynamic was facilitated by a construction sector fragmented into micro-enterprises, which found the unauthorized site to be a production model suited to its specific technology and labor force (Zanfi, Curci, & Formato, 2015).

The legislative attempt to resolve these issues led, in 1985, to the approval of the first building amnesty (condono edilizio) under the socialist government led by Craxi, occurring only months before the "Galasso Law" for landscape protection (Berdini, 2010; Zanfi, Curci, & Formato, 2015). Although the stated objective was to definitively regularize unauthorized structures and curb the phenomenon in the future, its implementation was fundamentally distorted (Zanfi, Curci, & Formato, 2015). Despite assurances that this amnesty would be a singular event, the first Berlusconi government approved a second measure in 1994, followed by a third in 2003 proposed by the same majority (Berdini, 2010). These repeated amnesties, often utilized for fiscal purposes to generate immediate revenue, fueled grave social, territorial, and fiscal consequences, leading to a loss of state authority in enforcing the urban plans and regulations that delineate the future of cities (Berdini, 2010; Zanfi, Curci, & Formato, 2015).
To date, no public accounting has been provided regarding the real impact of these three laws in terms of regularized buildings, hectares of agricultural land consumed, or the overall economic and environmental balance (Berdini, 2010). The culture of unauthorized construction now appears to permeate public administrations themselves, marking a transition from a primitive "necessity-based" abusivismo to a phase in which the State itself promotes the cancellation of rules (Berdini, 2010). Emblematic examples include the 2009 "Piano Casa," which permitted volumetric increases in derogation of urban planning norms, and the landscape derogations granted for the World Swimming Championships or the G8 summit in La Maddalena (Berdini, 2010). Thirty years after the first amnesty, the phenomenon remains unresolved and has acquired a unique complexity, maintaining a central position within the contemporary "Southern Question" (Zanfi, Curci, & Formato, 2015). Such dynamics of systematic derogation and lack of oversight render the Italian case an inconceivable and unknown phenomenon among other European nations (Berdini, 2010)

COASTAL RECLAMATION AND PRIVATIZATION

nauthorized development (abusivismo edilizio) in Italy is not a monolithic phenomenon; rather, it is articulated into specific branches, among which coastal development represents one of the most incisive and transformative manifestations. It constitutes a parallel modality through which a significant portion of the national territory has been urbanized, defining spatial and temporal outcomes that diverge from official planning (Chiapperino, 2021). This "littoralization" (Zanfi, Curci, & Formato, 2015) is not merely a process of demographic concentration, but a genuine race toward the contact line between sea and land. This dynamic has transformed the historical marginality of the coast—understood as an uncertain and ever-evolving morphology (Braudel, 2008)—into an object of a "desire for the shore" (desiderio di riva) linked to well-being and leisure (Chiapperino, 2021).

While first-generation unauthorized development responded to primary housing needs, the coastal variant is defined as speculative development, where interest is concentrated on the littoral with spatial outcomes that overturn established settlement models. The coast thus becomes the stage for a "situated utopia," where the individual desire to secure a privileged "sea view" position prevails over planning (Chiapperino, 2021). In this process, the landscape undergoes a process of banalization and erosion, transforming into a space to be mechanically consumed (Chiapperino, 2021).

THE CONNECTION WITH LAND RECLAMATION

The transition from productive land management to informal subdivision did not occur through a simple absence of rules, but developed through a systematic distortion of pre-existing infrastructure. A significant role in this transformation must be attributed to the Fascist-era land reclamations (bonifiche) and the subsequent Agrarian Reform. Although these initiatives were designed to "order" the territory, they unintentionally provided the logistical framework for its subsequent exploitation (Zanfi, Curci, & Formato, 2015). The allocation of small plots of land in areas that would soon acquire enormous tourist appeal acted as an involuntary catalyst; the agrarian grid made fragmentation and unauthorized subdivision possible in ways that would otherwise have been technically unfeasible (Zanfi, Curci, & Formato, 2015).

What was originally conceived as a rigid system for the control of water and soil was betrayed by a fragmented vision of landed value. Self-promoted building stock thus established itself along the farm tracks penetrating from the hinterland to the coast, utilizing roads born for agricultural reclamation as axes of saturation for a pavillionaire matrix (Chiapperino, 2021). The grafting of this "seaside city" onto originally productive territories has generated extremely fragile locations, where urban quality is prematurely compromised by hurried construction (Zanfi, Curci, & Formato, 2015). The impact on marine and terrestrial ecosystems is devastating: water pollution caused by household discharges and coastal erosion accelerated by the dismantling of dune systems testify to the depletion of scarce environmental resources (Zanfi, Curci, & Formato, 2015). Unauthorized development has fragmented the transitional zones between sea and land, redefining natural systems according to individual metrics that ignore the territorial dimension and compromise the intrinsic value of the coastal resource (Chiapperino, 2021).

f.31

SECOND HOUSE CULTURE

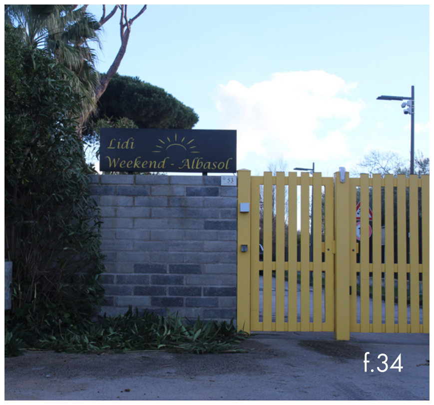
Starting from the second half of the 20th century, the secondary residence ceased to be a privilege of the elite to become an object of dreams and projects for every social class, assuming extraordinary symbolic value (Zanfi, Curci, & Formato, 2015). This model of residential tourism, based on the seasonal use of owned homes, has generated a permanent impact on the landscape despite the limited temporality of the habitation (Chiapperino, 2021; Curci, 2012). However, this rush toward real estate investment has shown its limits in the long term, attracting tourist demand toward assets characterized by deficient construction quality and the need for constant maintenance due to salt corrosion (Chiapperino, 2021).
The socio-economic outcome of this demand for accumulation is a process of spoliation and the denial of the right of access to resources (Formato, 2021). The privatization of the shoreline was materially accomplished through the appropriation of positional rent, supported by the existing infrastructural armature. This appropriation manifests through peremptory signs: opaque fences, barriers, and physical obstacles that define the boundary between public and private space (Chiapperino, 2021). In this scenario, the coastal asset shifts from a civic and shared good to an economic good to be capitalized, generating forms of restricted satisfaction that subtract space and rights from the community, hindering the free use of state-owned (demaniale) resources (Chiapperino, 2021).

The Agro Pontino represents the perfect emblem of the destructive cooperation between historical planning and contemporary unauthorized development. In this territory, the "machine" of land reclamation—designed as a living, integrated organism of canals and roads—has been turned against itself. The farm grid, while ensuring geometric order, created an intrinsically rigid environment: when unauthorized development saturated the plots of land assigned by the Agrarian Reform (Zanfi, Curci, & Formato, 2015), the system lost its capacity for adaptation.
Informal urbanization has interrupted the ecological continuity between the reclaimed hinterland and the coastline, replacing the natural flexibility of dune systems with a rigid barrier of concrete and fencing. This loss of resilience is evident in the territory's inability to react to climate change and rising sea levels: where dunes would have provided adaptive protection, unauthorized villas now represent an insurmountable obstacle that accelerates erosion and the salinization of aquifers. The Agro Pontino thus demonstrates that a territory born from a project of absolute order, if left to the mercy of informal subdivision, paradoxically becomes the most fragile place and the least prepared to manage the complexity of future environmental transitions.

Closed access to Agro Pontino shoreline


f.32


f.33



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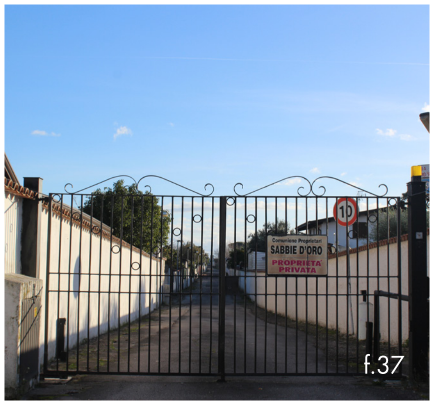
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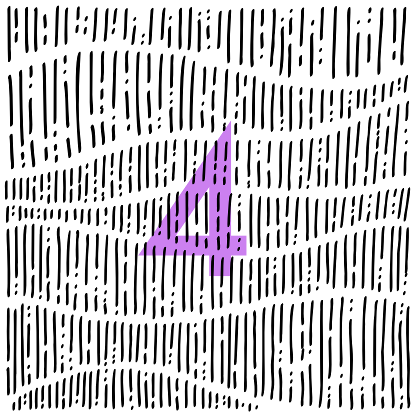

4

WATER RETURN

2100

Proprio così. Il mar Tirreno si incuneava nella penisola come una spada che trafigge dal basso. Apriva a metà le province di Terni e di Viterbo, fino all'altezza del lago di Bolsena, che da tre secoli era tornato a essere il cratere secco e brullo di un antico vulcano, come il lago di Vico, quello di Bracciano e molti altri. La Terra, sotto questa prospettiva, non era poi tanto diversa dalla Luna. Il fiordo tiberino aveva creato una grossa penisola in quello che una volta era l'alto Lazio. A nord del golfo di Maremma Latina, la costa era coronata da isole di recente formazione. Il golfo frastagliato di Saturnia era un'altra delle rare riserve naturali italiche – una meraviglia di anfratti marini, spiagge tropicali, sorgenti termali e rovine etrusche congelate nei secoli – protetta al largo dall'isola Alberese, dall'isola di Santo Stefano (di fronte all'isola del Giglio, mentre Giannutri era ormai solo uno scoglio) e dalle isole del Leccio sul lato meridionale. A sud invece il golfo di Maremma Latina si chiudeva con due magnifiche insenature profonde, mete ambite dai giganti di tutto il Paese: il seno di Tarquinia e il seno di Aurelia. Qui venivano a depositare le uova le tartarughe marine tropicali che avevano colonizzato il Mediterraneo, attratte dalle sterminate popolazioni di meduse di cui questi animali sono ghiotti.

That's right. The Tyrrhenian Sea wedged itself into the peninsula like a sword piercing from below. It split the provinces of Terni and Viterbo in half, up to Lake Bolsena, which for three centuries had returned to being the dry and barren crater of an ancient volcano, like Lake Vico, Lake Bracciano, and many others. From this perspective, the Earth was not so different from the Moon. The Tiber fjord had created a large peninsula in what was once upper Lazio. North of the Gulf of Maremma Latina, the coast was crowned by newly formed islands. The jagged Gulf of Saturnia was another of Italy's rare nature reserves—a marvel of sea caves, tropical beaches, thermal springs, and Etruscan ruins frozen in time—protected offshore by the island of Alberese, the island of Santo Stefano (opposite the island of Giglio, while Giannutri was now just a rock), and the Leccio islands on the southern side. To the south, the Gulf of Maremma Latina ended with two magnificent deep inlets, popular destinations for giants from all over the country: the Seno di Tarquinia and the Seno di Aurelia. This is where the tropical sea turtles that had colonized the Mediterranean came to lay their eggs, attracted by the endless populations of jellyfish on which these animals feed.

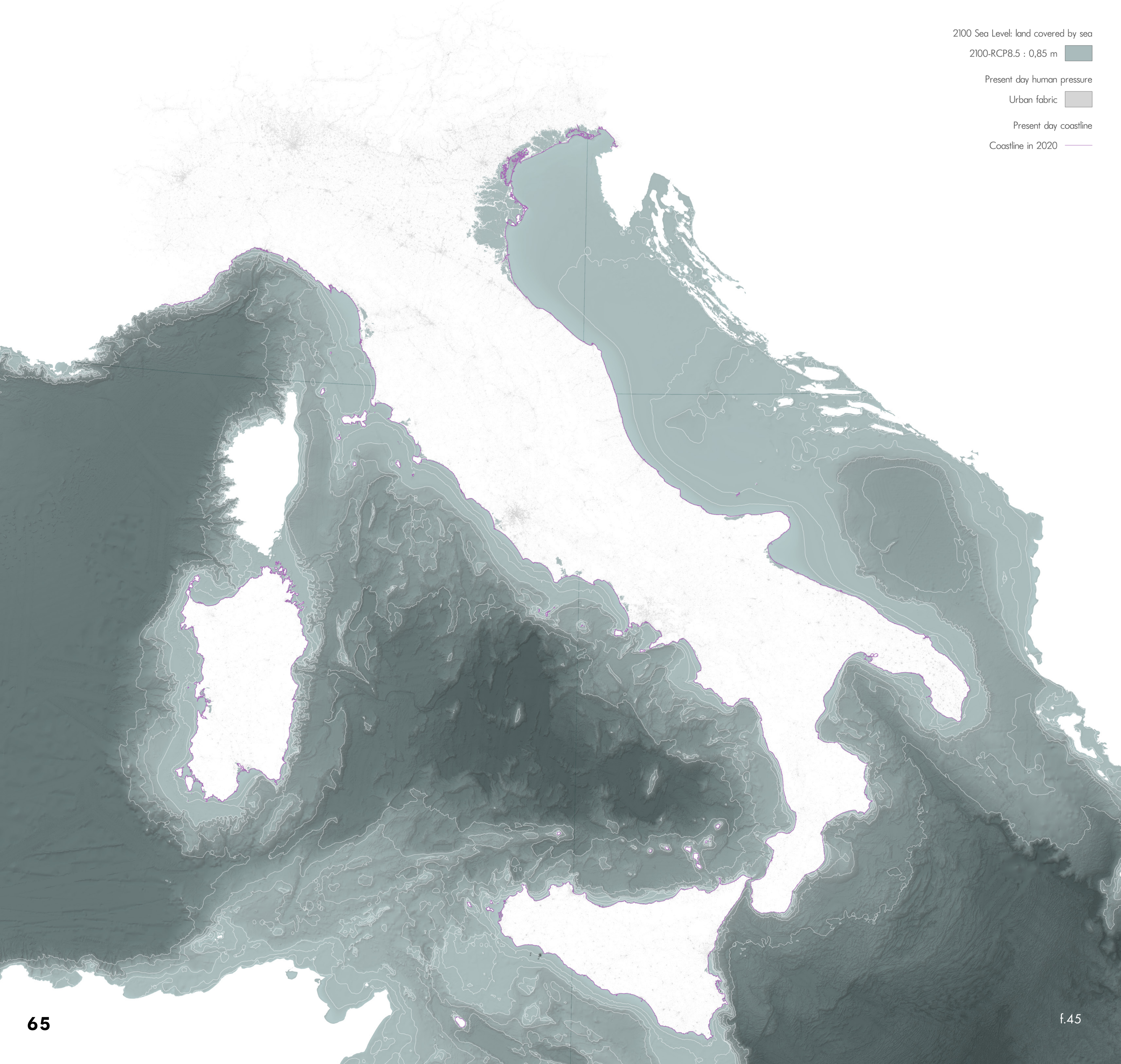
"Viaggio nell'Italia dell'Antropocene. La geografia visionaria del nostro futuro" di Pievani, Varotto, 2021.

SEA LEVEL RISE PROJECTED IN ITALY

The Sea Level Rise (SLR) can be defined as one of the most relevant impacts of climate change for the Cryosphere, with surface and ocean warming. This issue drives multiple related hazards having relevant consequences especially for coastal ecosystems.
The Global Mean Sea Level can be addressed to evaluate SLR for future scenarios and in the modelled pathway used (from the IPCC reports), under all scenarios the rate will keep rising in the next century: under RCP2.6, increase to 4–9 mm yr−1 while under RCP8.5, increase to 10–20 mm yr−1.
These rising rates allow to define the grow of the GMSL in future scenarios, relative to 1986–2005. In 2050: under RCP2.6, GMSL will rise 0.24 m, under RCP8.5, GMSL will rise 0.32 m. In 2100: under RCP2.6, GMSL will rise 0.43 m, under RCP8.5, GMSL will rise 0.84 m (H.-O. Pörtner et al., 2019).
Starting from various scientific research that have addressed this issue (Bondesan et al.,1995; F. Antonioli et al., 2017; K. Lambeck et al., 2011), the thesis addresses the climate change effects projecting the global Sea Level Rise in the Italian and mediterranean context: the expected relative sea-level rise may change the present-day morphology, flooding up about 5500 km2 of coastal plains (F. Antonioli et al., 2017).
Italian coasts stretch for more than 7500 km and rapid urbanization has led to the expansion of coastal settlements, together with urban conurbation, tourist services, natural heritage sites and strategic infrastructures (F. Antonioli et al., 2017).
The map presented was obtained using a Digital Terrain Model of 90m: this detail does not allow for local specific analysis (that needs more detailed DTM to be studied) but highlights the major areas that will be prone to coastal flooding in 2100.
For much of the Italian coast, the scenario shows increased vulnerability of the littoral zones and coastal plains, with the only exception occurring in south-west Calabria and north-eastern Sicily (because of the strong positive vertical movements) (K. Lambeck et al., 2011).
The northern Adriatic region is characterized by almost flat topography and high rates of land subsidence: the Po Delta area happens to be the most prone to marine flooding with inland areas of Emilia-Romagna (lying under sea level) being at risk. In this scenario, the coastline is expected to retreat inland to a point less than 10 km from Ferrara (F. Antonioli et al., 2017; K. Lambeck et al., 2011).

The northern sector of Venice, Grado and Marano Lagoons is potentially vulnerable too, together with Marche and Abruzzi coasts and the Lesina and Varano Lakes in Apulia Region (K. Lambeck et al., 2011).
In Sardinia, the wetland area of Cagliari and Oristano are hotspot for the phenomena while in Sicily, where erosion occurs, the Trapani and Catania plains are the most vulnerable areas (K. Lambeck et al., 2011).
The SLR can be observed in the north Tyrrhenian coast, the Versilia area, the Ombrone River Delta and the Orbetello Lagoon while in the central Tyrrhenian Sea, the coast near Rome and the southern Latium, with the Volturno littoral and the Sele River (K. Lambeck et al., 2011).

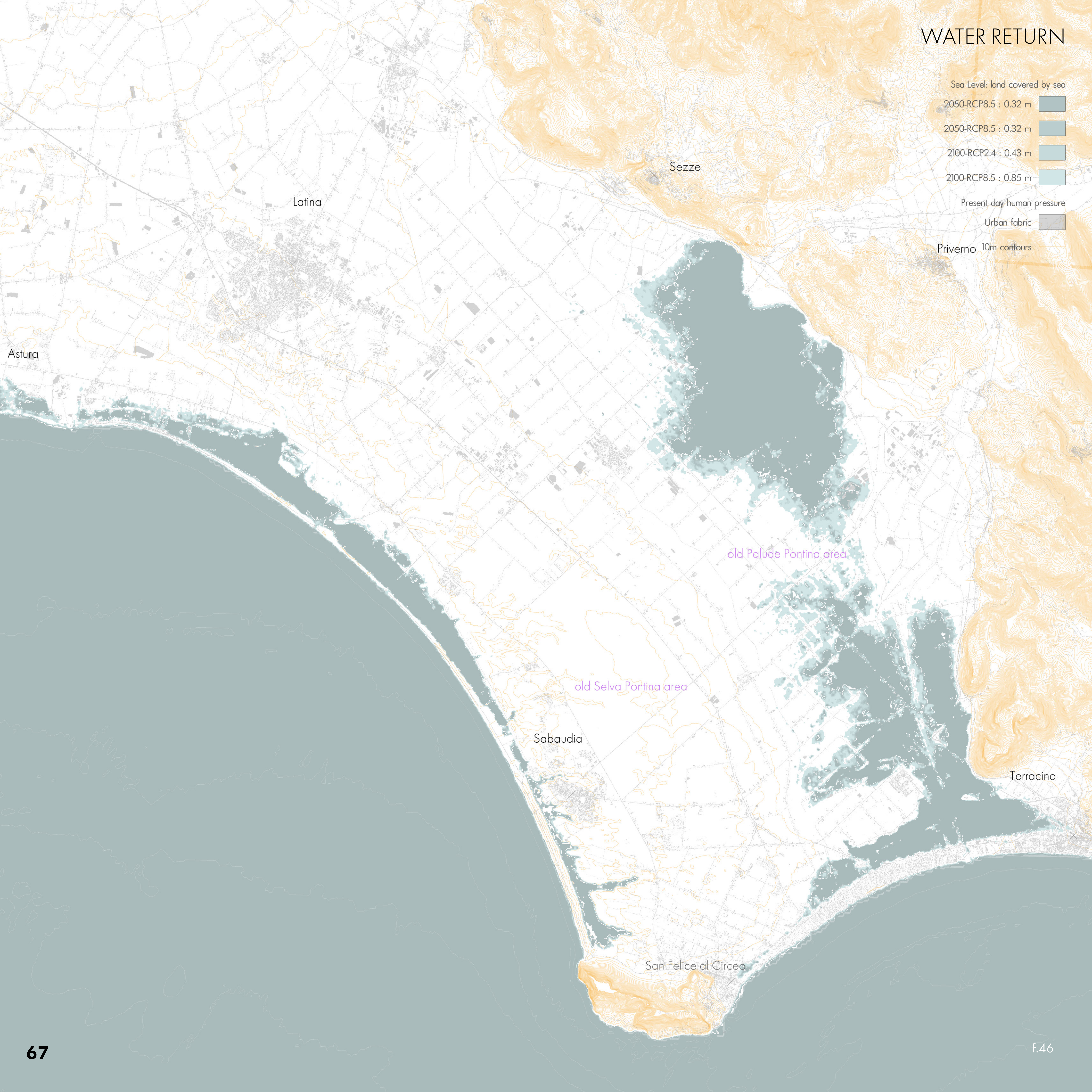
WATER RETURN



f.45

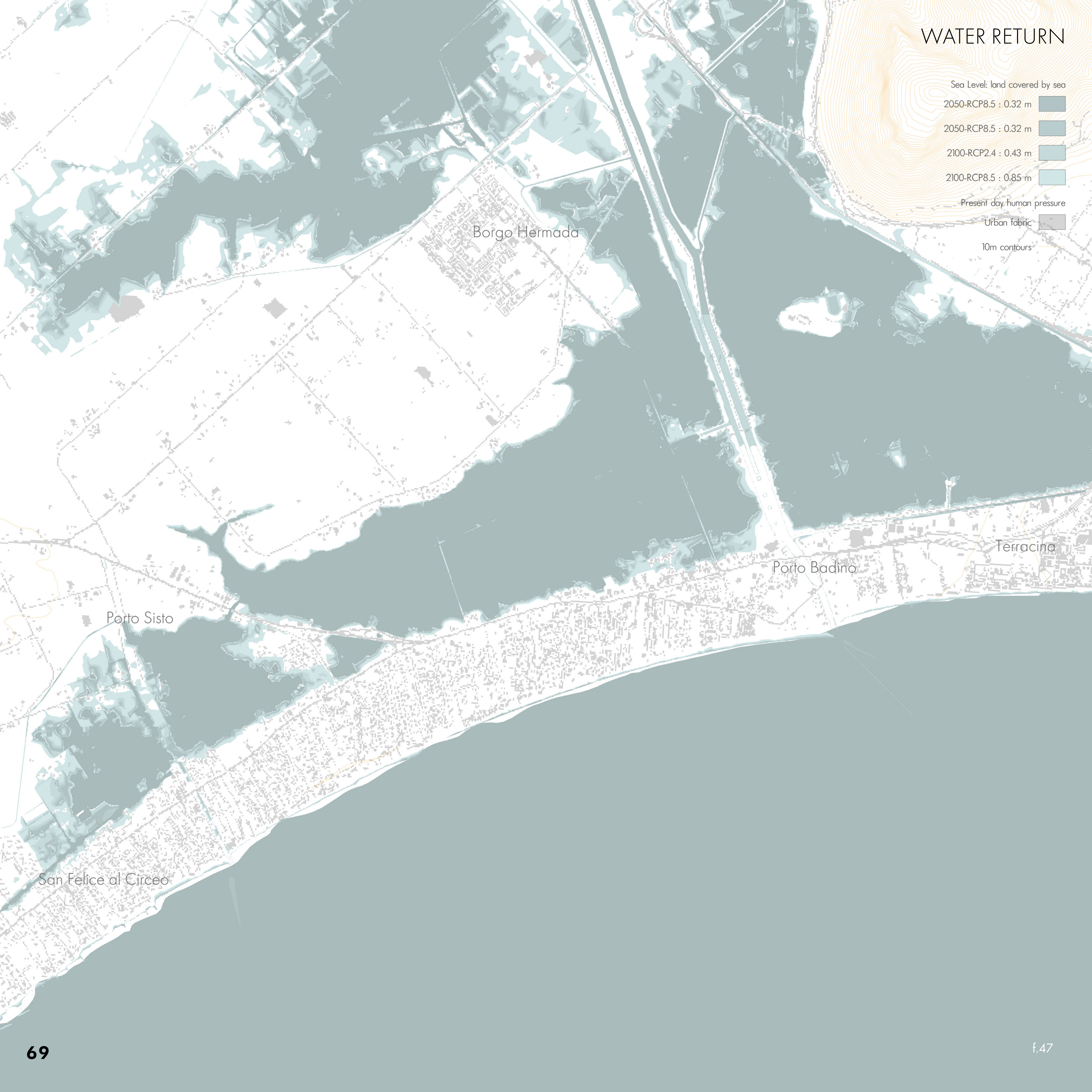
SEA LEVEL RISE IN AGRO PONTINO CASE STUDY

The Agro Pontino offers an unusually clear lens through which to observe the implications of sealevel rise. Few coastal plains in the Mediterranean combine such a low elevation, such an extensive history of land reclamation, and such a direct geomorphological connection to the sea. For centuries this territory functioned as a vast wetland system, shaped by the oscillations of marine and fluvial waters. Only in the last hundred years it was drained, engineered and stabilized through largescale reclamation works.
This makes the area a kind of open laboratory: a place where the projected rise of the sea interacts with a landscape that was once aquatic, then forcibly transformed into agricultural and urban land. When future scenarios of sealevel rise are applied to this context, the underlying logic of the territory becomes visible again.
The maps produced for this thesis aim precisely to reveal this dynamic: the possibility that water may return to the places from which it was removed.The first map is based on a 30 m DTM, useful for identifying the broad patterns of vulnerability across the entire Agro Pontino, highlighting areas affected by the projected future inundation for 2050 and 2100.
What emerges is striking: the zones at risk correspond almost exactly to the historical footprint of the Pontine Marshes. The depressions that once hosted lakes, swamps and stagnant waters reappear as the first surfaces exposed to marine intrusion. This is not a coincidence: much of the Agro Pontino lies at or below sea level, and its current habitability depends on a dense network of pumps, canals and hydraulic barriers. In the absence of major structural interventions, the projected rise of the sea would simply reactivate the ancient hydrographic logic of the plain. Water would not “invade” the territory as an anomaly; it would follow the natural topography, filling the same basins that existed before the reclamation.


WATER RETURN
Sea Level: land covered by sea
2050-RCP8.5 : 0.32 m
2050-RCP8.5 : 0.32 m
2100-RCP2.4 : 0.43 m
2100-RCP8.5 : 0.85 m
Present day human pressure
Urban fabric
10m contours
Sezze
Latina
Priverno
Astura
old Palude Pontina area
old Selva Pontina area
Sabaudia
Terracina
San Felice al Circeo

f.46

The second map, produced using a 5m DTM, allows for a much more detailed reading of the coastal fringe. Dune ridges, retrodunal depressions and former lagoons appear with clarity. These features outline what was once a complex system of coastal wetlands, dynamic, adaptive environments capable of absorbing fluctuations in sea level.
When the projected sealevel rise is applied to this higherresolution model, the coastline shifts inland and the ancient wetland mosaic becomes legible again: areas that today appear stable and dry reveal their latent aquatic nature.
Yet the contemporary landscape is no longer configured to accommodate this behaviour. Urbanisation, intensive agriculture and the rigid hydraulic infrastructure of the reclamation have altered the metabolism of the territory. The natural capacity of wetlands to adapt to rising waters has been replaced by a system that depends on constant mechanical control.
This means that the return of water, if unplanned and unmanaged, would be more abrupt and destructive than in the past. The very processes that once allowed the territory to coexist with water have been suppressed, leaving a landscape that is both exposed and structurally fragile.The idea, lying at the basis of the project, is that sealevel rise does not create a new geography, but reveals the old one.


WATER RETURN
Sea Level: land covered by sea
2050-RCP8.5 : 0.32 m
2050-RCP8.5 : 0.32 m
2100-RCP2.4 : 0.43 m
2100-RCP8.5 : 0.85 m
Present day human pressure
Urban fabric
10m contours
Borgo Hermada
Terracina
Porto Badino
Porto Sisto
San Felice al Circeo

f.47

5

SCENARIO BUILDING PROCESS

CLIMATE CHANGE AND GLOBAL DEBATE

The history of climate change began in the 19th century, when scientists started to question the role of the atmosphere in regulating the Earth's temperature. This was made possible by scientific insights and discoveries, such as the atmosphere's ability to retain solar heat, or that gases – such as carbon dioxide and methane – were responsible for this "greenhouse effect", which allowed the creation of quantitative models for assessing climate change.
These models were developed by Svante Arrhenius, who quantified the relationship between atmospheric CO_2 and global temperature, estimating that doubling CO_2 could raise the temperature by ~5.7 °C(Federico Mascolo, 2020).
In the twentieth century, the study became more detailed: Vernadsky analyzed the carbon cycle and Milanković demonstrated how astronomical cycles impacted the climate over a period of thousands of years. After the Second World War, with the advent of new technologies and the use of satellites, it became clear that CO_2 levels were rising rapidly, as evidenced by the famous Keeling curve in the 1950s and 1960s. The first computer climate models, created during the same period, showed that the increase in greenhouse gases would cause measurable global warming(Federico Mascolo, 2020).
In the 1960s and 1970s, the topic moved out of the laboratories and into the political debate, thanks to government reports and studies commissioned by the oil industry that pointed to potential future risks. The 1979 World Climate Conference officially recognized climate change as an urgent issue.
The next step was to turn it into a political issue (Federico Mascolo, 2020) that recognized the responsibility of human beings and all countries, which was necessary in order to turn our attention to possible and necessary mitigation and adaptation measures
In fact, the current climate debate focuses on scientific evidence that global warming is caused by human activities, superseding the approach of previous decades, which believed that climate change was determined entirely by natural factors
Currently, the main points include measuring global temperature increases, exceeding the 1.5°C threshold in 2024, and projections of further increases that exceed human adaptation capacities, always considering a global responsibility. This change in approach required a leap in the scale for these studies, starting already from the 80s and 90s. This results in the establishment, dating 1988, of the IPCC and the signing of the United Nations Framework Convention on Climate Change in 1992 facilitated global cooperation. Since then, the IPCC's regular reports have increasingly confirmed the connection between human actions and global warming, turning a scientific matter into one of the most crucial political, economic, and social challenges of our era

THE IPCC AND THE 2023 ASSESSMENT REPORT

The Intergovernmental Panel on Climate Change (IPCC) is the main international body for assessing climate change, contributing to this more informed and solution-oriented debate. The IPCC was established as an United Nation (UN) body in 1988 by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP) with the aim of providing a clear and scientifically sound overview of the current state of knowledge on climate change and its potential environmental and socio-economic impacts.(IPCC, n.d.-a)
The IPCC was created to provide policymakers with regular scientific assessments on climate change, its implications and potential future risks, as well as to put forward adaptation and mitigation options(IPCC — Intergovernmental Panel on Climate Change, n.d.) (RSI EDU, 2022)
In the climate debate, the IPCC acts as a scientific authority that does not produce new research but synthesizes and evaluates existing research worldwide, presenting its findings in periodic reports that outline the causes, impacts and mitigation and adaptation strategies, becoming a key reference point for global climate policies(RSI EDU, 2022). In fact the IPCC's structure is the result of the convergence of intentions and concerns from various sources, starting with those of governments, becoming an advisory body with a global scope that would provide governments with scientific information and theories. (Forgione, 2024)
Despite its global role in coordinating the data available to various countries around the world, the public image of the IPCC remains that of a place of consensus and a neutral body, detached from political considerations and focused solely on the evaluation of scientific facts(Forgione, 2024).
The studies of the organization results in the drafting of Assessment Reports about the state of scientific, technical and socio-economic knowledge on climate change, its impacts and future risks, and options for reducing the rate at which climate change is taking place.
The IPCC also produces Special Reports on specific topics agreed by its member governments, as well as Methodology Reports that provide practical guidelines for the preparation of greenhouse gas inventories (IPCC — Intergovernmental Panel on Climate Change, n.d.).
This SYR, synthesis report of the official one and main reference for the public, distills, synthesizes, and integrates the key findings of the three Working Group (H. Lee & J. Romero, 2023b).
The IPCC work is shared among three Working Groups, a Task Force and a Task Group. The activities of each Working Group and of the Task Force are coordinated and administrated by a Technical Support Unit (TSU).
The IPCC Working Group I (The Physical Science Basis) examines the physical science underpinning past, present, and future climate change. The Working Group II (Impacts, Adaptation and Vulnerability) assesses the vulnerability of socio-economic and natural systems to climate change, negative and positive consequences of climate change and options for adapting to it. Finally the Working Group III (Mitigation of Climate Change) focuses on climate change mitigation, assessing methods for reducing greenhouse gas emissions, and removing greenhouse gases from the atmosphere(IPCC, n.d.-b).

Regarding the Task Force on National Greenhouse Gas Inventories (TFI), this body develops and refines methodologies for calculating and reporting greenhouse gas emissions, while the Task Group on data support provides guidance to the IPCC's Data Distribution Centre on the curation, traceability, stability, availability and transparency of data and scenarios related to IPCC reports(IPCC, 2025).
Over the years, the IPCC became a western-driven organization to a global and inclusive effort," and this results in the IPCC becoming the backbone of the international climate policy, starting from the presentation of the climate crisis as a global problem and responsibility(Directorate-General for Climate Action, 2023). Since the first publication in 1990, these reports have become so influential and widely acclaimed feeding also into the UNFCCC processes.
The UNFCCC (United Nations Framework Convention on Climate Change)Is the UN's efforts to negotiate a pact aimed at curbing harmful climate change. It is a global agreement between nations to address harmful human disruptions to the climate system. The organization relies on the scientific assessments provided by the Intergovernmental Panel on Climate Change (IPCC) to inform its policy and negotiations on climate change.
The IPCC's findings directly influence the direction of UNFCCC negotiations, such as the Paris Agreement (a legally binding international treaty on climate change adopted by multiple Parties, with the goal to hold "the increase in the global average temperature to well below 2°C above pre-industrial levels" and pursue efforts "to limit the temperature increase to 1.5°C above pre-industrial levels(Unfccc, n.d.) , providing the necessary scientific foundation for these policy-making efforts(UN, n.d.).
The influence of the reports extends also to treaties and agreement, growing with the various Assessment Report, which are useful to consider to understand the change in impact and consideration around the scientific and political community.
The First Assessment Report (AR1) was released in 1990 for the establishment of the United Nations Framework Convention on Climate Change (UNFCC) in 1992 and had a considerable influence on the first conference of the parties, held in Berlin in 1995. It was the first major scientific synthesis effort on climate change and marked, together with the first Conference of the Parties (COP1), the start of international negotiations on emission limits.
The Second Assessment Report (AR2) was released in 1995 and, following the climate change debate which was focusing on solid evidence on human influence on global warming. This report was decisive for the negotiation and adoption of the Kyoto Protocol in 1997, the first legally binding international treaty that imposed emission reduction targets on industrialized countries.
The Third Assessment Report(AR3), released at the start of the new Millenium in 2001, it's mainly know for its explicit discussion on mitigation and adaptation strategies, starting to transform the report into solution-oriented studies. The report influenced the review process of the Kyoto Protocol and subsequent Conferences of the Parties (COPs), reinforcing the call for coordinated international action.

The real turning point for the IPPC reports was marked in 2007 by the Fourth Assessment Report (AR4), stating with high confidence that global warming is unequivocal and primarily caused by human activities. Its findings had a profound impact on political and public discourse, significantly increasing awareness of the climate crisis, and for that was rewarded with the Nobel Peace Prize of the same year of release.
From the Fifth Assessment Report (AR5) we start to see a change in methodology, with the introduction of Representative Concentration Pathways (RCPs), which are indicate a representative trend in greenhouse gas and aerosol concentrations for a given climate target, which in turn corresponds to a given trend in human emissions(CORDIS, 2023). The use of quantitative projections allowed the report to become essential in shaping the Paris Agreement (2015) adopted at COP21 (The Paris Agreement | UNFCCC, n.d.).
The latest report is the Sixth Assessment Report (AE6), which provided the most comprehensive and precise synthesis to date. The Synthesis Report released in 2023 served as the scientific foundation for the first Global Stocktake under the Paris Agreement, a key mechanism for assessing collective progress towards climate goals. Its conclusions underscored the urgency of immediate, deep, and sustained action across mitigation, adaptation, and climate finance, guiding discussions at recent COP negotiations. (Violaine Hacker, 2023

The latest synthesis report of the Assessment Report, which is the one the thesis will be referring to, is the Sixth Assessment Report (AR6) released in 2023, synthesizes and integrates materials contained within the three Working Groups Assessment Reports and the Special Reports contributing to the AR6. It addresses a broad range of policy-relevant but policy-neutral questions approved by the Panel and is the most comprehensive assessment of climate change undertaken thus far by the IPCC.(H. Lee & J. Romero, 2023).
The Synthesis Report emphasizes near-term risks and options for addressing them to give policymakers a sense of the urgency required to address global climate change. The report also provides important insights about how climate risks interact with not only one another but non-climate-related risks. It also dedicates space to the definition of the interaction between mitigation and adaptation(H. Lee & J. Romero, 2023b)
Considered as a "survival guide for humanity," it identifies significant problems and details the characteristics of the levers for transforming societies and the economy(Violaine Hacker, 2023). The main issues addressed can be divided in five pillars:

- role of human activities in global warming:
- global warming of +1.5°C by 2030
- increasing of possible abrupt and irreversible changes
- the limits of current adaptation
- financial flows remain insufficient

STRUCTURE AND PROCESS

Everything that was studied and discussed by the latest IPPC report is synthesized and made accessible to the public by the Synthesis Report (SYR) , which was prepared in accordance with the procedures of the IPCC, starting from a scoping meeting to develop a detailed outline of the AR6 Synthesis Report(H. Lee & J. Romero, 2023b).

The meetings were held in Singapore from 21 to 23 October 2019 and the outline produced was approved by the Panel at the 52nd IPCC Session from 24 to 28 February 2020 in Paris, France, in accordance with IPCC procedures, the IPCC Chair, in consultation with the Co-Chairs of the Working Groups, nominated authors for the Core Writing Team (CWT) of the SYR. (H. Lee & J. Romero, 2023b)

The SYR can be better understood by looking at the structure of the document, which develops in multiple sections. The first section works as an introduction, which explains both the methodologies and the topics addressed in the following chapters, followed by three other sections, which, while still being extremely interconnected, focuses on different themes and approach regarding current climate change.

The second section 'Current Status and Trends', opens with the assessment of observational evidence for our changing climate, historical and current drivers of human-induced climate change, and its impacts. It assesses the current implementation of adaptation and mitigation response options. (H. Lee & J. Romero, 2023b)

The section 3, named 'Long-Term Climate and Development Futures', provides an assessment of climate change to 2100 and beyond in a broad range of socio-economic futures. It considers long-term impacts, risks and costs in adaptation and mitigation pathways in the context of sustainable development. (H. Lee & J. Romero, 2023b)

Taking a step back in time, section 4 focuses on 'Near-Term Responses in a Changing Climate', assesses opportunities for scaling up effective action in the period to 2040, in the context of climate pledges, and commitments, and the pursuit of sustainable development.(H. Lee & J. Romero, 2023b)

What makes them unique is that they "include summaries for policymakers that are approved, word by word, by all 195 government members of the IPCC – including the EU" (Philippe Tulkens, Head of Unit in the Commission's Directorate-General for Research and Innovation, nd.) (Directorate-General for Climate Action, 2023). Indeed a key point of the report is the presence of Summary for Policymakers (SPM) , approved line-by-line by representatives of 195 member governments, showing both how much consensus and legitimacy is valued by the organization, but also that the report doesn't not need to remain a sterile scientific analysis, but need to be seen as a launch platform for innovation in sustainable proposals and adaptable solutions.

The Summary for Policymakers provides a high-level condensation of the understanding of the current state of the climate, including how it is changing and the role of human influence, the state of knowledge about possible climate futures, climate information relevant to regions and sectors, and limiting human-induced climate change. (Masson-Delmotte et al., 2023)

The general report and its synthesis is supported by three special reports, dating 2019:

- the Special Report Global Warming of 1.5°C (SR1.5), 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(IPCC, n.d.);
- the Special Report Climate Change and Land report (SRCCL) on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems IPCC, n.d.);
- the Special Report the Ocean and Cryosphere in a Changing Climate report (SROCC), which ultimately focuses on details the rapid changes occurring in the cryosphere, including melting glaciers, shrinking sea ice, and thawing permafrost, as well as the warming, acidification, and deoxygenation of the oceans.(UNESCO, 2024b)

SCENARIO AND MODELLED PATHWAY

One of the reason why the latest report is considered extremely useful and advance in the climate science report field is because it's findings refer to previsions of future climate circumstances, thanks to quantitative modelled scenarios.
Modelled scenarios and pathways are used to explore future emissions, climate change, related impacts and risks, and possible mitigation and adaptation strategies. The recreations o f future scenarios are based on a range of assumptions, like socio-economic variables, combined then with quantitative data regarding climate change to produce specific projections.
Even though they start from socio economic bases, most do not make explicit assumptions about global equity, environmental justice or intra-regional income distribution. IPCC is neutral with regard to the assumptions underlying the scenarios in the literature assessed in this report, which do not cover all possible futures(H. Lee & J. Romero, 2023b).
Before diving into the different scenario that we can find in the report, it's necessary to understand how they were produced and what makes the such a necessary tool for modern climate studies.
During the last years we witnessed the development of the Shared Socioeconomic Pathways (SSP) as a set of scenario, established by the climate change research community in order to facilitate the integrated analysis of future climate impacts, vulnerabilities, adaptation, and mitigation. (Riahi et al., 2017)
The SSPs are based on five narratives describing alternative socio-economic developments, including sustainable development, regional rivalry, inequality, fossil-fueled development, and middle-of-the-road development.(Riahi et al., 2017)

WGI assessed the climate response to five illustrative scenarios based on Shared Socio-economic Pathways (SSPs)21 that cover the range of possible future development of anthropogenic drivers of climate change found in the literature. (H. Lee & J. Romero, 2023b)

The SSPs considered by the report go from level " very low" to level " very high", though " low", "intermediate", "high" levels. High and very high GHG emissions scenarios (SSP3-7.0 and SSP5-8.522) have CO_2 emissions that roughly double from current levels by 2100 and 2050, respectively. The intermediate GHG emissions scenario (SSP2-4.5) has CO_2 emissions remaining around current levels until the middle of the century. The very low and low GHG emissions scenarios (SSP1-1.9 and SSP1-2.6) have CO_2 emissions declining to net zero around 2050 and 2070, respectively, followed by varying levels of net negative CO_2 emissions.(H. Lee & J. Romero, 2023b)
A step forward is taken by the he IPCC Sixth Assessment Report (AR6) by combining SSPs and RCPs, which indicate a representative trend in greenhouse gas and aerosol concentrations for a given climate target (in terms of radiative forcing in 2100), which in turn corresponds to a given trend in human emissions.(NCCS, 2020)
We have three RCP scenarios, connected to the previous explained SSP:

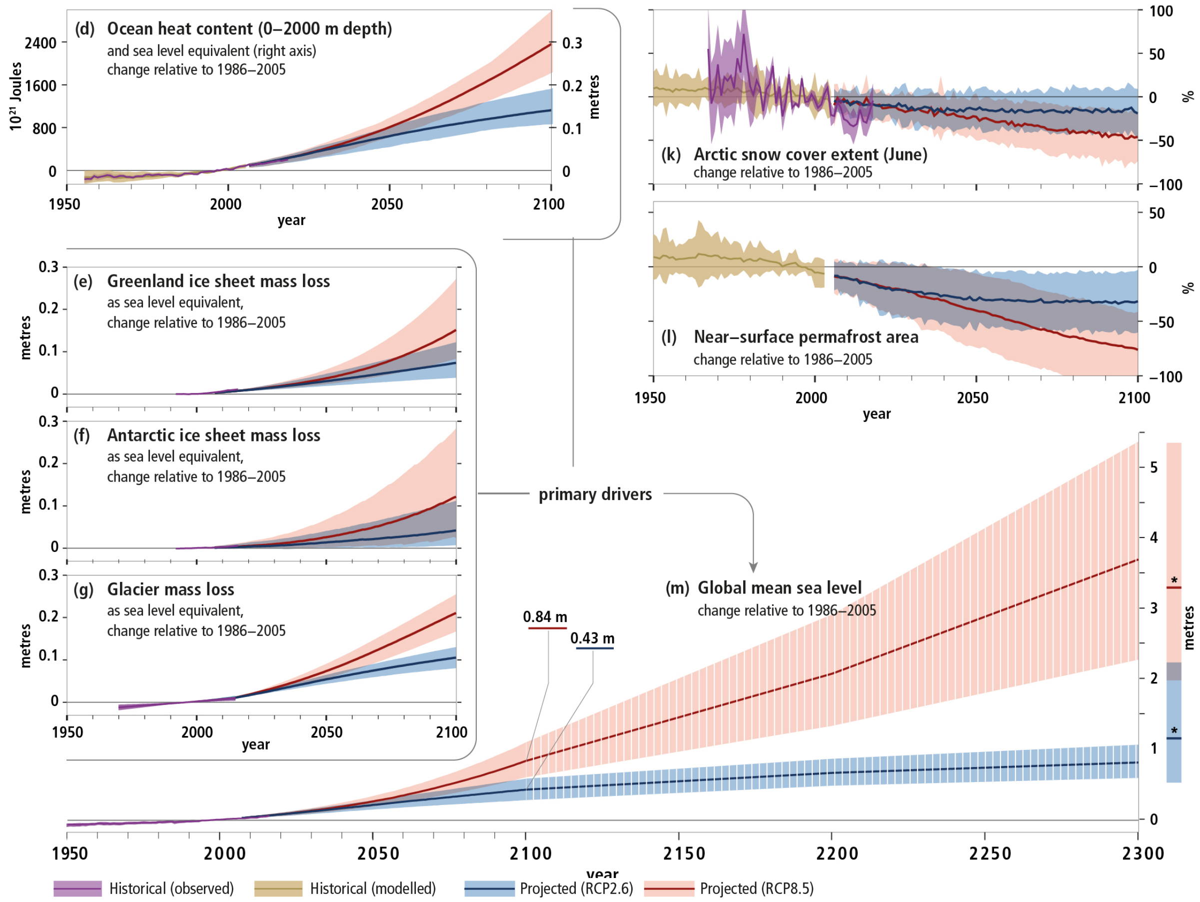
- RCP2.6 (Low, SSP1 -2.6): Measures are being taken to protect the climate. The increase in greenhouse gases in the atmosphere will be halted within 20 years through immediate reductions in emissions. This will enable the targets of the 2016 Paris Climate Agreement to be met. Compared to 1850, the radiative forcing will amount to 2.6 W/m^2 in 2100.(NCCS, 2020)
- RCP 4.5 (Intermediate, SSP2 – 4.5): Greenhouse gas emissions are curbed, but their concentrations in the atmosphere continue to rise over the next 50 years. The "+2 °C" target is not achieved. Compared to 1850, the radiative forcing will amount to 4.5 W/m^2 in 2100.(NCCS, 2020)
- RCP 8.5 (Very High, SSP5-8.5): No measures are taken to protect the climate. Greenhouse gas emissions continue to rise. Compared to 1850, the radiative forcing will amount to 8.5 W/m^2 in 2100. (NCCS, 2020)

This combination resulted into a Scenario Matrix Architecture that brings together more and more pieces of the puzzle that is our future. The combination of SSPs and RCPs used in AR6 is the first comprehensive application of the scenario matrix to mitigation and represents the first step towards the inclusion of the scenario matrix in climate change research.(IPCC, n.d.-a)
In conclusion, the AR6 SYR confirms that unsustainable and unequal energy and land use as well as more than a century of burning fossil fuels have unequivocally caused global warming, with global surface temperature reaching 1.1°C above 1850–1900 in 2011–2020.
This has led to widespread adverse impacts, related losses and damages to nature and people. The nationally determined contributions (NDCs) committed by 2030 show the temperature will increase by 1.5°C in the first half of the 2030s, and will make it very difficult to control temperature increase by 2.0°C by 2100, confirming the alarming reality we could be facing by the end of our century where every increment of global warming will intensify multiple and concurrent hazards in all regions of the world. (H. Lee & J. Romero, 2023b)

SROOC REPORT ON CLIMATE CHANGE IN SEAS

Cryosphere is defined by the World Meteorological Organization (WMO) the fifth earth sphere alongside the atmosphere, hydrosphere, lithosphere and biosphere and it supports unique habitats relates to climate system through global exchange of water, energy and carbon (Qin et al., 2018).
As previously analysed, Climate Changes are affecting this sphere and the world's ocean and cryosphere are taking the heat for this phenomenon (H.-O. Pörtner et al., 2019).
The "Special Report on the Ocean and Cryosphere in a Changing Climate", produced by the IPCC (Intergovernmental Panel on Climate Change) during the Sixth Assessment Cycle, in 2019 addresses these issues.
Physical changes observed and their impacts
To easily understand the various Physical Changes observed we can identify three major changes: global warming, ocean warming and Sea Level Rise (SLR).
Considering the global warming a visible shrink of the cryosphere, with mass loss from ice sheets and glaciers and reductions in snow cover, Arctic Sea ice extent and increased permafrost temperature (H.-O. Pörtner et al., 2019).
Then, the cryosphere has taken up more than 90% of the excess heat in the climate system (since 1970): marine heatwaves have doubled in frequency (since 1982) and are increasing in intensity (H.-O. Pörtner et al., 2019). By absorbing more CO2, the ocean has undergone increasing surface acidification and extreme events have increased.
The Global Mean Sea Level is rising due to ice loss (glacier mass, Greenland and Antarctic ice sheets) and ocean thermal expansion.
The GMSL has risen of 3.6 mm yr−1 between 2006 and 2015 with the ice sheet and glacier as the dominant (over thermal expansion), connected to anthropogenic forcing since the 1970 (H.-O. Pörtner et al., 2019)
The sum of ice sheet and glacier contributions over the period 2006–2015 is the dominant source of sea level rise (1.8 mm yr−1, very likely range 1.7–1.9 mm yr−1), exceeding the effect of thermal expansion of ocean water (1.4 mm yr−1, very likely range 1.1–1.7 mm yr−1) 22 (very high confidence).
The observed changes have impacted multiple ecosystems with changes in seasonality, populations and interactions of plants and animals: hydrological and freshwater changes in high mountain and polar regions; marine geographical shifts an biochemical changes.
Moreover, the coasts appear as one of the ecosystems more affected by ocean warming: marine heatwaves, acidification, loss of oxygen, salinity intrusion and sea level rise.
Coastal ecosystems suffer of habitat contraction, geographical shift of associated species and loss of ecosystem functionality and direct human disturbances with anthropogenic barriers preventing landward shift of marshes.
In this context, coastal wetlands are a distinct and increasingly threatened ecosystem, having lost

approximately 50% of their area over the past century (due to human pressures, SLR and extreme events). These vegetated coastal environments play a crucial role in storing carbon and adapting to changing conditions: they protect shorelines from storms and erosion, and act as natural buffers against the impacts of rising sea levels (M. Kirwan & Temmerman, 2009).
The sea water intrusion (because of the sea level rise) affects the composition of coastal wetlands species, spreading marine species and reducing habitats for estuarine ones.
These impacts regard communities and populations in multiple regions with diverse outcomes regarding the governance, the food security, local cultures and tourism (H.-O. Pörtner et al., 2019).
Coastal communities, especially, are exposed to climate-related hazards as tropical cyclones or extreme flooding.



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FUTURE SCENARIOS

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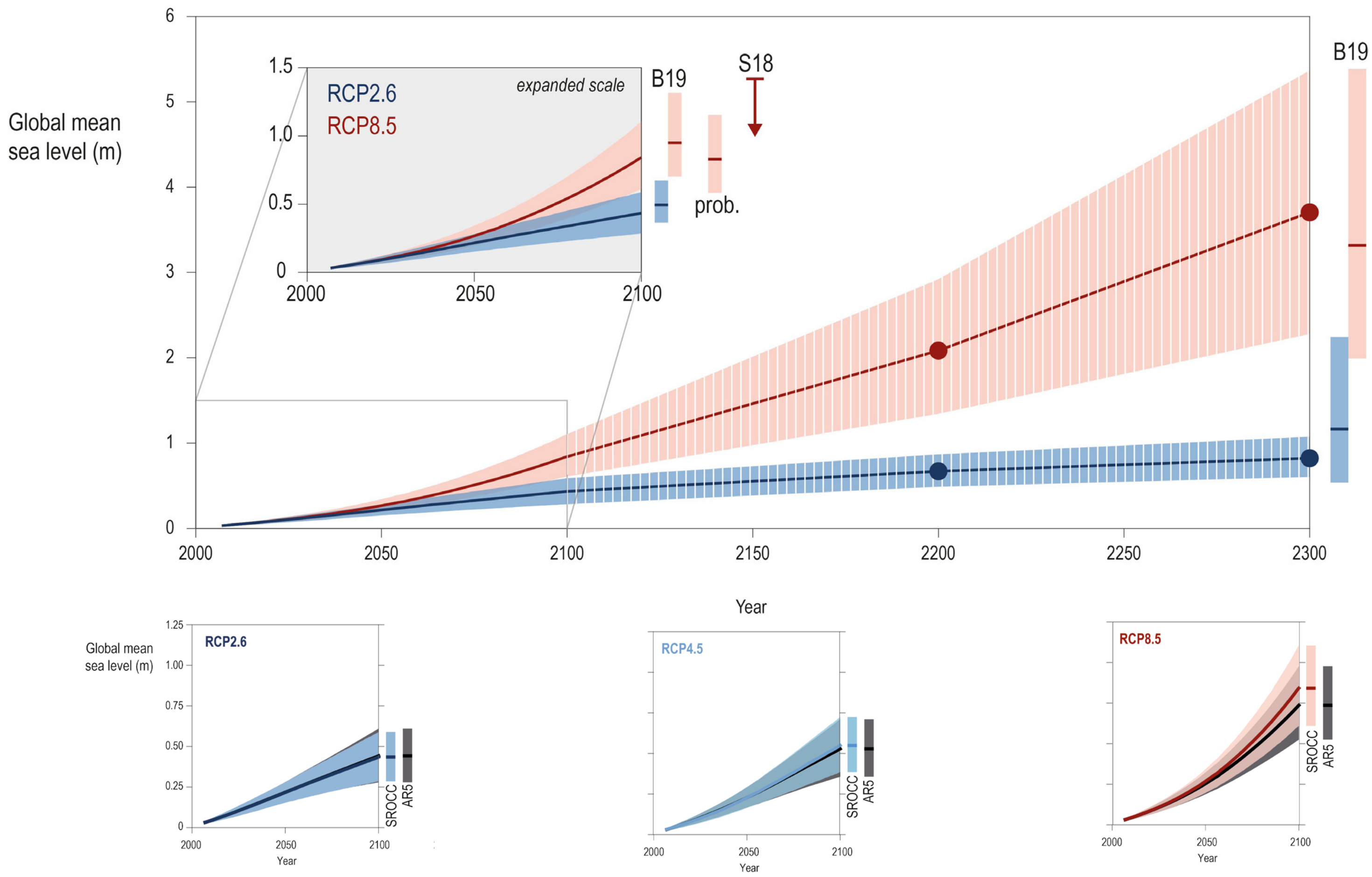

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CHANGES THORUGH HISTORY

To study the SLR is possible to start analysing the past changes; observing the phenomenon throughout times allow to better understand the relation between rising temperatures and rising sea level.
The GMSL clearly has not been still in the distant past and studies trying to reconstruct the fluctuations of it state that it was considerably higher than today during past climate states that were warmer than pre-industrial (H.-O. Pörtner et al., 2019; Mazzini et al., 1999).
The reconstruction of ancient shoreline elevations shows the variations and here two periods are presented: one warmer than the other (H.-O. Pörtner et al., 2019).

- During Last Interglacial ("LIG"; ~130.000 years ago) surface temperature was 0.5-1°C warmer than today while sea surface temperatures were like today.
- Even if the modest global warmth, the Global Mean Sea Level was likely 6–9 m higher (Dutton et al., 2015; Kopp et al., 2009)
- In the mid-Pliocene Warm Period (mPWP; ~3.0 million years ago) CO2 concentrations were similar to today and global mean temperature was 2ºC–4ºC warmer than pre-industrial.

In this period probably GMSL was 25 m higher than today (Dutton et al., 2015; Kopp et al., 2009).
For the closer past (2400 years preceding 20th century) less evidences are available and, even if reconstruction get more difficult, it is possible to identify variations of around 9 cm (Kopp et al., 2016).
With the ongoing of time and the developing of technologies, getting closer to the 20th century data get more reliable and accessible (thanks to tide gauges especially).
Modelling and defining the various sources to current Sea Level Rise allows to define different contributions and calculating the SLR in recent history.

- Thermal expansion is the excess heat is absorbed by the ocean (obtained from in situ observations).
- It is estimated to be 1.40 mm yr-1 (1.08–1.72) for 2006-2015 (WCRP Global Sea Level Budget Group, 2018)
- Ocean mass changes correspond to land ice and terrestrial water storage changes. It has increased of 1.7(1.4–2.0) mm yr–1 over 2003–2015 (WCRP Global Sea Level Budget Group, 2018)
- Glaciers mass loss is agreed to have contributed to sea level change during 20th century (Bamber et al., 2018).
- Greenland (Artic) and Antarctic ice sheets mass changes contribution to SLR has been greater in the 2012-2016 (0.55 and 0.68 mm yr-1) and 2002-2011(0.73 and 0.23 mm yr-1) than in 1992-2001 (0.02 and 0.14 mm yr-1), proving the rising trend (R.K. Pachauri & L.A. Meyer, 2014).
- The water stored in land is composed by ice, snow, surface water, soil moisture and groundwater (except land ice) and its changes contribute to contributing to SLR too. These are caused by climate variability and direct human interventions, in the past century mainly groundwater depletion and impoundment of water.
- Together, the human action has contributed by 0.15–0.24 mm yr–1 to SLR (Wada et al., 2017).

Together these contributions make possible to use different times ranges for showing Global Mean Sea Level rise (Pfeffer et al., n.d.).

- 1.4 mm yr−1 between 1901 and 1990
- 2.1 mm yr−1 between 1970 and 2015
- 3.2 mm yr−1 between 1993 and 2015
- 3.6 mm yr−1 between 2006 and 2015

Concluding, in the recent years (1993-2015) the thermal expansion and the glacier mass loss represent the two largest sources, accounting respectively for 43% and 20%.
If the 1-2mm yr-1 rise has characterized the past century, under all scenarios the rate will keep rising in the next century; the rising in 2100 is here presented.

- Under RCP2.6, increase to 4–9 mm yr−1
- Under RCP8.5, increase to 10–20 mm yr−1

These rising rates allow to define the grow of the GMSL in future scenarios, relative to 1986–2005 (H.-O. Pörtner et al., 2019).
In 2050:

- Under RCP2.6, GMSL will rise 0.24 m (0.17–0.32 m)
- Under RCP8.5, GMSL will rise 0.32 m (0.23–0.40 m)

In 2100:

- Under RCP2.6, GMSL will rise 0.43 m (0.29–0.59 m)
- Under RCP8.5, GMSL will rise 0.84 m (0.61–1.10 m)

If, as previously observed, under all scenarios the Global Mean Sea Level will be higher because it depends on processes operating on long time scales (glacier melt, thermal expansion and ice sheet mass loss); even if the rise in temperature slows, the sea level will keep rising (Solomon et al., 2009).
Although this value (the GMSL) allows to understand the rise of the mean level, the actual Local Sea Level varies regionally (varying ±30% on the GMSL), because of anthropogenic factors such as groundwater extraction. Even if right now observations show regional changes, all ocean basins are rising (because of changing winds, air-sea heat, freshwater fluxes and atmospheric pressure) (Hamlington et al., 2018).
Extreme events, represented by water level hieghts, are an issue who needs to be addressed too: due to GMSL, events that now are historically rare are going to be more common by 2100 (all scenarios) and, because of this, th intensity and frequency of flooding will increase.

IMPACTS AND RESPONSES OF SLR IN COASTAL AREAS

Considering the risk and its components to define the risk (Thywissen, 2006; UN-Habitat, 2004), coasts represent, in all their various forms, the ecosystems most exposed by Sea Level Risk. Populations and infrastructures result to be, in these areas, at high risk.
These spaces are affected by SLR together with other climate-related changes (temperature and precipitation patterns) and, especially, by the effects of human activities (H.-O. Pörtner et al., 2019).
Coastal areas are characterized by various rich ecosystems, such as saltmarshes, mangroves or coastal wetlands, that can adapt to Sea Level Rise and hosts multiple populations and species. These ecosystems expect mainly three categories of impact: habitat contraction, loss of biodiversity and migration (lateral and inland).
Vulnerability, then, differs along the ecosystem and is strongly linked with human pressure and interventions (Thywissen, 2006; UN-Habitat, 2004).
Human action contributes to these impacts with actions such as land reclamation or barriers preventing migration or sediment movements.
Fragmentation of wetlands and actions limiting the adaptation of coastal ecosystems influence badly the changing dynamics of the coasts, heading to phenomena such as “coastal squeeze”.
Shoreline erosion, then, can also contribute to coastal squeeze with it being connected only to SLR or to both natural sloping and artificial infrastructures (as defense structures)
Flooding and salinization, too, both strongly influenced by sea level rise (SLR), reduce ecosystems’ ability to provide services, such as coastal protection or populations support (H.-O. Pörtner et al., 2019).

The impacts, caused by the Sea Level Rise, are hazardous elements of the risk: these are linked to multiple processes such as sediments movement by rivers.
For coastal ecosystems six hazard categories are presented to sum up the multiple phenomena; these are taken from the SROCC Report by IPCC (H.-O. Pörtner et al., 2019)

- Submergence of land by mean sea levels (permanent)
- More frequent or intense flooding
- Enhanced and coastal erosion
- Loss and change of ecosystems
- Salinization of soils, ground and surface water
- Impeded drainage
- Human activities

Submergence of land and flooding

The land submergence is particularly relevant for coastal areas where human pressure and urbanization phenomena have been taking place in the last century. Projections especially show an expected population increase compared to national dynamics in the Low coastal area (LECZ, below 10 m of elevation) (Merkens et al., 2016).

This growth will cause a grow of exposure for extreme sea levels events: flood risks will increase by 2-3 orders of magnitude levels by 2100, in the lower SLR level for RCP2.6

However, for flood risk the hard coastal protection measures (as they will be better exposed later) results to be very effective and these options will be implemented globally, reducing the exposure.

Enhanced coastal erosion

The erosion processes happening is causing, globally, losses of land, since this exceed the land gains. Human actions are one of the main causes of these modifications and the erosion is globally increasing too (Hinkel et al., 2014; Mentaschi et al., 2018a).

However coastal systems respond dynamically to Sea Level Rise because exchanges of material (bio-chemical or physical) have made possible to maintain a stable morphology (Passeri et al., 2015). However, higher SLR, modifications in waves (energy, direction), acidification and other processes, including human pressure, can reduce these abilities.

From 6000 to 17,000 km2 of land could be lost by 2100 (Hinkel et al., 2014)

Salinization

Saline water intrusion is a fundamental process to be observed in various typologies of coastal ecosystems, like in coastal wetlands, in surface water and in soils, where it gets more frequent going farther inland, or in groundwater, where it is amplified by droughts and extraction.

Groundwater, affected by changing precipitation patterns (less frequent and concentrated), will be impacted by SLR in water quality, increasing the salinization (due to flooding). The freshwater availability and the vegetation dynamics, consequences of the modification in water quality, are already affected by anthropogenic influences, like groundwater pumping (Rotzoll & Fletcher, 2013).

In Surface water, the quality is affected by the intrusion of saline water; in estuaries or rivers, the direct increased salinity or the altered conditions can affect the quality. The impact of salinisation is relevant in deltas or in low-coastal wetlands can be significant in river deltas or low-lying wetlands, especially during low-flow periods such as in the dry season.

In Soils, this process, mainly due to sea water intrusion, causes soil degradation; in particular soil salinity is related to distance from progressive distance from river, delta and river mouth or land elevation. In the exposed soils this changes lead to changes in carbon dynamics (microbial community, soil enzyme activity and metal toxicity) affecting agriculture (Sánchez-Rodríguez et al., 2018).

Ecosystems

Coastal wetlands, globally, are reducing due to changing climate (with its effects) and other events, including flooding, changes in sediment movement and human pressure.

For these ecosystems, a morphological dynamic is needed to maintain stability: sediment trapping allows wetland to grow and accumulate more organic material. The wetland ecosystems itself is able to grow vertically at SLR rates, providing that the sediment trade-off is functioning and healthy, exiting material and supporting growth.

The lateral changes at the boundary, however, represent the potential risk for these ecosystems: the marsh retreat (due to SLR) can be offset with inland migration of the ecosystem, maintaining the functionality of the system. So, the constraint of the boundary of the wetland, "coastal squeeze", due to both environmental and anthropogenic causes can determine the loss of functionality (M. L. Kirwan et al., 2016; M. Kirwan & Temmerman, 2009; Mariotti & Carr, 2014; Temmerman et al., 2003).

Then, coral reefs ecosystem represents the most threatened by climate modification, as warming and acidification; strong difference is seen with the seagrasses which won't be much affected by SLR.

Together, all the various coastal ecosystems protect the coast, stabilizing the shoreline and attenuating the wave energy.

Human activities

Lastly, Sea Level Rise will affect multiple human activities, especially the ones located in the coastal areas.

Coastal agriculture will be impacted by land submergence, land loss due to erosion and salinization (in soil and groundwater).

Tourism and related recreation activities address landscape, as beaches, and others cultural elements; the SLR will impact these identity, culture and functionality features (like transportation, ports etc.)

Aquaculture and ocean farming are impacted by the ocean warming and the acidification, affecting habitats and fishes environment.

ADAPTIVE RESPONSES TO SLR

The Sea Level Rise and its impacts, together, define the risk but actions can be taken to adapt and mitigate the effects. In fact, part of the risk is defined by the mitigation efforts that is activated to diminish the risk consequences (Thywissen, 2006; UN-Habitat, 2004).
Multiple actions can be taken in a long-term prospect, even without considering the possible variations at the local scale (Magnan et al., 2016) and intervening in the human causes.
The scale of the action is relevant since often the measures are taken as a reaction to experienced disasters or short-term risks (H.-O. Pörtner et al., 2019).
Four main groups can be defined, following the SROCC Report by IPCC (H.-O. Pörtner et al., 2019).

- Hard protection measures; interventions protecting the coast with dikes, embankments, sea walls and surge barriers etc.
- Ecosystem-based adaptation (EbA) measures try to combine the benefits of protection and advance, working with the conservation and restoration of ecosystems (such as reefs and coastal vegetation).
- Advance and retreat actions refer to the modification of the coastline, creating new land by building into the sea (e.g., land reclamation), or removing it.
- Accommodation interventions work on reducing the vulnerability of coasts, making them capable of sustaining life and communities.

Where land is scarce but high exposure occurs (like urban context), hard protection and advance can be efficient (economically) but increase the exposure itself. On the contrary, where space is available ecosystem-based solutions can be suitable, with retreat being possible in areas with low density.
To guarantee effective solutions to Sea Level Rise, long-term perspective is needed, coordinating between responses, prioritizing social vulnerability and taking from local knowledge and specific potential ability.

Protection

With protection are defined interventions that block the propagation of Sea Level Rise in the inland, both the extreme events and the mean level rise (H.-O. Pörtner et al., 2019; Nicholls, 2018).
Hard Protection approach considers using dikes, seawalls, barriers or breakwaters to address, mainly, flooding as well as saltwater intrusion.Sediment-based approaches consider, instead, nourishments, dunes or other material movement to protect the shore and the coast. Ecosystem-based approach can be considered too, especially since normally these approaches are used combined to reach "hybrid measures" (green-belt or habitat design in designed seawalls)(Nicholls, 2018).
However, maintenance represents one of the key elements: both in sediment-based interventions or in rising water tables. Multi-functional flood defenses, then, combining flood risk and other functions for people are suitable for urban areas where there is a limited space resource. These solutions have proven to be effective and cost efficient but can lead to alteration of hydrodynamic (meaning possible flooding or erosion), as well as meaning, in times, an approach where always higher defenses are needed, with the consequent higher exposure being caused.

Accommodation

These responses address one specific component of the risk, the vulnerability (Thywissen, 2006; UN-Habitat, 2004). Looking at the coastal risk, the goal in this case is to limit the effects on coastal populations, activities or ecosystems, making possible to live in these areas.

Accommodation is a fundamental element of adaptation: flood proofing, raising building and drainage systems and planning, working with materials or key funcitioning infrastructure (H.-O. Pörtner et al., 2019).

Land use changes are also relevant, especially for salinity intrusion (slat tolerant crop species) together with institutional responses.

Ecosystem-based adaptation

Sustainable management, in these responses, address conservation and restoration of ecosystem (such as coastal wetlands) to obtain the effects of protection and advance.

For coastline protection ecosystem-based measures work to attenuate waves and act as impediment for storm flows in wetlands, providing retention (H.-O. Pörtner et al., 2019).

Still for protecting the coastline with raising elevations and reduce erosion, trapping and stabilizing sediments can be a useful instrument, with the possibility of building with the detritus too (Shepard et al., 2011).

Ecosystems like wetlands (or mangroves) are defined as able to attenuate waves, reducing floods (Barbier & Enchelmeyer, 2014). However, the effectiveness of these solutions is deeply linked with the context and how appropriate interventions are for the specific ecosystem. The characteristics of the landscape are relevant since these solutions tend to be highly variable over season, years or long-term, in the case of a wetland, for example, the density of the biomass (Koch et al., 2009).

The maintenance, for these solutions, can be excluded under some circumstances, since these actions tend to adapt to changes, but can become important after unexpected rapid changes or extreme events (Koch et al., 2009).The act of creating new land, building farer in the sea, reduces the coastal risk for the inland. This process has a long history, especially in cities and in dense areas and includes (Wang et al., 2014):

- Land reclamation, with pumped fill material (like sand)
- Natural accretion of land, reached with vegetation planting and low areas
- Termed "polder-creation" with drainage

The advance method was, in the past, not directly developed to address Sea Level Rise but it can still provide safety, assuring (unlike the protection method) no risk for catastrophic failure (H.-O. Pörtner et al., 2019).On the contrary retreat consist in moving out the exposed elements to reduce coastal risk represents one possible option, including (H.-O. Pörtner et al., 2019):

- Migration, the voluntary movement of people
- Displacement, the involountary movement due to unforeseen impacts
- Resettlement, a managed operation of retreat and relocation

f.50

ITALY AS A LOOK-OUT FOR COASTAL CLIMATE IMPACTS

According to the latest projections of the Intergovernmental Panel on Climate Change, at the end of the century, coastal zones and low-lying ecosystems will be increasingly threatened by rising global mean sea levels.(Furlan et al., 2022)
The recent report on global climate change, studied in the previews sections of this chapter, warned countries on the risk induced by sea-level rise and its impacts. This report must be seriously considered for the assessment of coastal vulnerability and flooding hazard in response to the fast retreat of the coastline. (Michiel Schaeffer et al., 2012) Although this warning must be intercepted by every country of the globe, there are places that, for various reasons, need to do so faster and in a more efficient way (Antonioli et al., 2017a).
Among these we find the Mediterranean region, which can be considered a hot-spot for the ongoing anthropogenic climate change. While the fact the most of the Mediterranean population (around 75%) lives in coastal areas highlights the obvious need for immediate intervention, is not the only reason why this geographical areas is at risk more than others. In general the average rate of sea level rise in Europe slightly exceeds the global average and is accelerating. But there are significant regional variations, which shows that in Southern Areas of Europe, such as the Mediterranean, higher sea level rise rates are expected. (Editorial Team, 2024)
The Mediterranean is also characterized by a strong variability in the vertical movements of the coasts, which vary from area to area due to tectonic, volcanic and anthropic activity(MEDITERRANEAN | Estimates of Sea Level Rise on the Coasts by the End of the Century Are Rising, 2023).
Considering this is safe to assume that will also face severe erosion by the end of the century, at least 20% of Mediterranean beaches are projected to lose more than 50% of their area.(Editorial Team, 2024)
The sum of these phenomena will cause changes in Medicanes (Mediterranean tropical-like cyclones) and meteotsunamis (high-frequency ocean waves caused by rapid atmospheric pressure changes). The reason behind this variation is the rising sea surface temperatures and altered atmospheric circulation patterns, increasing risks for coastal regions and contributing to the SLR(Editorial Team, 2024).
The most critical areas include the coasts of Turkey , the northern Adriatic, the Aeolian islands, the coast of Italy, especially in the central area, and eastern Morocco. (Antonioli et al., 2017a)
Italy is located at the very center of this region and serves as a significant territory for observing climate change and sea level rise due to its central Mediterranean location, diverse coastline, high population density in coastal areas, and vulnerability to extreme weather events. As a hotspot for climate change, Italy can expect exacerbated impacts of extreme events and permanent variations of its landscape .(Davide Donati & Salvatore Pascale, 2022)
The country’s specific geographical features and the concentration of human and economic activity along its coasts make it an ideal, albeit alarming, natural laboratory to observe the various impact of sea level rise.

Italian coastal urbanization

As previously stated, over the last century, Europe has undergone important economic, social, and cultural changes, leading to the abandonment of hilly mountain areas and the expansion of urban and industrial settlements in flat areas. In particular, southern European cities experienced population concentration increases up to the 1980s. The strong human pressure in those areas led to major expansion of construction activities, mainly around the major cities and along the seacoast , where urban extent is even faster than in other regions.(Smiraglia et al., 2023). Most of the Mediterranean population is concentrated in the coastal region, where housing (mainly secondary housing in certain areas), services and tourism are the main factors of land uptake(Smiraglia et al., 2023). For this reason the artificial surfaces in coastal areas are mainly dedicated to industrial, defense and harbor constructions, or touristic exploitation.

Italy contributes to increase coastal urbanization and land consumption indices. We can refer to the environmental data made available by ISPRA to observe Italian soil consumption within specific distances from the coastline and to track its temporal evolution.

Nearly a quarter of the land within 300 meters from the coast has been urbanized, while 19% of the area between 300 and 1,000 meters and 8.7% of the area between 1 and 10 km have been affected. This data gains relevance if we consider that, in comparison, only 6.5% of the rest of the territory has undergone soil consumption.(ISPRA, 2024)

This is the result of Italian fast coastal urbanization happened from the 1950s onwards, driven by mass tourism and a lack of planning, leading to a quadrupling of urbanized areas by 2001 and severe ecosystem damage. Before this boom, human modification of coastal and riverine areas began in the Middle Ages and intensified with industrialization. In the ancient period, coastal cities like Ravenna flourished due to their strategic harbor locations, but some settlements later shifted inland for defense or other reasons. (Adriatic Ionian Ecoregion (AIE) Coastal Urbanization Definition, n.d.)

This a high degree of linear urbanization along the coast, with peaks around centers of production and areas of intense tourist development, lead Italy to develop some of its major cities along the coast and, even though the general population growth is decreasing, the pressure on these vulnerable coastal areas is increasing. The Italian coastal population is particularly concentrated in the regions of the Mezzogiorno. According to recent data (2019), it totals approximately 16.9 million inhabitants, accounting for 30% of the country's total population, even though these municipalities represent only 8.2% of the national total. (ISPRA, 2024)

This high concentration of people in vulnerable coastal areas makes it crucial to study sea level rise in Italy and implement measures to protect communities and infrastructure from its impacts.

Variety of coastline types and morpho dynamics

The coastline of Italy stretches almost 8,000 kilometers, featuring an impressive variety of geomorphological settings influenced by intricate interactions of geological, climatic, and oceanographic factors (Anzidei et al., 2014).The nation's peninsular shape, together with its islands and microtidal waters, results in various coastal configurations, such as rocky cliffs and headlands, sandy deltas, barrier-lagoon systems, and low-lying alluvial plains(Pranzini E. & Williams A.T., 2013). These various morphologies indicate different sedimentary and tectonic environments, leading to diverse morpho dynamics and responsiveness to coastal risks

According to national assessments by ISPRA (2023), Italy's coastline extends for approximately 8,353 km, of which 92% remains natural, while 3.8% is artificial and 4.2% is classified as modified or "fictitious." Among natural coasts, 63% are low sandy or alluvial, and 37% are high rocky or cliffed, reflecting an extraordinary geomorphological heterogeneity. This wide range of coastal types makes Italy a natural laboratory for studying sea-level rise (SLR) impacts, as both low-lying deltas and elevated rocky shores respond differently to hydrodynamic and climatic forces.(Giuseppe Mastronuzzi, n.d.)

To be more specific, the northern Adriatic coast is dominated by extensive lowlands and deltaic systems, such as the Po Delta, characterized by active sediment deposition, high subsidence rates, and significant exposure to sea-level rise and flooding (Amadio M., 2012). In contrast, the Tyrrhenian coast features alternating rocky promontories and pocket beaches, often backed by cliffs formed in carbonate and volcanic rocks (Antonioli et al., 2017a).The southern and insular coasts, including Sicily and Sardinia, host mixed sandy and rocky environments where tectonic uplift, wave exposure, and limited sediment input produce complex morpho dynamic patterns (Maselli et al., 2020).

Italian coastal morpho dynamics are influenced by both natural processes—such as wave climate, sediment transport, and tectonic activity—and anthropogenic pressures, including urbanization, harbor construction, and sediment extraction (ISPRA, 2023). Shoreline retreat and erosion currently affect nearly 42% of Italian sandy coasts, with the most severe losses occurring in the Adriatic regions (Anfuso et al., 2022). To mitigate these dynamics, national and regional programs are increasingly focused on integrated coastal zone management (ICZM) and the restoration of natural sediment processes, aligning with the EU Strategy on

Specifically, the northern Adriatic coastline features vast lowlands and delta formations, like the Po Delta, marked by ongoing sediment accumulation, elevated subsidence rates, and considerable vulnerability to sea-level increase and flooding(Amadio M., 2012). Conversely, the Tyrrhenian coast displays a mix of rocky jutting points and small beaches, frequently supported by cliffs made of carbonate and volcanic stones(Antonioli et al., 2017a). The southern and island coasts, comprising Sicily and Sardinia, feature diverse sandy and rocky landscapes where tectonic uplift, wave action, and restricted sediment supply create intricate morpho dynamic patterns .

Italian coastal morpho dynamics are shaped by natural factors—like wave climate, sediment transport, and tectonic movements—and human pressures, including urban growth, harbor development, and sediment removal (ISPRA, 2022). Shoreline retreat and erosion now impact almost 42% of sandy coasts in Italy, with the greatest losses seen in the Adriatic areas. To address these dynamics, national and regional initiatives are increasingly concentrating on integrated coastal zone management (ICZM) and revitalizing natural sediment processes, in line with the EU Strategy on Adaptation to Climate Change.

Ecological and historical heritage along the coastline

In Italy, coastal landscapes amount to almost 8000 km, and their biodiversity and cultural heritage are a distinctive part of Italian territory, which is often subject to land consumption.(Smiraglia et al., 2023)

As previously stated, Italian shores have an exceptional assortment of environments from sandy shorelines and hill frameworks to rough cliffs, coastal tidal ponds, and broad seagrass glades of Posidonia oceanic which together frame a mosaic of tall biodiversity and environmental efficiency (Bianchi & Morri, 2000)(Relini & Ryland, 2007). National evaluations by ISPRA highlight that over 40% of the Italian coast is included inside secured ranges or Natura 2000 destinations, reflecting the countrys exertion to protect coastal environments of exceptional biological esteem (ISPRA, 2022)

Past their normal significance, Italian coasts exemplify a millennial authentic and social legacy. The coastal zone has long served as a hallway of exchange, settlement, and social trade from Etruscan ports to Roman harbors and medieval sea republics. UNESCO perceives a few Italian coastal scenes (e.g., Venice and its Tidal pond, Cinque Terre, Amalfi Coast, Syracuse and the Rough Necropolis of Pantalica) as World Legacy Destinations for their remarkable social centrality and authentic coherence (UNESCO, 2024a)

This interconnection between normal and social values characterizes the Italian coastal scene as a territorial capital (Barca & Pugliese, 2019), where environmental frameworks and human legacy coexist and co-evolve. In any case, anthropogenic weights counting coastal urbanization, mass tourism,

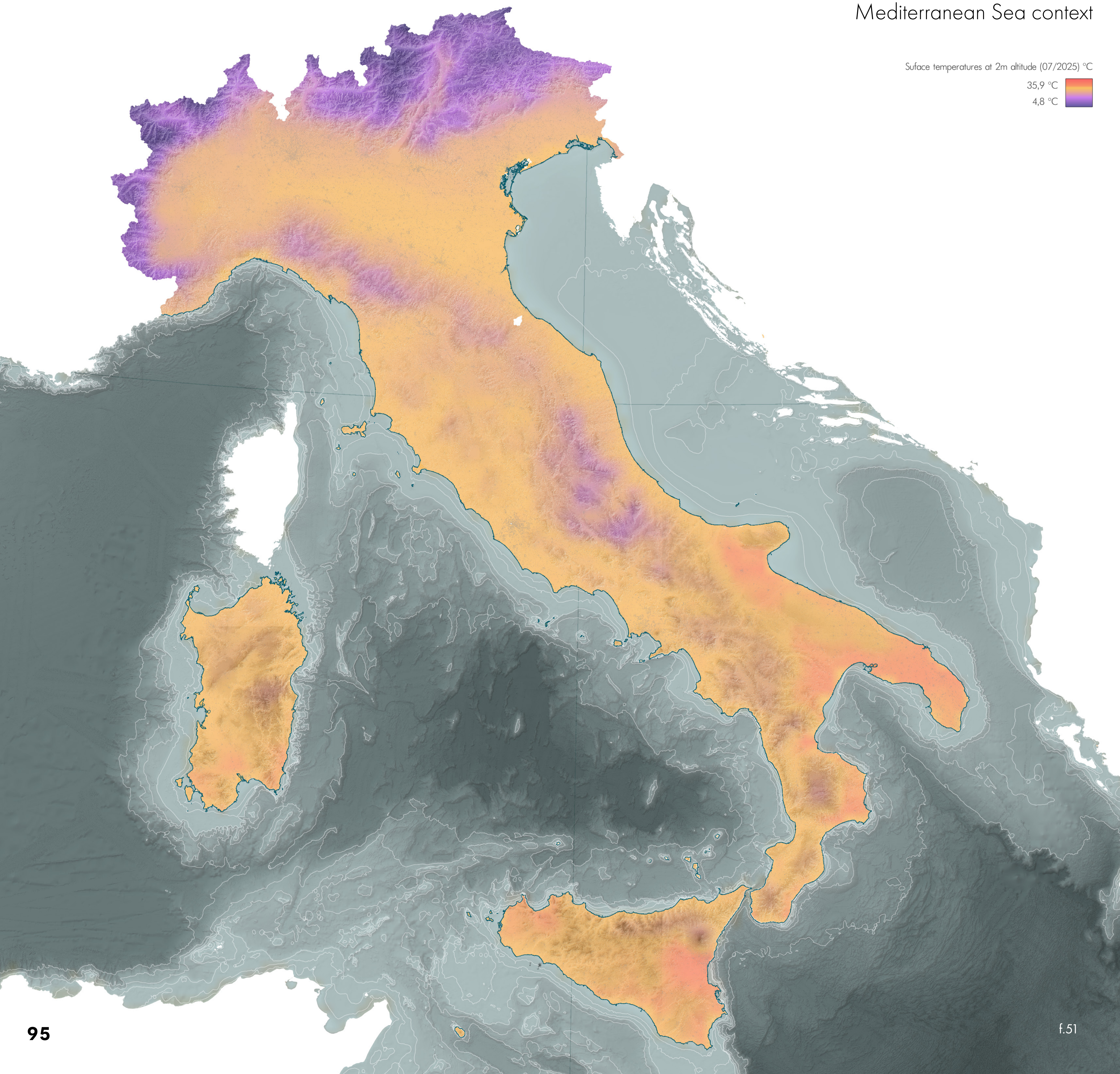
CLIMATE DRIVERS AFFECTING THE COAST

To fully grasp the phenomenon of sea level rise (SLR) and its consequences, it is essential to examine the root causes. Among these, the increase in land and ocean temperatures is a key factor: global warming leads to the melting of glaciers and polar ice caps as well as the thermal expansion of oceans, causing sea levels to rise. In the Italian setting, marked by vast coastal regions with dense populations and considerable human-induced pressures, examining these processes is crucial for risk evaluation and establishing focused adaptation strategies designed to safeguard coastal infrastructure and promote sustainable land management.

ATHMOSFERIC WARMING

Globally, 2024 was the warmest year on record. In particular, estimates obtained from the fifth generation ECMWF reanalysis dataset (ERA5) available in the Copernicus Climate Change Service (C3S) indicate that the global average temperature exceeded the previous record set in 2023 by 0.12 °C and was 1.60 °C above the pre-industrial average for the period 1850-1900. (Emanuela, 2025)
Italy has been no different: 2024 was the warmest year since records began (Figure 2.1), reaching an average anomaly of +1.33 °C compared to the 30-year period 1991-2020, one tenth of a degree higher than 2022, the previous warmest year. The exceptional intensity of the temperature anomaly can be attributed to the persistence of large-scale climatic anomalies over much of the Mediterranean and central-eastern Europe, which contributed to the advection of particularly warm and humid air masses from the Atlantic. In addition, the presence of higher than usual humidity values, favoured by the phenomena explained above, may have contributed to a temporary increase in the greenhouse effect, reinforcing the night-time temperature anomalies(Emanuela, 2025).
Considering these data and observing them in relation to the IPCC's RCP scenarios, we can predict that Italy's climate in 2100 will experience an increase in average temperatures of approximately 3.2°C for RCP4.5 and approximately 6.3°C for RCP8.5. The average temperatures expected for Italy are higher than global temperatures because climate change will affect the whole world in the same way: the Mediterranean basin, of which Italy is a part, is considered one of the "hotspots" of climate change, with warming exceeding the global average increase by 20%.
The climate in Italy in 2100 will be characterised above all by instability. We will see an increase in extreme weather events, such as torrential rains, unseasonal frosts, tropical nights and periods of drought.. (Fiandesio, 2022)

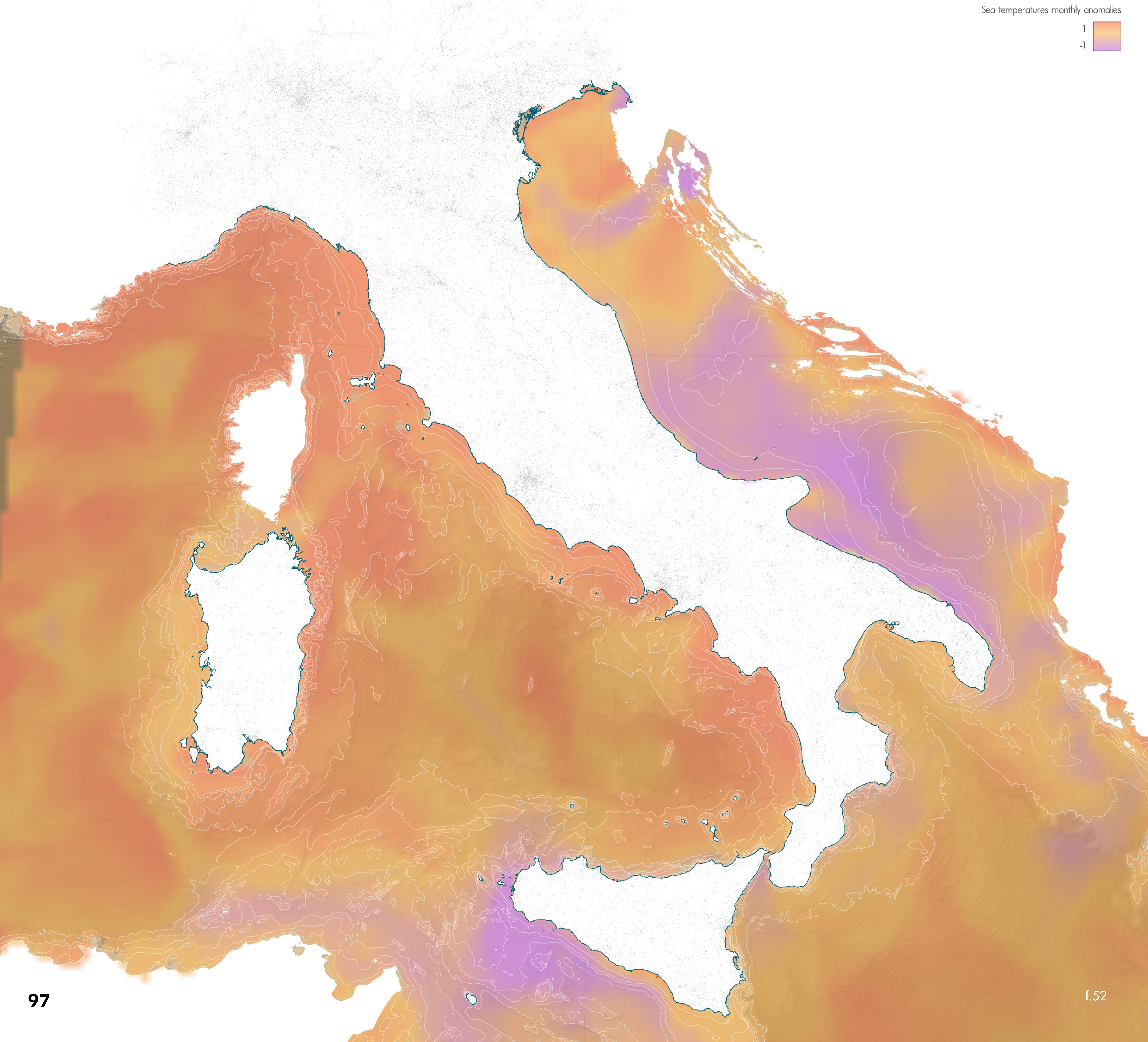
SCENARIO BUILDING PROCESS
Mediterranean Sea context



f.51

OCEAN WARMING AND MARINE HEATWAVES

With regard to global sea surface temperatures, 2024 was characterised by high sea surface temperature anomalies, often associated with intense marine heatwaves. In tropical areas, these caused widespread coral bleaching in April 2024. (Emanuela, 2025)
The surface temperatures of Italian seas were affected by persistent weather conditions favourable to insolation and remained consistently positive, with an average annual anomaly compared to the 1991-2020 period of +1.24 °C, the highest since 1982 and almost 0.3 °C higher than the previous record set in 2022. These conditions certainly contributed to the record high average sea level observed in the northern Adriatic Sea. More specifically, we can see that the average annual SST values for Italian seas in 2024 range from 19.0 °C in the Ligurian Sea to 21.6 °C in the Ionian Sea. For all seas, in 2024 the lowest monthly values were recorded in February, while the highest were recorded in August. The lowest monthly average value was recorded in the Adriatic Sea (13.7 °C), while the highest was recorded in the Ionian Sea (29.1 °C, more than 1.5 °C higher than in 2023). (Emanuela, 2025)
We are particularly interested in thermal anomalies, as they are one of the main causes of overall overheating. These anomalies have also led to an unprecedented intensification of marine heat waves: in 2024, the Mediterranean experienced an average of 246 days of Marine Heat Waves (MHWs), with regional variations reaching 205 days in the western basin and as many as 288 days in the eastern basin. The average duration of MHWs varied between 27 and 65 days, with a frequency of 5 to 8 events and an annual total of MHW days ranging from 169 to 288. (Azzola et al., 2025
These data show that the Mediterranean Sea is experiencing accelerated warming, with temperature anomalies exceeding 5°C above the seasonal average, triggering a phenomenon known as "tropicalisation". In Italy, the warming of sea waters has direct implications for biodiversity, fishing and tourism, as well as contributing to sea level rise due to thermal expansion (Danise, 2024) .
The Italian coastline, already vulnerable to phenomena such as erosion, is now particularly exposed to the effects of marine warming, which can intensify extreme events such as heat waves and violent weather phenomena, but also have future and permanent consequences.



f.52

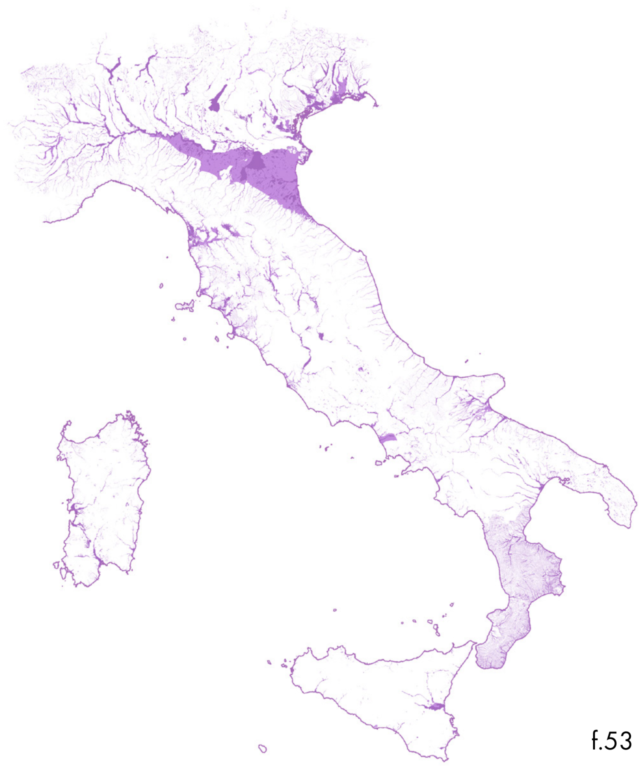
SEA-LEVEL RISE HAZARD

Sea level rise (SLR) is a major threat for coastal zones, inducing hazards such as coastal flooding, permanent submersion of coastal zones, coastal erosion, salt intrusion in surface- and groundwater, problems with water management, and coastal ecosystem degradation or loss (van de Wal et al., 2024a).
As sea level is bound to rise over the next few centuries, we can assure, considering the data collected, that coastal areas communities ties will be increasingly threatened by sea level changes at various timescales, ranging from episodic extreme events to interannual–centennial changes. (van de Wal et al., 2024a). As already stated, global sea-level rise projections for 2100 range between 530 and 970 mm (IPCC, 2013, RCP 8.5 (www. ipcc.ch)), and up to about 500e1400 mm(H. Lee & J. Romero, 2023b). This should warn the countries that will be affected early by this changes, in order to start working for the assessment of coastal vulnerability(Antonioli et al., 2017a)
Italy should start facing the reality of change in its territory that await it. The first sign of sea level changes and rise acceleration started to show in the 19th century and yielded a 20th century rise that is extremely likely faster than during any of the previous 27 centuries. (Antonioli et al., 2017a)
With this trend and the current changes in climate, Italy's sea level rise could reach 0.18–0.23 meters by 2050 and 1.3–1.5 meters by 2100, depending on emissions scenarios. (H. Lee & J. Romero, 2023b)
These values of sea-level rise will threaten many coastal cities, low-lying islands and coastal plains, even in absence of land subsidence. Even if the emissions of greenhouse gas will decrease, a sea-level rise between 28 and 61 cm is still expected for the same period. In this optimistic scenario, more than half a meter of sea-level rise will have an important impact along the coasts, causing diffuse erosion of the shorelines. (Antonioli et al., 2017a)

COASTAL HAZARDS

Studying climate change on a larger scale, moving down to Italy, requires to apply and observe all the various consequences at a local level.
Previously three major drivers were studied locally in Italy: how each of them is presented and its consequences.
Sea Level Rise, among them, represents a major threat to coastal zones, being expected to rise in the next few centuries and inducing multiple hazards. Communities living in these places will be affected by sea level changes and extreme events (van de Wal et al., 2024b).
The risks related to these changes are strongly connected with the exposure: coastal zones have high rates of population growth and urbanization, and this will increase the number of infrastructure and people possibly affected.
Coastal zones typically host fertile deltas and plains, causing concentration of settlements and economic activities; valuable activities and strategic infrastructures are located in these areas, resulting in high vulnerability.
Cities, particularly, were historically built along the shoreline or in deltas and even smaller changes of Sea Level will quickly be visible, due to population pressure (van de Wal et al., 2024b).
Hazards cause by SLR can be grouped in: coastal flooding (and submersion) with high tides being mild chronic or intense and episodic during storms; coastal erosion; salt intrusion in surface and groundwater affecting drinkable water and agriculture; ecosystem degradation or loss affecting coastal wetlands, biodiversity and carbon storage (H.-O. Pörtner et al., 2019; Paprotny et al., 2018; van de Wal et al., 2024b).
To better study these hazard category, four steps are used: conceptual definition, underlying drivers, impacts and implications, occurrence pattern in Italy

FLOODING HYDRAULIC HAZARD



f.53

Conceptual definition
"Flooding" or "inundation" are used to define the phenomena where seawater inundate dry land, exceeding a specific threshold: water can overflow, overtopping the level of barriers, typically artificial or natural, or degrading and lowering these because of prolonged over washing (van de Wal et al., 2024b).
"Compound flooding", then, corresponds to a composition of events that, even if differing for the driver, take place at the same time: a combination of hazards.
Normally, indeed, floods can be caused by river discharge or surface run-off, affected by climate-driven changes too; heavy precipitation can concur, especially in cities located in lagoons or estuaries, to insufficient drainage causing flooding events composed by multiple factors (van de Wal et al., 2024b).

Drivers and Impacts
For flooding (or inundation) extreme levels are caused by tides, storm surges, waves and relative mean sea level, all dynamic factors depending on season or climate (Zanuttigh et al., 2014).
The Sea Level Rise drives flooding mainly by directly raising the mean water level and so decreasing the waves or storm levels need; the water depth alteration, then, modify tides and waves in low waters, while the weather changes lead to intensification of storm surges and rainfall discharge.
Especially for compound flooding events, storm surges play a significant role, yet they are not the only contributing factor: even non-extreme events could be linked with non-extreme flooding. Observe precipitation, affected by climate change with modified patterns and resulting increment, is fundamental to understanding river discharge and river flow (van de Wal et al., 2024).
Flooding event have affected European, and Italian, coastline throughout history, with economic, social and environmental repercussions (Ferrarin et al., 2022; Paprotny et al., 2018). Human actions in coastal areas have altered the risk: manmade infrastructures (eg. barriers) have caused decline of habitats and ecosystems normally protecting the shoreline with wetlands and dunes, substituting these and taking on responsibilities for possible failing.

Occurrence pattern in Italy
Mediterranean coasts are expected to submerge or flood because of SLR and many areas, like Turkey coasts or aeolian islands will be critical (Lambeck et al., 2011; van de Wal et al., 2024b).
In Italy the northern Adriatic region, characterized by flat topography and high rates of land subsidence. In this area, like in others located in the center of the peninsula, rivers play a fundamental role too, together with storms, high surge levels and high-water tidal levels (Bondesanf et al., 1995; Lambeck et al., 2011).
Here large portions of land lie below mean sea level and water pumping systems keep them dry: these depressions are closed by lagoons and river dikes, avoiding marine water ingressions, are responsible for guaranteeing security (Antonioli et al., 2017b).
The equilibrium of lagoons and wetlands depends on tidal and marshes morphologies, that have been declining being submerged, going from "intertidal" to "subtidal" and enhancing the bottom sheer stress

(Antonioli et al., 2017b; Bondesanf et al., 1995).
Lagoon floors are becoming flatten and this morphological simplification is leading shallow-estuarine to become marine embayment (Bondesanf et al., 1995)
Venice represents an optimal example since multiple drivers can be identified for floodings: astronomical tide, storm surges, high-frequency surge, seiches, local wind, PAW (planetary atmospheric waves), sea level variability and relative SLR (Ferrarin et al., 2022).
However, the nontidal contribution is growing and, together with the relative SLR, has caused an increase in floodings frequency. If storm surges are responsible for extreme events, is the amplification of tides due to SLR that cause the recurrent floods (usually compound floodings) (Ferrarin et al., 2022; van de Wal et al., 2024b).

COASTAL EROSION AND SHORELINE RETREAT


f.54

Conceptual definition
Coastal erosion consists in permanent loss of land because of sea, a series of morphological changes in the ecosystems in multiple timescales and caused both by natural and anthropogenic drivers (Mentaschi et al., 2018b; van de Wal et al., 2024b).
Among the various typologies, like lagoons, islands, dunes, rocky shores or beaches, the most common is the sandy beaches; these shorelines represent the most vulnerable to erosion too.
Human action has intervene in these modifying their capacity to adapt and recover from erosion: it has modified the material flows in river, preventing terrestrial sediments to reach the coastline (Aiello et al., 2013).
Dams and interventions are favoring costal erosion over river sediment deposit, modifying the shoreline dynamics which typically is influenced by: wind, wave, sediment supply and geology (van de Wal et al., 2024b; Zanuttigh et al., 2014).
Drivers and impacts
Costal erosion share multiple drivers with the flooding and tides, storm surges, waves and SLR can cause erosion.
Deficits in sediment budget is normally caused by modifications in the balance between sediment transport moved by the sea and the sediment supply of rivers. So, in the Mediterranean, beach accretions have characterized coasts without high population pressure.
Dams and in-stream gravel mining have affected the basins, as well as hydropower production, altering both fluvial and coastal ecosystems. These two environments are strongly linked since the production zone is connected to the deposit one: the balance of supply and sediment storage create accretion and erosion of the shoreline (Aiello et al., 2013; van de Wal et al., 2024b).
Sediment granulometry, the energy and the characteristics of waves and streams define the process, together with the sloppiness (bathymetry) and the geomorphology of the coasts

Reclamation projects and interventions in river, like gabion, longitudinal defenses and channelization, reforestation and infrastructures building are common human interventions modifying the tradeoff of sediments (Aiello et al., 2013).
Land subsidence and SLR interact, driving hazards for flat deltas with high human pressure. The erosion is connected to subsidence, since the reduction of land vertically and horizontally brings the sea closer to human infrastructure and to the barriers (like earthen levees) protecting these.

Occurrence pattern in Italy

Italian seas have different behaviors related to the SLR: in contrast to the Adriatic and Tyrrhenian Sea, the Ionian Sea is currently witnessing a decreasing sea level trend
Looking at the Ionian coasts, a reduction in sediment supply from the upstream basins has created a imbalanced sediment budget; due to activity in the catchment basin the solid discharge is less than the one moved by the coastal drift. Erosion areas can be observed north of the river mouths and accretion to the south of these (Aiello et al., 2013).
The Po River Delta, similarly, has been studied in timeseries and a strong accretion has happened in the past, corresponding to large reclamation works. Now a stability period has been observed, following a rapid decrease moment (between 50s and 70s) (Fabris, 2021).
For the Tyrrhenian coast, in northern Tuscany, coast occupation has increased in recent decades because of tourism activities, threatened by a severe erosion phenomena: downdrift of harbors and other anthropic infrastructures used as solution to this problem (Anfuso et al., 2011).
Gryones, breakwaters and artificial islands, or seawalls and rip-rap revetments were built to prevent erosion, as well as jetties in river mouths; more expensive solutions tried in this area consist in nearshore scraping, submerged groynes and gravel beaches or beaches nurshments (the most expensive solution among the others) (Anfuso et al., 2011).
These solutions present limits in their local impact: they shift downdrift the erosion process that can not be handled without a strategic plan. (Anfuso et al., 2011; Romagnoli et al., 2022).

WATER SALINIZATION AND GROUNDWATER INTRUSION

f.55

Conceptual definition

Saltwater intrusion consists in an increased extent of the mixing zone between inland freshwater and saltwater, increasing the salt content both in surface waters and in groundwaters (van de Wal et al., 2024b).

This phenomenon affects the use of water for agriculture (salt damaging crops), freshwater wetlands and communities. Rivers and aquifers are affected by high salinity too, with delta regions and low elevation coastal zones being some of the most exposed territories to this process, living off the relations of these complex interactions (van de Wal et al., 2024b).

Drivers and impacts

Saltwater intrusion (SWI) threatens water resourcing and freshwater availability: the intrusion of saline waters further inland, though river courses, is influenced by the sea level and the river discharge.

The relevance of Sea Level Rise and of the river discharge reduction in future scenarios varies through all Europe: coastal morphology, physical and geological characteristics strongly influence the saltwater intrusion, affecting the interaction between groundwater, surface water and marine water (van de Wal et al., 2024b).

Sea Level Rise, shortening the pathway of saltwater, will facilitate inundation and salt intrusion while human activities, such as excessive pumping from coastal aquifers, may cause land subsidence phenomena.

Occurrence pattern in Italy

This phenomenon is deeply linked with the specific characteristics of local conditions: multiple cases have been studied throughout the years. In a coastal aquifer along the Adriatic Sea, the "Ravenna Pine Forest", many events have led to the intrusion of saline groundwater: land subsidence, land reclamation and drainage, urban development, groundwater extractions, coastal dune destruction. So today the freshwater in the coastal aquifer consists of low salinity water lenses floating on the saltwater wedge (Giambastiani et al., 2007).Land reclamation is one of the most invasive processes: creating a complex drainage system and turning wetland into agricultural land. Together with tourism, industrial and urban development, the pressure on groundwater has grown, with always more extraction leading to land subsidence sinking the are next to the sea (Giambastiani et al., 2007).

Using SLR scenarios to address salinization, small differences are predicted between scenarios, mainly because groundwater flow and solute transport are slow processes. Limited precipitations doesn't allow for an efficient acqufier recharge and so the salt load will increase because the saline groundwater being already present: by +133% for a 0.475 m sea level rise and by 290% for a 0.9 m sea level rise (Giambastiani et al., 2007).

A comparable situation has been documented in the Pisan plain, between the mouth of the Arno River along the Thyrrenan coasts, where the piezometric levels and electrical conductivity have been measured, as well as surface water and phreatic aquifer, to understand the high chloride concentrations observed

inland and derived from sea water. This showed how artificial channel (Navicelli channel in this case) can drive salinization process infiltrating shallow aquifers (Franceschini et al., 2016).
Lastly , the Variconi coastal lagoon is another Tyrrhenian case study is where freshwater resources are highly vulnerable to seawater contamination driven by groundwater overexploitation, landuse change and climaterelated pressures. A strong hydraulic connection insists between surface water bodies and the coastal aquifer: the river mouth recharges the system and the area receives freshwater from regional aquifer but seasonal evapotranspiration water-table lowering can cause high salinization (saltwater upcoming) (Mostoccio et al., 2019).
When SLR scenarios are included, the model predicts substantial inland migration of saline water, severely affecting the fragile transitional ecosystems of the Variconi lagoon (Mostoccio et al., 2019).

f.56

CONCLUSIONS

Sea Level Rise represents one of the most significant and irreversible consequences of climate change, directly affecting coastal territories and challenging the stability of landscapes that have long been shaped by human control. In low-lying coastal plains, the rise of the sea does not simply introduce a new risk factor, but exposes the structural fragility of landscapes that were historically transformed through rigid and extractive processes.

aWithin this framework, the Agro Pontino emerges as a particularly revealing case, where climate-driven dynamics intersect with a deeply altered territorial metabolism.

The projected scenarios of sea level rise do not impose an external or unprecedented geography on the Agro Pontino. Rather, they reveal a latent spatial order rooted in the historical configuration of the Pontine Marshes. Areas identified as most vulnerable correspond closely to former wetlands, lakes, and depressions that once regulated the relationship between land and water. This correspondence highlights a critical point: water does not "invade" the territory as an anomaly, but follows its original topography, reactivating a hydrographic logic that was suppressed through large-scale land reclamation.

However, unlike in the past, the contemporary landscape is no longer equipped to absorb these dynamics. The eradication of wetlands, the intensification of agriculture, and the rigid hydraulic infrastructure introduced during reclamation have replaced adaptive systems with a landscape dependent on continuous mechanical control. As a result, the potential return of water—if unmanaged—becomes more abrupt and destructive, exposing the vulnerability of a territory that has lost its capacity to negotiate change. In this sense, sea level rise does not generate a new crisis; it amplifies an unresolved one.

This thesis argues that responding to climate-related risks such as sea level rise cannot rely on further rigid, top-down reconstructions of the landscape. Approaches that impose control—similar in logic to the reclamation itself—risk reinforcing the same vulnerabilities that produced the current condition. Instead, the project proposes a paradigm shift: embracing transition rather than resisting it. Sea level rise is interpreted not solely as a threat, but as a process through which adaptive landscapes—such as coastal wetlands—can re-emerge as resilient infrastructures.

Through the case of the Agro Pontino, the research demonstrates how landscape architecture

can operate as a mediating discipline, capable of reactivating the ecological memory of the territory while addressing contemporary socio-spatial challenges. The proposed approach does not seek to restore an idealized past, but to reinterpret pre-reclamation conditions through a contemporary lens, where water becomes an integrated and productive element of the landscape rather than an adversary to be excluded.
Central to this vision is the idea of "returning": returning to adaptive systems, to hybrid ecosystems, and to a landscape capable of accommodating uncertainty. Wetlands and transitional waters are understood as dynamic spaces that can simultaneously mitigate climate risk, enhance biodiversity, and support new forms of public use. Their reintroduction is framed as an opportunity to develop projects that allow natural processes to operate, rather than attempting to fix the landscape into a static configuration.
In this context, the role of landscape architecture is redefined. Rather than organizing or imposing form onto the territory, the project strengthens existing ecological potentials, limits urban pressure, and promotes accessibility and collective engagement. By fostering a culture of coexistence with irreversible environmental processes, the landscape becomes not only more resilient, but also more inclusive and legible to its inhabitants.
Finally, the thesis emphasizes the importance of designing across time. Past interventions in the Agro Pontino largely failed to account for long-term environmental transformations, resulting in landscapes unprepared for change. In contrast, the proposed masterplan operates simultaneously at multiple temporal horizons: addressing present-day issues such as illegal development and infrastructural discontinuities, while preparing the territory for future scenarios shaped by rising sea levels. This temporal continuity allows the landscape to remain functional, adaptable, and meaningful over time.
Ultimately, the Agro Pontino serves as an open laboratory where the effects of sea level rise reveal both the limits of past territorial models and the potential for alternative futures. By embracing water as both risk and resource, this thesis proposes a landscape-based approach to climate adaptation—one that acknowledges transformation as an inherent condition of coastal territories and positions landscape architecture as a critical tool for navigating that transformation.

5

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FIGURES

- Figure 1 – Torre Flavia Marshland, recognized among the most valuable natural sites in Italy. Available at: https://www.orticaweb.it/la-palude-di-torre-flavia-e-tra-i-74-siti-piu-belli-ditalia/
- Figure 2 – Wetlands as ecosystems of biodiversity and cultural heritage. Available at: https://bloglemu.blogspot.com/2023/10/humedales-biodiversidad-y-cultura.html
- Figure 3 – Authors' elaboration based on data from https://www.ramsar.org/
- Figure 4 – Authors' elaboration based on data from https://www.eea.europa.eu/en/datahub/datahubitem-view/6fc8ad2d-195d-40f4-bdec-576e7d1268e4
- Figure 5 – Authors' elaboration based on data from https://www.isprambiente.gov.it/it/banche-dati
- Figure 6 – Great egret standing near a wetland environment. Available at: https://www.pexels.com/photo/photo-of-great-egret-standing-on-grass-near-body-of-water-2895673/
- Figure 7 – Visual material related to World Wetlands Day 2022. Available at: https://www.surfrider.org/news/happy-world-wetlands-day-2022
- Figure 8 – Historical photograph of the Pontine Marshes. Available at: https://www.finarte.it/asta/libri-autografi-e-stampe-roma-2018-12-10/fotografia-paludi-pontine-paludi-pontine-28772
- Figure 9 – Butteri, bovari, and ranocchiari as traditional rural professions in the Pontine area. Available at: http://www.borghidilatina.it/main/butteri-bovari-ranocchiari.htm
- Figure 10 – Butteri, bovari, and ranocchiari as traditional rural professions in the Pontine area. Available at: http://www.borghidilatina.it/main/butteri-bovari-ranocchiari.htm
- Figure 11 – Butteri, bovari, and ranocchiari as traditional rural professions in the Pontine area. Available at: http://www.borghidilatina.it/main/butteri-bovari-ranocchiari.htm
- Figure 12 – Land reclamation processes in the Agro Pontino. Available at: https://www.tirrenicazero.it/2023/12/27/bonifica-agro-pontino/
- Figure 13 – Archival images from the "Agro Sonoro" project on the Pontine Plain. Available at: https://www.bonifica-agropontino.it/agro-sonoro-dalle-immagini-alle-note-i-filmati-e-le-foto-depoca-della-pianura-pontina-prendono-vita/
- Figure 14 – Archival images from the "Agro Sonoro" project on the Pontine Plain. Available at: https://www.bonifica-agropontino.it/agro-sonoro-dalle-immagini-alle-note-i-filmati-e-le-foto-depoca-della-pianura-pontina-prendono-vita/
- Figure 15 – Archival images from the "Agro Sonoro" project on the Pontine Plain. Available at: https://www.bonifica-agropontino.it/agro-sonoro-dalle-immagini-alle-note-i-filmati-e-le-foto-depoca-della-pianura-pontina-prendono-vita/
- Figure 16 – Archival images from the "Agro Sonoro" project on the Pontine Plain. Available at: https://www.bonifica-agropontino.it/agro-sonoro-dalle-immagini-alle-note-i-filmati-e-le-foto-depoca-della-pianura-pontina-prendono-vita/
- Figure 17 – Archival images from the "Agro Sonoro" project on the Pontine Plain. Available at: https://

www.bonifica-agropontino.it/agro-sonoro-dalle-immagini-alle-note-i-filmati-e-le-foto-depoca-della-pianura-pontina-prendono-vita/

- Figure 18 – Historical image depicting fascist Italy under Benito Mussolini. Available at: https://www.alamyimages.fr/photo-image-en-italie-le-fascisme-benito-mussolini-37964792.html
- Figure 19 – Historical image depicting fascist Italy under Benito Mussolini. Available at: https://www.alamyimages.fr/photo-image-en-italie-le-fascisme-benito-mussolini-37964792.html
- Figure 20 – Archival images from the "Agro Sonoro" project on the Pontine Plain. Available at: https://www.bonifica-agropontino.it/agro-sonoro-dalle-immagini-alle-note-i-filmati-e-le-foto-depoca-della-pianura-pontina-prendono-vita/
- Figure 21 – Historical map of the Pontine Marshes. Available at: https://www.antiquarius.it/it/agro-pontino-lazio-meridionale-/15491-pianta-delle-paludi-pontine.html
- Figure 22 – Historical engraving depicting the Pontine Marshes. Available at: https://casanatense.contentdm.oclc.org/digital/collection/stampe/id/77/
- Figure 23 – Landscape-related prints by Carlo Antonini. Available at: https://www.calcografica.it/stampe/autore.php?id=antonini-carlo
- Figure 24 – Historical overview of the Pontine territory. Available at: http://www.borghidilatina.it/main/la-storia.htm?id=8
- Figure 25 – Historical notes on the land reclamation of the Agro Pontino. Available at: https://www.bonifica-agropontino.it/cenni-storici/
- Figure 26 – Historical notes on the land reclamation of the Agro Pontino. Available at: https://www.bonifica-agropontino.it/cenni-storici/
- Figure 27 – Views of the Pontine Marshes commissioned by Pope Pius VI. Available at: https://www.cartageo.com/B0020607-IT-VEDUTE-DELLE-PALUDI-PONTINE-FORMATE-PER-ORDINE-DI-PAPA-PIO-VI-FOGLIO-3.html
- Figure 28 – Illustration from Canale Mussolini, Part One, by Antonio Pennacchi, illustrated by S. Cardinali (Mondadori).
- Figure 29 – Historical photograph of the Pontine Marshes. Available at: https://www.finarte.it/asta/libri-autografi-e-stampe-roma-2018-12-10/fotografia-paludi-pontine-paludi-pontine-28772
- Figure 30 – Photograph by the authors.
- Figure 31 – Photograph by the authors.
- Figure 32 – Photograph by the authors.
- Figure 33 – Photograph by the authors.
- Figure 34 – Photograph by the authors.
- Figure 35 – Photograph by the authors.
- Figure 36 – Photograph by the authors.

- Figure 37 – Photograph by the authors.
- Figure 38 – Photograph by the authors.
- Figure 39 – Photograph by the authors.
- Figure 40 – Photograph by the authors.
- Figure 41 – Photograph by the authors.
- Figure 42 – Photograph by the authors.
- Figure 43 – Photograph by the authors.
- Figure 44 – Artistic representation addressing rising sea levels. Available at: https://www.emilygilmanbeezley.com/studio-trunk-store/original_art_products/rising-sea-levels?product_gallery=92653
- Figure 45 – Authors' elaboration based on data from https://dataspace.copernicus.eu/explore-data; https://tinitaly.pi.ingv.it/
- Figure 46 – Authors' elaboration based on data from https://geoportale.regione.lazio.it/
- Figure 47 – Authors' elaboration based on data from https://geoportale.regione.lazio.it/.
- Figure 48 – Climate change assessment visuals from the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Available at: https://www.ipcc.ch/report/sixth-assessment-report-cycle/
- Figure 49 – Climate change assessment visuals from the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Available at: https://www.ipcc.ch/report/sixth-assessment-report-cycle/
- Figure 50 – Exhibition artwork visualizing sea level rise. Available at: https://cromer-artspace.uk/exhibition-at-cromer-artspace-brings-sea-level-rise-into-view/
- Figure 51 – Authors' elaboration based on data from (https://dataspace.copernicus.eu/explore-data
- Figure 52 – Authors' elaboration based on data from https://data.marine.copernicus.eu/products.
- Figure 53 – Authors' elaboration based on data from (https://dataspace.copernicus.eu/explore-data.
- Figure 54 – Authors' elaboration based on data from (https://dataspace.copernicus.eu/explore-data
- Figure 55 – Authors' elaboration based on data from (https://dataspace.copernicus.eu/explore-data
- Figure 56 – Reportage image documenting recent flooding events in Romagna. Available at: https://altreconomia.it/di-nuovo-nel-fango-reportage-dalla-romagna-alla-terza-alluvione-in-16-mesi/