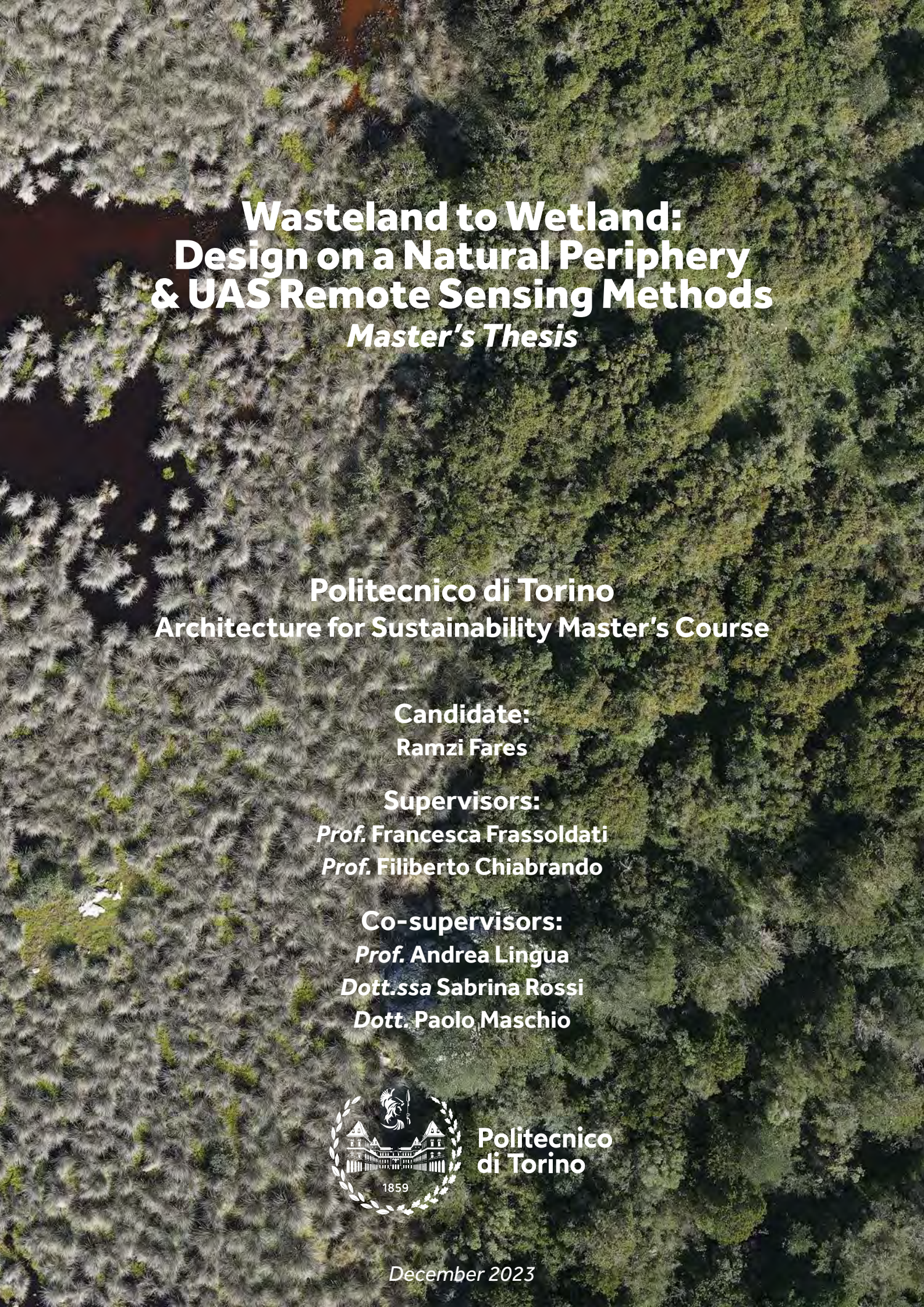
Wasteland to Wetland

Wetland of Porto Liscia



Wasteland to Wetland: Design on a Natural Periphery & UAS Remote Sensing Methods

Master's Thesis

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- I -
PREFACE

...Nature has no end set before it, and that all final causes are human fictions...

Spinoza, the Ethics

Preface

The Wetland of Porto Liscia is a geographical area of low brackish waters and deposited soil sediments of roughly 80 hectares (800,000m^2) - if not considering land vegetation and deep basins, located at the utmost north of the island of Sardegna-Italy, between the island of Culuccia to its North, the coast of Porto Liscia to the East, and the Gulf of Porto Pozzo to the West. It is the closing point of the Italian territory where migratory birds coming from Africa towards the Northern Hemisphere, seek refuge in its ponds and marshes that are home to a delicate plethora of fauna and flora in peril.

Wetlands embody the physical and conceptual implication of a frontier between land and water. These buffer zones fuse the collision of incompatible natural elements together, in consequence generating a world where the boundary between solid and fluid is blurred. "Uncertainty" is the very characteristic of a wetland's state of existence, for this reason mapping surveys are vital means that should be implemented beyond the practicality of using tools and devices to recognize the physical constituents of this frontier.

A multitude of exceptional variations can be observed in such areas such as: geological substrates, chemical compositions, salinity, carbon sequestration, temperature, depths, vegetal and animal species, adaptation mechanisms [1]... all of which along with immeasurable other unique natural features, come into play for the conception of a place that simultaneously does not exist on the landscape and is not withered by the waterscape.

For millennia, the attitude towards wetlands was that of ignorance or of a subjective outlook, mainly having its roots stemming from sanitary fear influences. Wetlands "were read as dangerous, useless, fearful, filthy, diseased and noxious".[2] That is due to hostile aspects towards human health like insects, mosquitoes, malaria, and the obstruction to agriculture they pose.

Thus, from this perspective emerges a utilitarian standpoint in regard to nature that is not marked by a definite period but has been inherent to human nature since early beginnings of civilizations. This perspective had permanently been discredited by many, including Spinoza who exposed the "falsity" of the idiom that everything that happens in nature must happen on the behest of people to the degree of how much it is useful.[3]

Wetland erasure for crop growing has been the case for thousands of years. For instance, Pliny the Elder conveys that in the year 593 BC roman legions were ordered to drain the wetlands in Latium - in which the city of Rome was founded and grew to be the capital city of the Roman Empire. Moreover, in 246–182 BC Carthaginian troops under Hannibal converted wetlands on the coast of Africa to plantations of olive trees. For 11 years of the first century, 30,000 men were assigned by Roman Emperor Claudius to drain Fucino Lake in Italy.[5] Emperor Hadrian built the Car dyke to drain the English Fens, a naturally marshy region supporting a rich ecology and numerous species... [6]

Paradoxically, but still within the utile, wetlands were acclaimed for offering sanctuary to those in need. The Venetian Lagoon during the 5th century provided shelter to the Venetian population escaping

from barbarian attacks. [7] In the late 9th century, King Alfred sought refuge in the Somerset marshes in England offering him enough time and refuge to survive and regroup with other compatriots to organize guerilla warfare against the daunting Vikings.[8] The Delta Po marshes have a history as well of being occupied and challenged over by different groups, including pirates, rebels, and outlaws, even up to recent times where incidents of slavery are still occurring through the exploitation of illegal immigrants under cruel and distressing conditions.[9] The marshy and inaccessible nature of the wetlands often made them suitable for those seeking refuge or engaging in various clandestine activities.

Correspondingly, the lagoons of the Wetland of Porto Liscia have long been lauded for their plentiful fishing opportunities. However, over time and due to various factors, these opportunities have dwindled. This territory was reclaimed by the government during the "Bonifica Integrale" period of fascist Italy (1920s) after the "Società Bonifiche Sarde" was established in 1918, aiming at rendering advantageous a once worthless area and eradicating malaria.[10] It's worth noting that the wetland territory originally extended significantly towards the West at Porto Pozzo, following the Riu Liu Banconi outlet. However, during the "Costa Smeralda" urban boom, this area was dismantled making way for the construction of the boats' port, and an artificial beach.[4] The result is a strange landscape - nothing about it is autochthonous to Sardegna – featuring Eucalyptus trees and industrial sand, an unappealing area that barely anyone intends to visit...

On one hand, this thesis aims to enhance the understanding of what constitutes the Wetland of Porto Liscia. This is achieved by adopting a historical viewpoint and utilizing modern technologies like UAVs and mapping to analyze its historical evolution and current state. The incorporation of historical records and advanced mapping techniques enables the creation of a comprehensive overview of the wetland's existing conditions.

From another perspective, this study seeks to investigate the implementation of a forward-looking non-invasive approach to address the wetland's challenges. From a consumeristic perspective, valuable access to the wetland has always been positively correlated with the amount of produce it can provide. However, by adopting a holistic strategy that employs a non-utilitarian approach, encompassing ecological, social, and economic considerations, a viable potential for the wetland can be forged. This involves identifying factors influencing wetland usage, valuation, and degradation, and devising innovative design solutions that balance human necessities with environmental preservation, in the hopes of altering the standardized misconception of wetlands as wastelands.

[1] Novelli – Demartis, Le zone umide della Sardegna

[2] Allen, A deep history of shallow waters

[3] Spinoza, The Ethics, I. Of God

[4] Fishermen of Porto Pozzo, Interview

[5] WHEELER, W. H. (1896). A history of the fens of south lincolnshire. published in Stamford by Paul Watkins 1991.

[6] Purseglove, J. (2017). Taming the flood: Rivers, wetlands and the centuries-old battle against flooding. William Collins.

[7] Centre, U. W. H. (n.d.). Venice and its Lagoon. UNESCO World Heritage Centre.

[8] King alfred in the Somerset Marshes – Part 1. Exploring Building History. (n.d.).

[9] Redazione, W. (2018, April 4). Schiavi nei campi del delta, Arrestati due Bengalesi. Rovigo IN Diretta.

[10] La storia dell'eucalyptus e delle Bonifiche Sarde. SardegnaForeste. (n.d.).

- II -

GENERAL OVERVIEW

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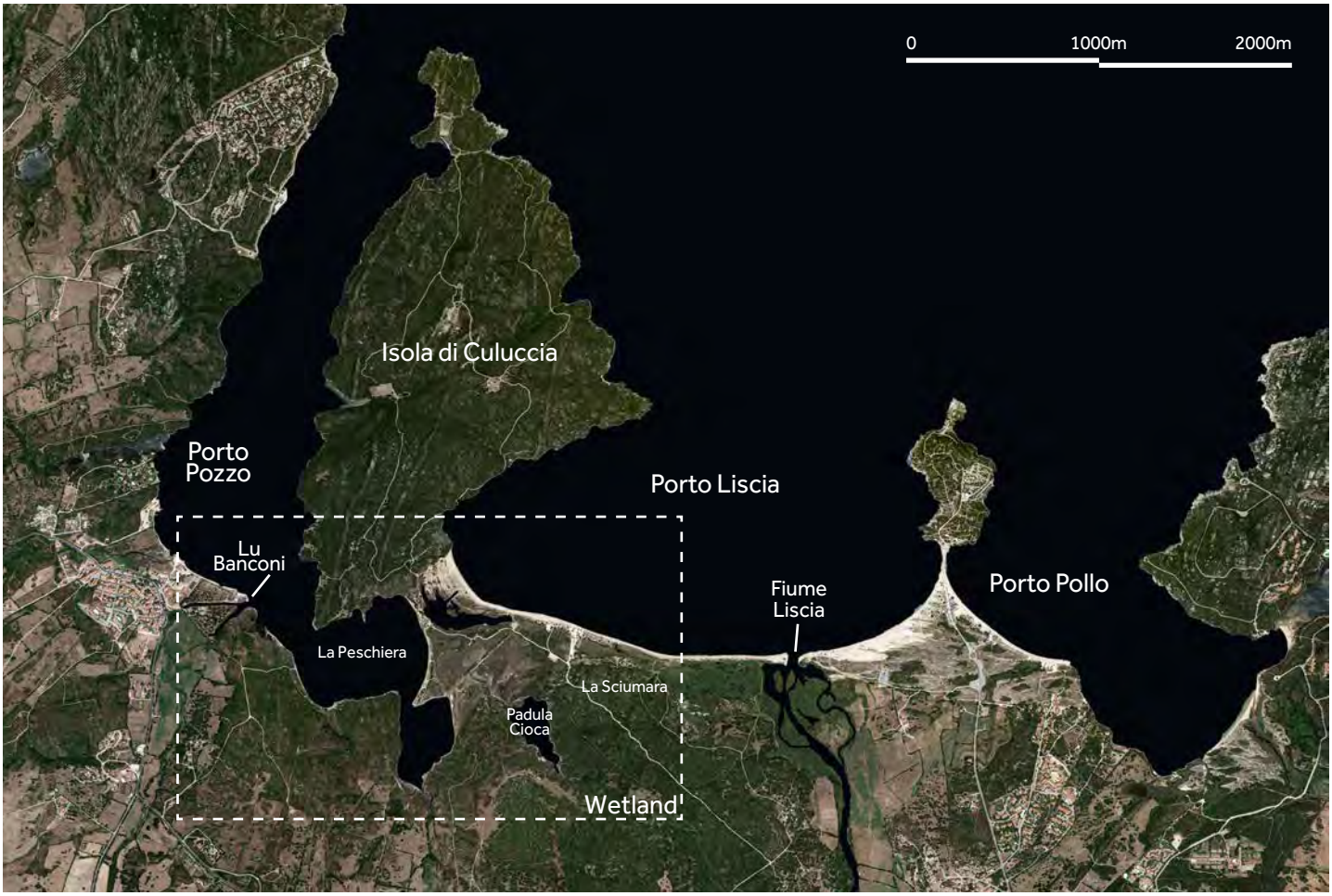
1. Introduction

The Wetland of Porto Liscia is situated in a lowland area between the Culuccia island and the coastline. Its boundaries are defined as follows: on the east side, a sandy strip referred to as "tombolo" extends all along the Liscia beach; on the west side towards Porto Pozzo, there is a dynamic portion of land, a result of sand deposits from Rio Lu Banconi; and on the south side, there are granite hills. [1]

The fishpond of the wetland "La Peschiera" covers an approximate area of 50 hectares and is privately owned. The water in the fishpond is primarily salty due to the limited freshwater supply from Rio Lu Banconi, which flows northwestward along the outer edge of the fishpond. This freshwater input has minimal influence on the overall salinity levels and the fishpond presents decreasing quantities of mullet, sea bass, mollusks, and crustaceans due to various factors, which led to the current implementation of an alternative production of a farm of oysters. [1]

At the southern eastern side of the wetland lies the "Padula Cioca" swamp, considered as the



Google Earth photo 29/06/2020

most savage part of the wetland due to its recession in the landscape. This swamp spans around 32 hectares and is also under private ownership. The swamp's ecosystem is jeopardized by the expansion of southern tourist settlements and environmental factors. [1]

The wetland under study is not the only marshy area found in this zone; adjacent to its eastern border and around the waters of the "Liscia" river, there is a sizable stagnant area called La Sciumara, which covers around 22 hectares of the landscape. This area whose depth varies with the seasons between one and a half meters to three to four meters, is fundamentally a fluvial pond which serves as a habitat for mullet and carp. [1]

On a general scale, the current common threat to the fauna, flora, and ecological continuation of all these portions of the wetland - besides the historical works of intervention covered in the next sections – is uncontrolled tourism. [1] [2] Therefore, this thesis will aim to explore how regenerative programs like national parks, or birdwatching grounds like the ones present elsewhere in the world contribute to preserving, raising awareness, and actively experiencing a certain ecosystem. [3]

[1] *Consiglio Regionale della Sardegna, Le Lagune in Sardegna: Una risorsa*

[2] *Dott.ssa Rossi Sabrina, Head of the Naturalistic Observatory of the Island of Culuccia*

[3] *Massoli-Novelli, R., & Demartis, A. M. (1989). Le Zone umide della sardegna: Stagni, Lagune, Laghi, paludi*

2. Flora:

Central to the functionality of the Wetland of Porto Liscia is first and foremost its intricate vegetation composition, which plays a pivotal role in shaping the environment. The vegetation comprises a diverse array of plant species that have developed exceptional adaptation mechanisms to thrive in varied waterlogged conditions.

Since different water bodies slither one way or another throughout the wetland, the resulting waters represent transitional characteristics fitting to either sweet water (that of the two rivers and underground sources) or of salt water. These waters are thus classified as brackish or brack water. If the amount of salt in water is identified as a "part" per thousand "parts" of water, considering sweet water having 0 ppt of salt, and a typical sea 35 ppt of salt, then brackish waters range all between 0.5 to 35 ppt of salt.[1]

If the degree of salinity affects the development of vegetation, then high levels of salt represent an "evolutionary barrier" for most species.[2] However, the vegetation proper to brackish swamps is characterized as being "halophilic", meaning that it can survive both in sweet water environments and brack water marshes.[3] Accordingly, dominant species of this class at Porto Liscia are the sea asparagus "Salicornia Fruticosa", sharp rushes "Juncus Acutus", and sea rushes "Juncus Maritimus"; all of which are edible plants.[4]

The prevalent reddish tint notable at the wetland is due to the presence of Salicornia. These "glassworts" usually grow on the peripheral zones of aquatic containers high in salinity and whose soils are typically dry or occasionally submerged.[5]

Rushes (Juncus) on the other hand, are hygrophilous (moist-loving) plants which prefer soils that are continuously lightly submerged or muddy. The presence of rushes is an indicator of water softening which is the removal of certain metal cations of hard water like calcium and magnesium.[5 6]

Furthermore, other classic species of plants thrive in this place like the "Spartina Versicolor" which forms charming collections of wavy grass landscapes. However, in some countries it is considered invasive, and it is used to reclaim estuarine territories for farming, agriculture and as a supply for livestock.[7]

Finally, this study would be remiss not to mention the invasive plant species that are currently sparsely distributed across the wetland. These species did not enter this region through natural alterations and interchangement of ecosystems but are instead a result of the far and near urbanization. Communities settling all over the savage territory essentially carried with them their prized high yielding types of domestic plantations. In this case, few traces of the garden decorative "Carpobrotus Acinaciformis" are already established, nonetheless, in other near public beach

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Reddish Salicornia antecedent to a vast field of Juncus . In the background three large pines (one dead) can be spotted

destinations - like Porto Pollo - it razes vast fields of territory overshadowing all the rest of the native species.

Another example of a non-autochthonous tree in this case, is the Mediterranean stone pine "Pinus Pinea" highly diffused around the Mediterranean basin all beginning as a part of a large roman cultural movement - "mare nostrum" or our sea - during the expansion of the roman empire. They scattered this tree in the basin most likely importing it from Asia minor to embellish the image of their empire with a kind of majestic and uniform landscape.[8] In this case of the wetland of Porto Liscia, urbanization in neighboring territories like Porto Pozzo for example, where vast canopies of Pine trees are spread in between constructions, could be the culprit behind the presence of a few numbers of this tree in the wetland.

[1] *Summerlin, P. (n.d.). File:water salinity diagram.png*

[2] *Więski, Kazimierz; Guo, Hongyu; Craft, Christopher B.; Pennings, Steven C, "Ecosystem Functions of Tidal Fresh, Brackish, and Salt Marshes on the Georgia Coast".*

[3] *Dijkema, Kees S. "Salt and brackish marshes around the Baltic Sea and adjacent parts of the North Sea: Their vegetation and management".*

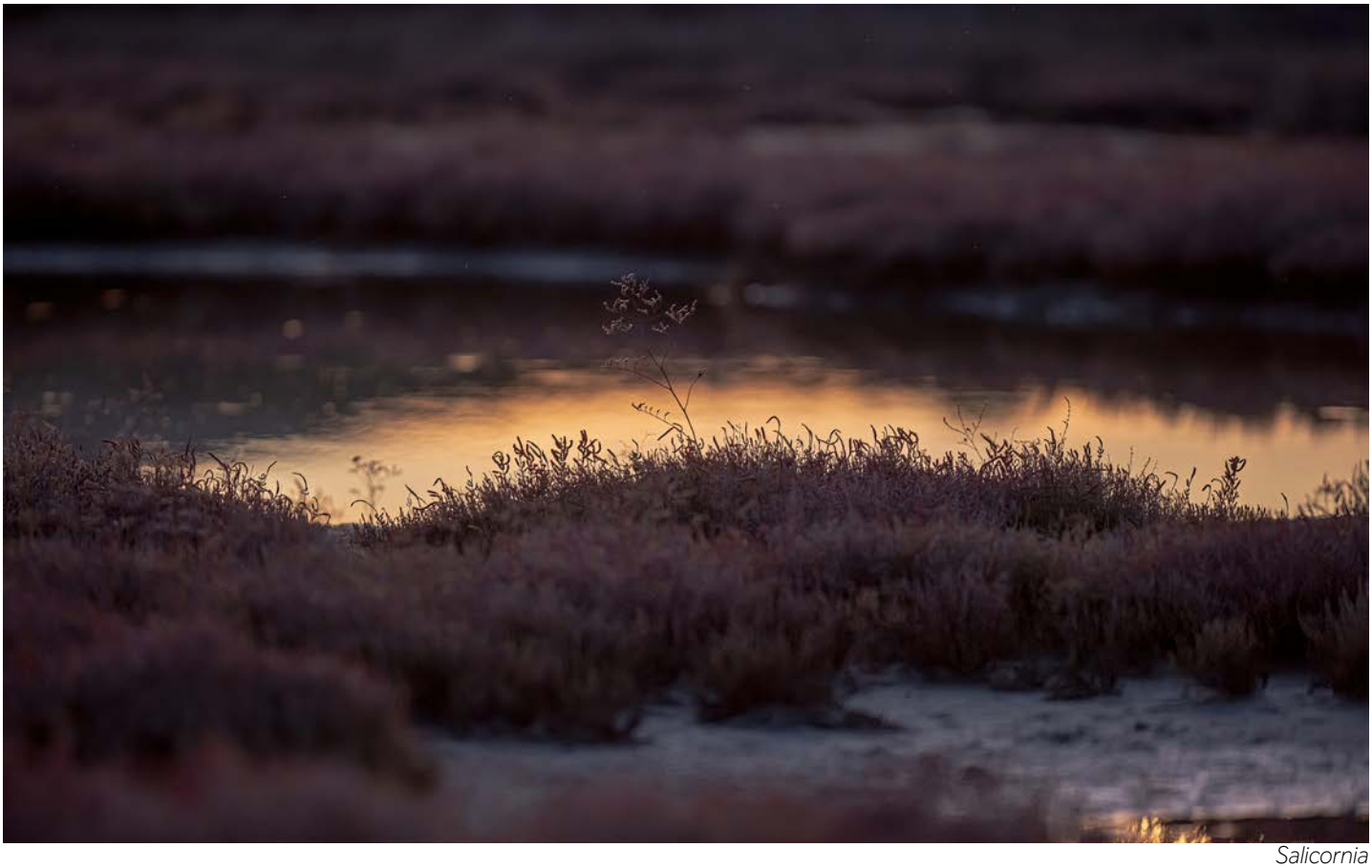
[4] *L'approdu, the Culuccia Island observatory gazzette. (2022). Through Middle Earth.*

[5] *Consiglio Regionale della Sardegna, Le Lagune in Sardegna: Una risorsa*

[6] *Encyclopædia Britannica. Hard water.*

[7] *Ainouche, M.L., et al (2009) Hybridization, polyploidy and invasion: lessons from Spartina*

[8] *Benzi, F., & Berliocchi, L. (1999). Paesaggio Mediterraneo: Metamorfosi e storia dall'antichità preclassica al XIX secolo.*



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Salicornia

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Juncus at the river Liscia

FLORA

February 2023

Spartina Versicolor

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Dune-forming Achillea Maritima & Juncus at the Beach

3. Fauna:

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Flock of Starlings

Wetlands, especially small ones like the Wetland of Porto Liscia, play a prominent ecological role in regard to animal biodiversity. They are considered "ecological corridors" in between larger extents of diverse natural sites, constituting stitches and places of rest and nourishment for many species as they disperse into surrounding areas.[1]

To measure a certain ecosystem's potential in providing a reliable habitat for biological proliferation or production, its primary productivity needs to be calculated. In a food chain, a certain amount of organic material is required for the existence of producers (autotrophs) that through photosynthesis – using carbon dioxide, light, water, and other chemicals[2] – provide a net primary product for consumers (heterotrophs) such as herbivores and carnivores. To evaluate primary productivity, the intake of carbon dioxide or the output of oxygen need to be determined. The resulting rates are expressed by grams of stored organic carbon per unit of area per unit of time. For example, the entirety of the ocean's annual productivity is 50×10^{15} grams (50×10^{9} metric tons) of carbon per year, which for the global area that the oceans occupy, results in about half of the planet's entire production.[3]

FAUNA

When performing within natural parameters, coastal and lagoon areas have been found to be exhibiting an unparalleled fertility potential. Accordingly, the primary productivity of wetlands has been roughly calculated to be 100 times that of oceans, 10 times that of grasslands and forests, and 5 times greater than most cultivated lands.[4]

The geographical characteristics of coastal wetlands as principally being their adequate shallow elevation resulting in an intricate connectivity to both land and sea, enables the influx of various organic matter that blend altogether and boosts nutrient circulation harnessing solar energy with exceptional efficacy. Multiple features therefore come into play to deliver an accelerated biomass production timeline compared to other aquatic environments.[4]

phot. Lorenzo Rivella

Cow

phot. Lorenzo Rivella

Marginated tortoise

FAUNA

Small invertebrates such as mollusks, crustaceans, and insects, and larger animals like fish, amphibians, reptiles, mammals, and others, are the major constituents of this biomass. Nevertheless, the effect of an "ecological corridor" is best discernable while observing the migratory routes animals pursue, especially birds, protagonists of a natural artistic panorama. During these periods, the majority of birds are observable in Sardinian wetlands. The journey they undertake is usually lengthy and challenging; typically, in between European southwestern wetlands and those of faraway Africa, always searching to settle in moderate meteorological conditions. They are therefore sighted in autumn (autumn pass) en route towards Africa, and in spring (spring pass) on their way back to Europe.[5]

Winter in wetlands is, however, not very severe, and always presents prospects for non-freezing waters that are rich with nutritive microorganisms and plankton. This allows for a certain population of sedentary birds to thrive all year-round in Sardinian wetlands, unlike their travelling counterparts.[5] In this sense, conventions like RAMSAR were signed in order to protect Sardinian wetlands that are in particular perpetual habitats for species and subspecies of non-migratory waterfowl (mainly ducks and geese).[1]

phot. Lorenzo Rivella

Osprey (Pandion haliaetus) - declared extinct untill 2011 - only 7 pairs live in between Sardegna and Tuscany

[1] L'approdu, the Culuccia Island observatory gazzette. (2022). Through Middle Earth.

[2] Autotroph. National Geographic Education.

[3] Encyclopædia Britannica, inc. (n.d.). Primary productivity.

[4] Consiglio Regionale della Sardegna, Le Lagune in Sardegna: Una risorsa

[5] Novelli – Demartis, Le zone umide della Sardegna

phot. Lorenzo Rivella

Flock of Flamingos

phot. Lorenzo Rivella

Flamingo

FAUNA

White Heron

phot. Lorenzo Rivella

Fox

phot. Lorenzo Rivella

phot. Lorenzo Rivella

Bee-eater

phot. Lorenzo Rivella

Grebes

Black Redstart

phot. Lorenzo Rivella

FAUNA

phot. Lorenzo Rivella

Common Kingfisher

phot. Lorenzo Rivella

Yellow-bellied Slider

FAUNA

White Heron

phot. Lorenzo Rivella

4. Bonifica Integrale, malaria, population, and production:

Mussolini sows the first seeds at a farm in Littoria (reclamation of the Agro Pontino) in 1934. Bettmann / Contributor / Getty Images.

phot. Cockerell, I. (2023, April 12). The Indian migrants lured into forced labor on Mussolini's farmland.

The unification of Italy brought about several laws concerning agriculture to sustain the newly formed territory. Starting from the late 19th century, these laws like the ones of 1862, 1865, 1866, and 1869, aimed at resolving the dilemma of marshy lands taking as an example modern Piedmontese and Lombard companies for the entirety of the country.[1]

The reclamation of what was once considered unproductive lands had utilitarian roots principally stemming from Italy's lack of fertile land for its rural settlements on one hand, and the hygienic need to tackle the fatal malarial diffusion in or around wetlands on the other.[2]

As a consequence, reclaimed areas were subject to one or more of the following arrangements: complete drainage or desiccation of swamps, channeling waters with canals, irrigation of dry areas, introduction of agriculture and domestic plantations, and construction or urbanization. Therefore, these previously barren areas were transformed into adequate places for decent habitation.[2]

Works carried out between 1870 & 1922, whether under the responsibility of the state, under private enterprise, or through subsidized settlements, spanned an extent of 1,390,980 hectares all over the territory. The following 14 years of the fascist period of Italy (1922 till 1943) brought about an expansion of reclaimed lands reaching new heights of 5,106,938 hectares, which means that 78.59% of the total reclamations happened during this era in which authorities viewed the "death inducing swamps" as a disobedient landscape feature that needs to be eradicated from the map of Italy to make way for the ideal fascist landscape. It is also worth mentioning that this vision was further fueled by the threat to food security in Italy caused by sanctions promulgated by the League of Nations.[2 3]

Moreover, the populations of Sardegna were constantly physically and psychologically burdened by malaria. As a fact, the scarcity of the population was in direct correlation with that matter: in the middle late 19th century (around 1860) 1/3 of total Sardinian deaths were caused by this disease, 97.5 per thousand of fatality (1920-1922) compared to 12 in all of Italy. The will to work, thrive and reproduce, mainly the drive for life, was waning where the "malaria landscapes" were present.[4] This paved the way for a domineering vision of conquest of these landscapes, in particular wetlands, to abolish what threatens the presence of a civilization.

Furthermore, the population density in Sardegna is in evident connection with its morphology: the number of inhabitants decreases drastically with altitude. Therefore, the highest densities are geolocated at the littoral coast and in between altitudes of 400 & 600m. The latter higher range has typically been favored since medieval times, because its elevation ensured security over widespread malarial infestations, and protection from either internal or external enemies.[4]

These enemies were typically sea pirates, assassins, delinquents, and bandits whose problem was dealt with slowly with the arrival of Piedmontese and Corsicans into the North of Sardegna. Therefore, in Gallura (North of Sardegna), a particular type of architectural settlement was founded: the "stazzu". Since the 18th century, the "stazzu" has been the reason behind the newly assured security over the dangers of uncontrolled lands. Originally a Corsican architectural style of construction, it is designed to be built on the summits of hills with nearby water springs.[5]

Production activities are affected by the characteristic structure of the "stazzu" being a unique closed-consumption economic model similar to a typical village. The farm's size is typically around 50 hectares, with the majority of the land being a pasture for agriculture and livestock. A socio-economic structure is then defined between landlords and those who work for them as "Master and Shepherd". [5 6]

Thus far, it is evident that most of what characterizes the historical, architectural, productive, and hygienic attributes of the anthropological evolution of Sardegna, is security on all levels that

establish pillars for a civilization. In particular, the wetland of Porto Liscia, was subjected to works of reclamation that are thoroughly analyzed in the following sections of surveying of this study. Canals, fish traps "lavorieri", small bridges, roads, and infrastructure, were all part of works of reclamation that brought into play changes in the previously existing attitudes towards the wetland.

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Current traces of the concrete bridge, canal, and triangular fishing system of "Bocche Gauliane" designed to be overflooded with high tide

[1] *Novello, E. (2003). La Bonifica in Italia: Legislazione, Credito e Lotta alla malaria dall'unità al fascismo. F. Angeli.*

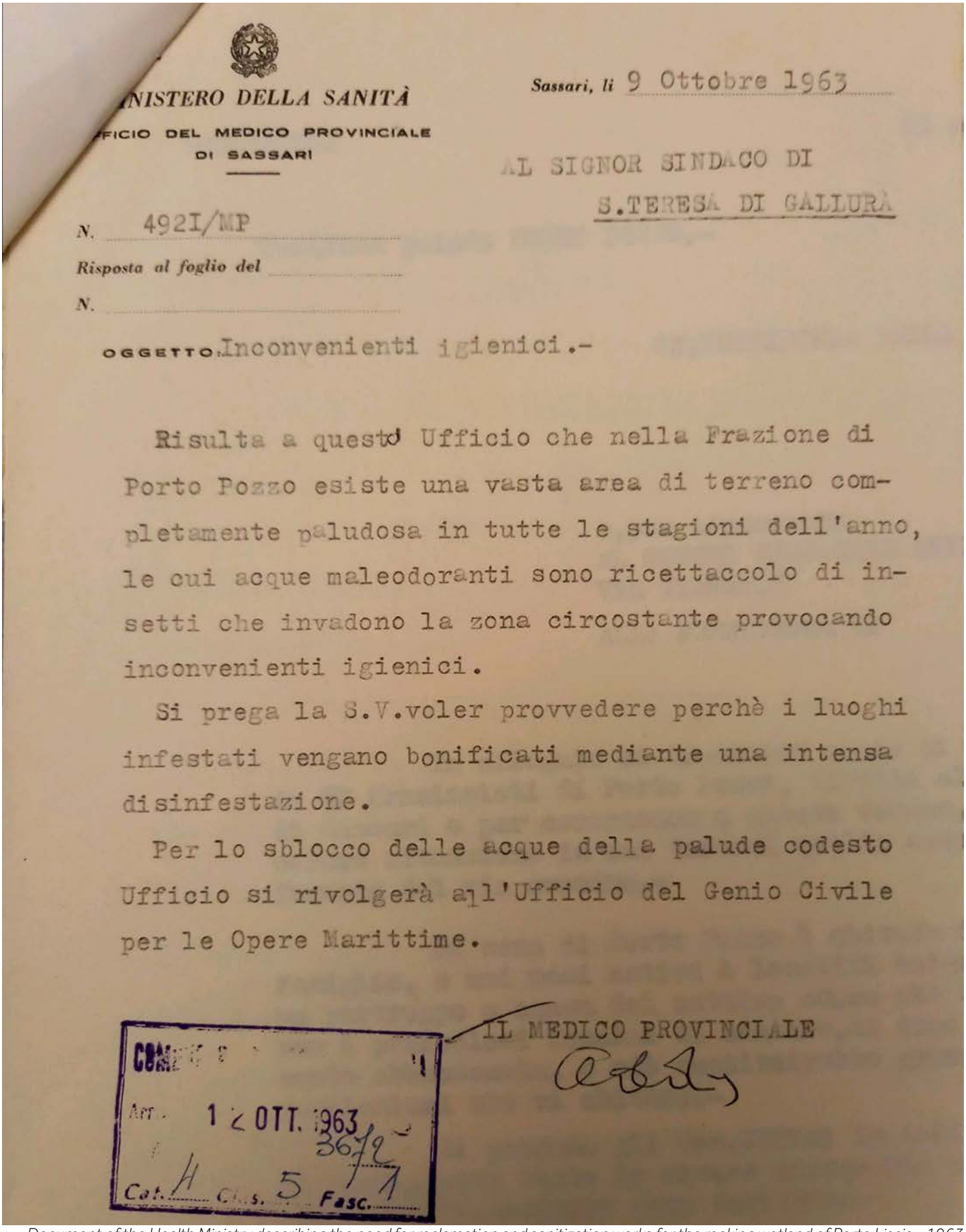
[2] *Bonifica Integrale in Italia. (1940). La Scuola di Mistica fascista.*

[3] *Caprotti, F., & Kaïka, M. (2008). Producing the ideal fascist landscape: nature, materiality and the cinematic representation of land reclamation in the Pontine Marshes Social and Cultural Geography.*

[4] *Mori, A. (2000). Memoria illustrativa della carta della utilizzazione del suolo della Sardegna.*

[5] *Ispettorato ripartimentale delle foreste (Sassari), & Paulo Filigheddu. (1966). Problemi e prospettive della Gallura.*

[6] *Dott. Pasquale Filigheddu. (1966). Relazione sul comprensorio del B.M. Liscia. tenuta dal Capo Ispettorato Ripartimentale delle Foreste di Sassari.*



MINISTERO DELLA SANITÀ
UFFICIO DEL MEDICO PROVINCIALE
DI SASSARI

Sassari, li 9 Ottobre 1963

AL SIGNOR SINDACO DI
S.TERESA DI GALLURA

N. 492I/MP
Risposta al foglio del
N.

OGGETTO: Inconvenienti igienici.-

Risulta a questo Ufficio che nella Frazione di Porto Pozzo esiste una vasta area di terreno completamente paludosa in tutte le stagioni dell'anno, le cui acque maleodoranti sono ricettacolo di insetti che invadono la zona circostante provocando inconvenienti igienici.

Si prega la S.V.voler provvedere perchè i luoghi infestati vengano bonificati mediante una intensa disinfestazione.

Per lo sblocco delle acque della palude codesto Ufficio si rivolgerà all'Ufficio del Genio Civile per le Opere Marittime.

IL MEDICO PROVINCIALE

Arr. 12 OTT. 1963
3672
Cat. 4 Cl. 5 Fasc. 1

Archivio Storico – Comune di Santa

Document of the Health Ministry describing the need for reclamation and sanitization works for the reeking wetland of Porto Liscia - 1963

5. Costa Smeralda:

The "Costa Smeralda" - coast of emerald - is a territorial, planning, or urbanistic endeavor that was officially initiated in March 1962 at Olbia-Sardegna, where the Costa Smeralda Consortium was publicly inaugurated in front of notary Mario Altea.[1]

It maintained the vision of several international entrepreneurs like English financer "John Duncan Miller" but chiefly the young prince "Karim Aga Khan" who recounted the following in one of his first Italian interviews: "I arrived in Porto Cervo with four or five friends, on a twelve-meter boat. There was nothing. It was the first time I saw the Costa Smeralda during the summer. I wanted to see a small piece of land that I had bought."[1]

The consortium intended to supervise the urban and residential development of the territory under its management. They also claimed to be monitoring the environmental safeguarding of the territory which extends to 55km along the coast from "Pitrizza" and "Capo Ferro" to the north, towards the "Rena Bianca" beach to the south, occupying a total area of 3114 hectares.[1] [2]

In the year 1994, the relationship between the Aga Khan and the regional policymakers fell into crisis for various commercial reasons. Hence, his requests to proceed with the second phase of the masterplan of the Costa Smeralda were never processed. The prince therefore abandoned his project maintaining a few personal and private interests in the region...[2]

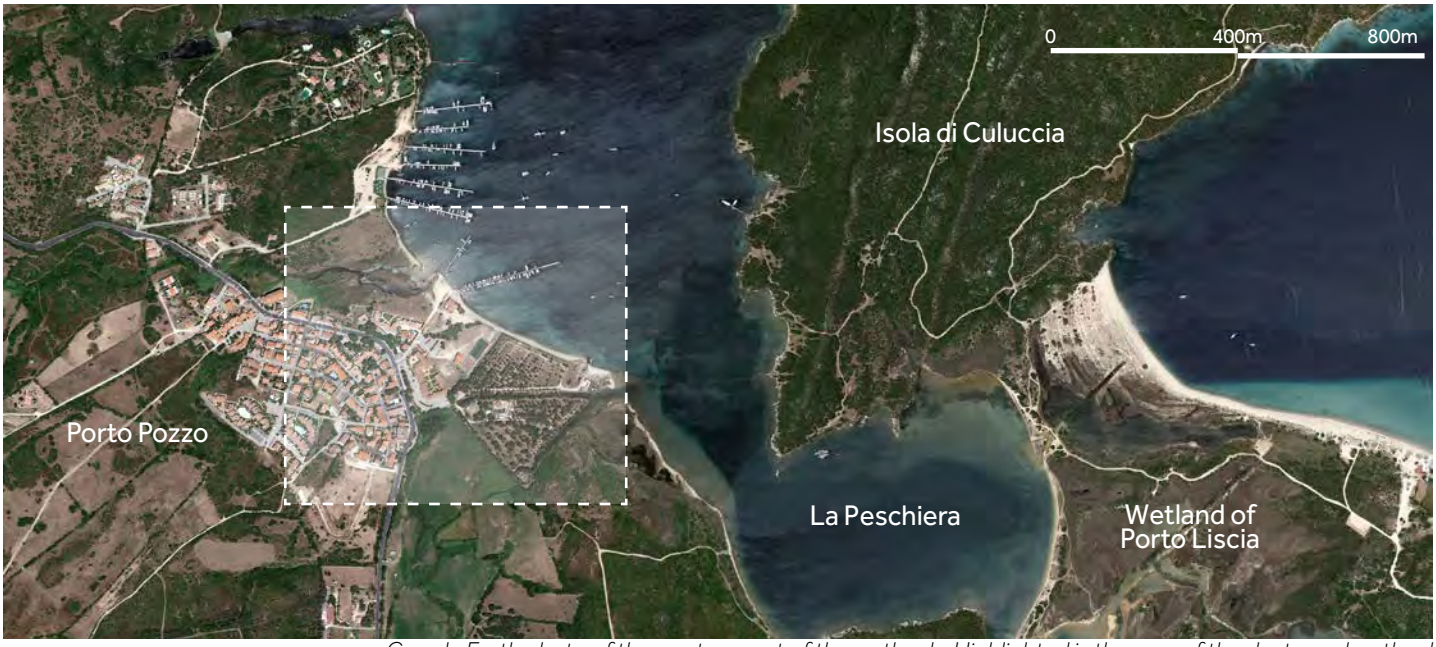
This study focuses on reviewing significant historical movements associated with the gradual transformation of the Porto Liscia wetland, situated at a specific location along the Costa Smeralda coastline. Two key aspects which warrant consideration are first, the importance of establishing a precise timeframe that starts exactly in 1962 and extends with some uncertainty until circa 1994, and second, the importance of investigating potential urban encroachments along the wetland's borders or, even more inappropriately, within its boundaries.

Accordingly, the most important infrastructural feature that fringes the wetland is the agglomerate urban setup of Porto Pozzo, which currently includes docks for boats, a restaurant with an artificial garden, a synthetic beach, a vast empty area serving as a car parking, and a residential network. Most of these features happen to exist in areas that were once a wilder wetland, a previous extension of what remains now. On this matter, more details will be examined in the fourth section of this thesis: the interview of the fishermen.[3]

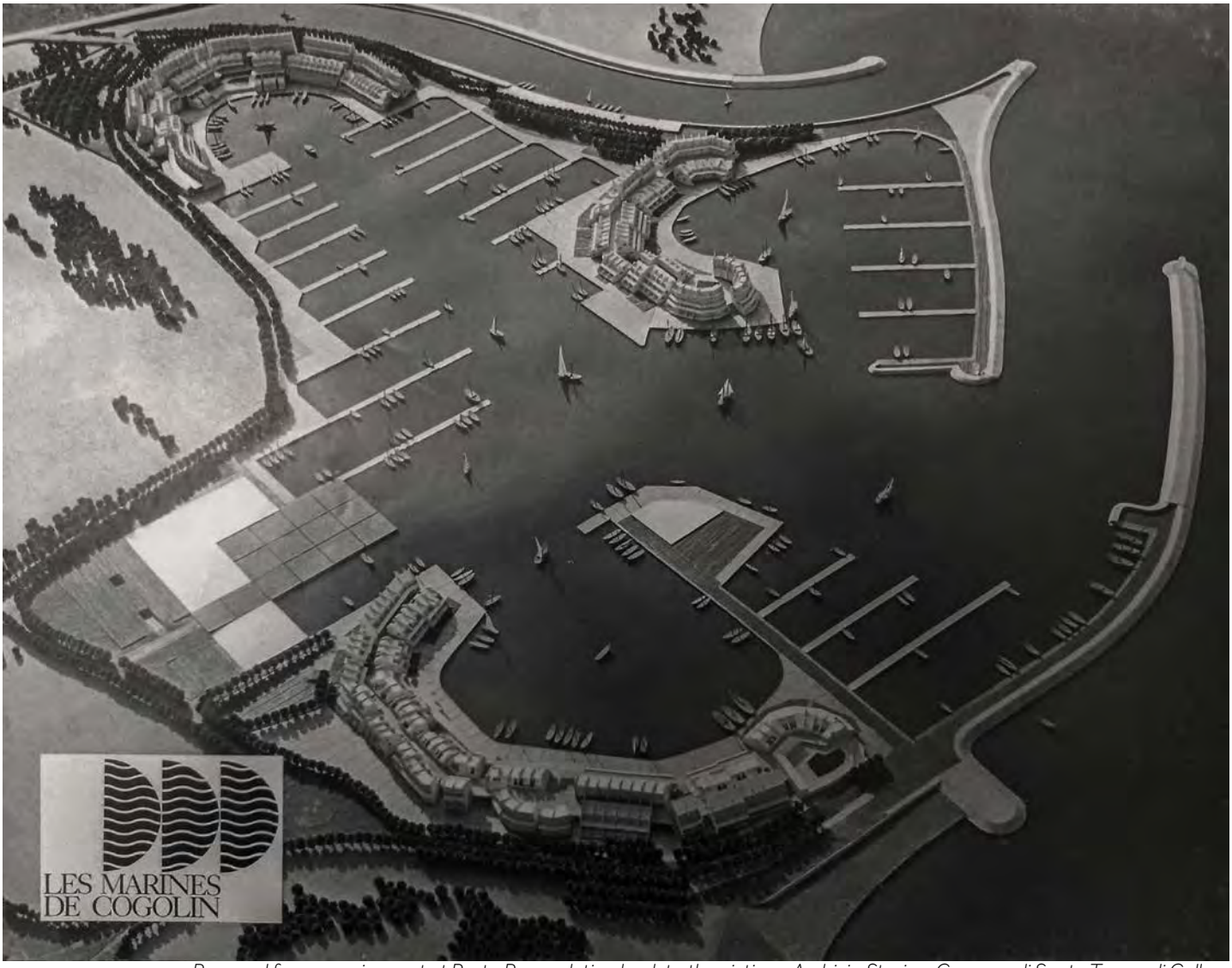
[1] La Stampa. (2022, March 17). Così nacque il mito della costa smeralda: Marzo 1962, l'aga Khan dà vita a un sogno che tutt'ora Resiste.

[2] Consorzio Costa Smeralda. (2023, August 9). https://www.consorziocostasmeralda.com/

[3] Fishermen of Porto Pozzo, Interview



Google Earth photo of the western part of the wetland - Highlighted is the area of the destroyed wetland



Proposal for a massive port at Porto Pozzo dating back to the sixties - Archivio Storico, Comune di Santa Teresa di Gallura

- III -

GEOMATICS & PHOTOGRAMMETRY

1. Significance of Remote Sensing

February 2023

UAS - Drone M300 RTK with L1 & P1 sytsems

"A picture is worth a thousand words" is the highest ideal the domain of representative cartography can aspire to achieve. Since early ages, cartographers attempted with their utmost capabilities to illustrate lands and geomorphological features, even features in water and sky. The significance of this kind of endeavor lies in assisting people's spatial referencing in the vastness and the unknown of this world. Navigation, planning, development, transportation, military operations, tourism, science, business, culture, history and many more, are all fields that could not have evolved properly without the development of the dual model of cartography being part science and part art. [1]

Accordingly, realism emerged as an artistic movement in the early half of the 19th century in France. It aimed to depict nature or everyday life's events without extra embellishment or imaginative impact. Photography followed during that period as a novel technology that not only facilitated the capture of an image, reducing time and physical effort, but also served as a scientific tool to produce imagery with high accuracy. [2]

As photography continued to increase in complexity and sophistication thanks to rapid technological advances, photographic equipment became more compact and practical, as what once was a large box evolved into a smaller portable device. Data acquisition platforms of all kinds benefited from this progress to improve their outdated techniques with more efficiency. Therefore, cameras were initially mounted on large fuel-powered military aircraft to secure dominion and spy over enemy territories. In most developed countries of the world with traditional strong militaries, archives of historical aerial photography are numerous and are currently all digitalized, like the IGM (Military Geographic Institute) of Italy. [1] [3]

In recent times, a new revolutionary industry emerged which is the civilian manufacture of UAV (unmanned aerial vehicle) or UAS (unmanned aerial systems), popularly known as drones with light high-definition cameras. [1] The originality of these systems being affordable, light, sophisticated, and commercially available, guarantees more effective academic or corporate research over a desired region.

For the sake of this study, a UAS was employed to scan the wetland of Porto Liscia with a rhythmic array of high-definition aerial photos. The drone was flying following a setup route at an average altitude of 100m, capturing images at almost every second of the flight duration. The whole survey was conducted in February 2023 during which the tides are at their lowest, hence revealing as many details as possible in the absence of deep waters which would otherwise conceal key features of the landscape. As for historical imagery, aerial military photos were acquired from the IGM and NCAP (National Collection of Aerial Photos) of the British military. [3] [4]

Thus far, it is still ambiguous how photos can become an accurate map. The process shall be explained in the following segments of this section related to photogrammetry and geomatics. These are emerging and contemporary scientific realms based on computational mathematics. In the words of computer scientist "Edsger Dijkstra": "a picture may be worth a thousand words, a formula is worth a thousand pictures". [5] This shall be demonstrated further to show how simple images can be the brick stones of a digital map known as "orthophoto" from which many other pieces of information can be retrieved including elevation data suitable for the production of 3D models...

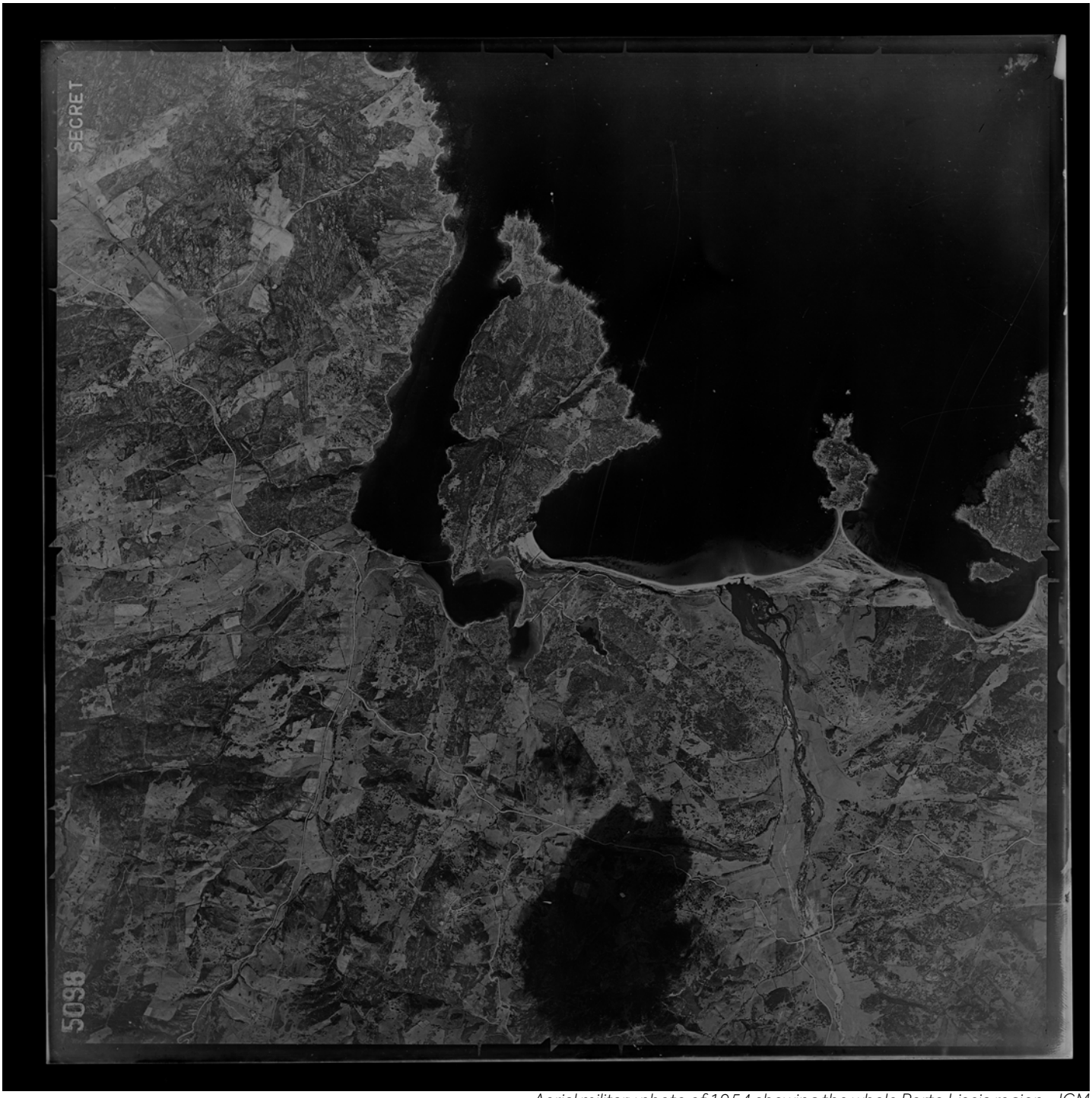
[1] Tiner, R. W., Lang, M. W., & Klemas, V. (2015). Remote sensing of wetlands: Applications and advances.

[2] Encyclopædia Britannica, inc. (2023, July 21). Realism.

[3] Pubblicati Dati e Carte d'Italia. Istituto Geografico Militare - IGM E-Commerce Site. (n.d.-b). https://www.igmi.org/

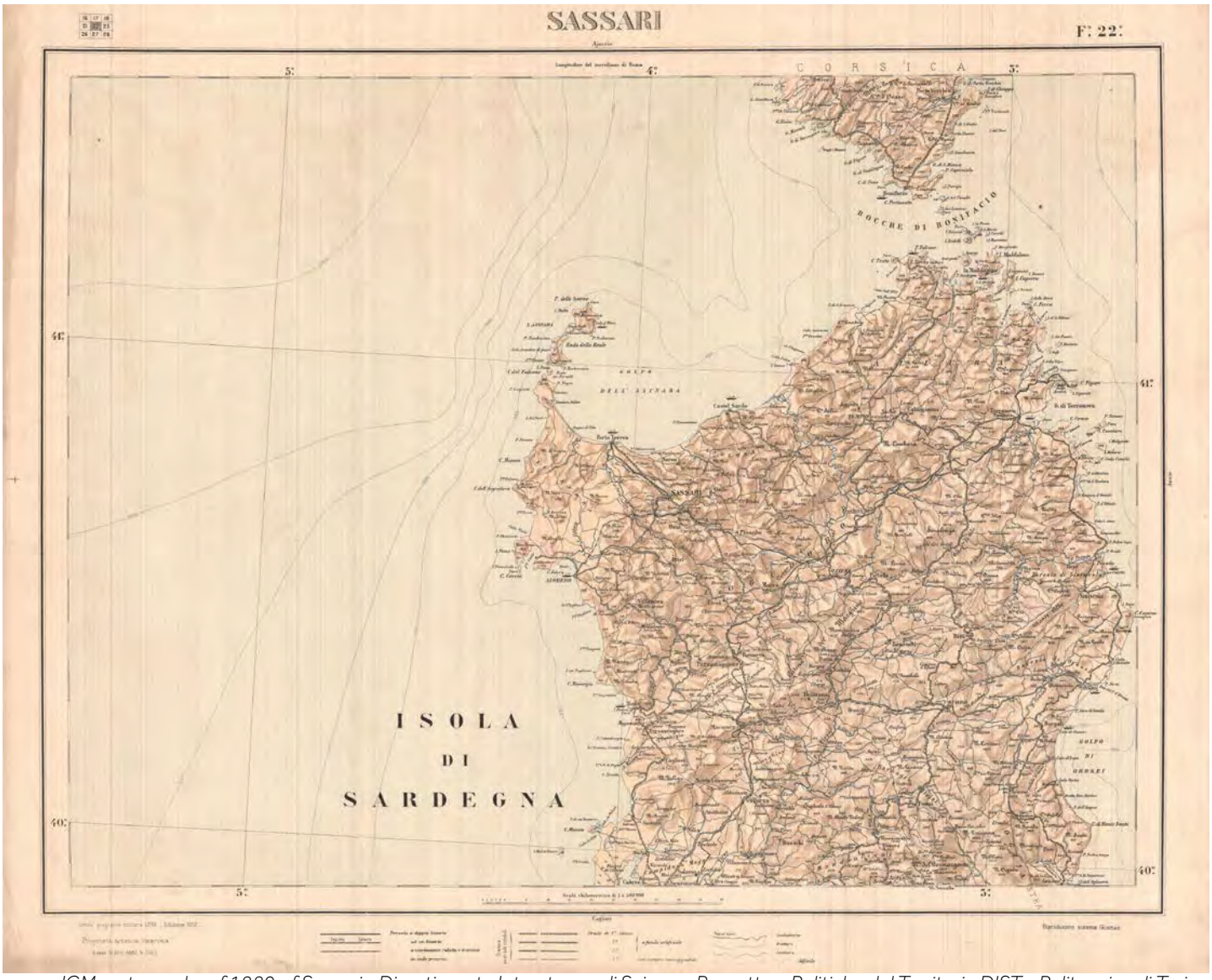
[4] National Collection of Aerial Photography: NCAP https://ncap.org.uk/

[5] Dijkstra, E.W. (July 1996), A first exploration of effective reasoning [EWD896]. (E.W. Dijkstra Archive, Center for American History, University of Texas at Austin)



Aerial military photo of 1954 showing the whole Porto Liscia region - IGM

2. Methodologies and Techniques of Geomatics



IGM cartography of 1889 of Sassari - Dipartimento Interateneo di Scienze, Progetto e Politiche del Territorio DIST - Politecnico di Torino

Any kind of project is essentially an individual or collective enterprise culminating in the accomplishment of a certain result. Our endeavor to seek the desired outcome is paved with many obstacles that require problem setting and solving strategies. In this study, the mysterious history and evolution of the wetland of Porto Liscia requires gathering data and processing it within resourceful methods and techniques to reach a clear understanding of the project's vital components. [1]

Therefore, the need to develop a sufficient database of the wetland to frame theories, proceed with design requirements, or conclude with rational analysis, is what a typical geomatics project aims at achieving. In this case, the geomatics project's initial phase is the entire venture of collecting field information, cartography, spatial data, measurements, ground, and aerial survey. These can be grouped as follows: existing sources, survey data, existing and prospective photography & maps, property divisions, and authority agencies... The ensuing phase is then to interpret the collected data through mainstream practices.[1]

Implemented in this study were numerous techniques of data gathering and processing, not all what the geomatics field can offer, but essential enough to accomplish the survey. In particular the GPS/GNSS technique, UAS for photogrammetry, structure from motion, and software (Metashape), were used to deliver final products that can be further enhanced with architectural procedures to produce contemporary maps and designs.

[1] *Ogaja, C. A., Adero, N. J., & Koome, D. (2023). Project design for geomatics engineers and surveyors.*

IGM cartography of 1958 of Porto Pozzo - Dipartimento Interateneo di Scienze, Progetto e Politiche del Territorio DIST - Politecnico di Torino

3. GPS/GNSS Technique

February 2023

"Leica CS20 Field Controller" (below) e "Leica GS18 GNSS RTK Rover" (above) with tilt error correction technology [7] - geolocating plant species

In 1887, a scientific breakthrough came into light when Heinrich Hertz demonstrated the existence of waves in a practical manner.[1] His findings led to many succeeding innovations in various fields, especially medicine, quantum mechanics, physics, energy, and broadcasting. Most relevant in the world of Geomatics is the advancement of navigation from an antiquated method relying on stars and maps into what is now recognized as "radionavigation".[2]

In the sixties, satellite navigation (SATNAV) systems came into being with the launch of the first military SATNAV system into space by the US government.[5] Currently, many countries maintain a multitude of SATNAV systems in space for navigation and georeferencing, like the American GPS (Global Positioning System), the Russian GLONASS (Global Navigation Satellite System), the Indian NavIC (Navigation with Indian Constellation), and the Japanese QZSS (Quasi-Zenith Satellite System). The agglomerate collection of all these SATNAV systems, their progression and improvement, is referred to as GNSS or Global Navigation Satellite System.[2]

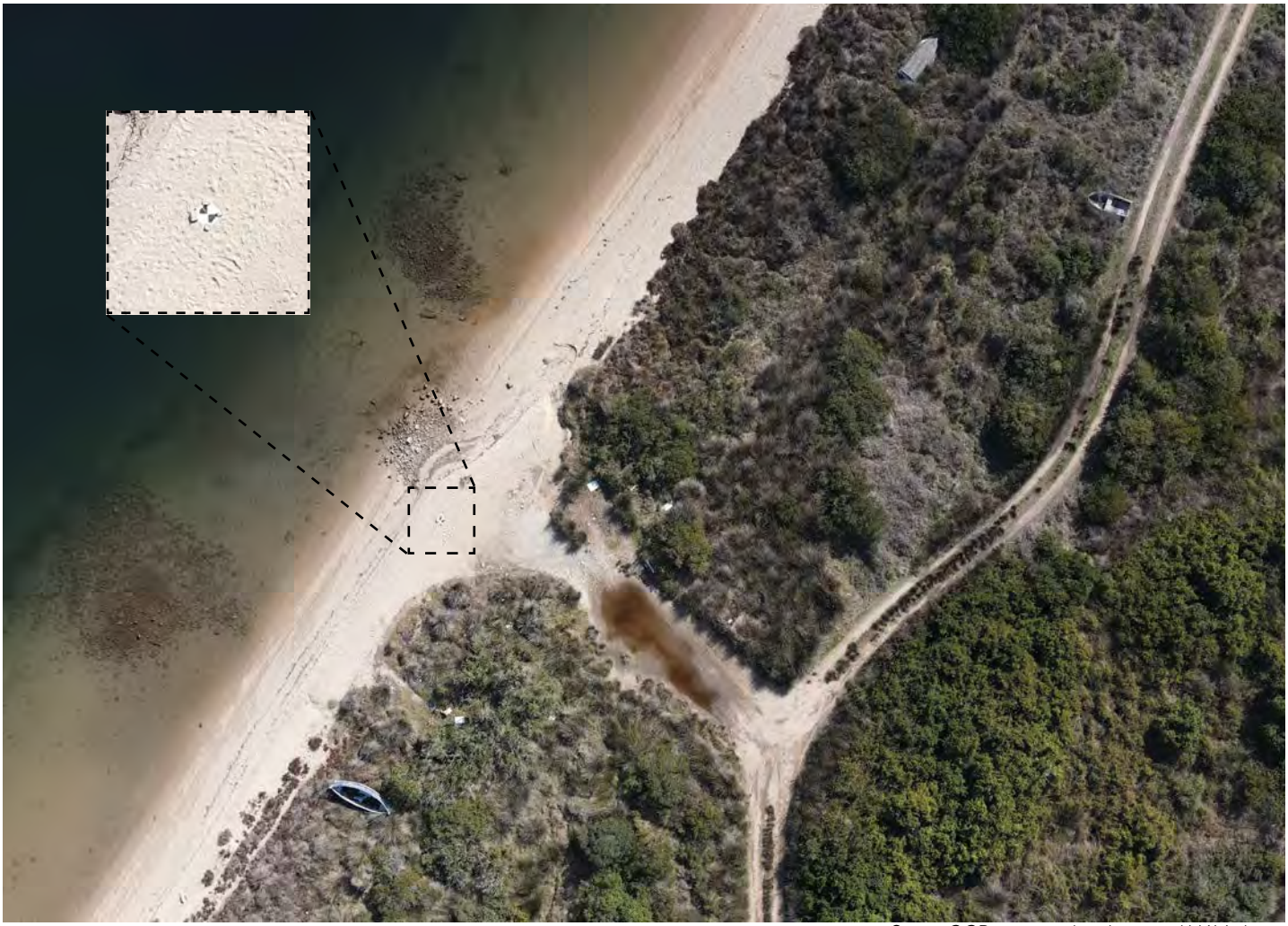
The GNSS system grants the acquiring of coordinates of realistically every point on the terrain and store it on a digital memory. This is achieved by using a field or rover mounted on a sharp rod with a

controller to adjust desired settings. A method that can be only implemented outdoors, it requires at least four or more satellites that must be in appropriate "geometric constellation" to receive position signals of accuracy in the meter range (10-100m). However, the technology of the rover based on ingenious solutions referred to as DGPS (Differential GPS), compensates for this vague error margin by restraining accuracy within the centimeter range (1-5cm). [3] [4]

The accelerated progress in the UAS systems mentioned briefly in the previous sections, maintains a significant relation as well with the technological implementation of GNSS. In fact, not only does typical surveying equipment like the rover use the GNSS technique, but UAVs as well can be equipped with an embedded GNSS controller. This means that the operator can preprogram the flight pathway following a grid or points array to scan the desired zone automatically - an essential prerequisite for producing the orthophoto. [5]

UASs equipped with GNSS have rendered the photogrammetric process a fully automated action. Nevertheless, to increase the accuracy of aerial photogrammetry, ground control points or GCPs have to be defined on land. The GCP is an actual fixed object point captured in the aerial photos with real three-

"Targeted" GCP marker measured with the rover



Same GCP captured in the aerial UAV photo February 2023

dimensional coordinates (x,y,z) that are manually measured by the rover. Therefore, before elaborating the drone photos, these distinguished points can be demarcated on the field as "natural" i.e., an edge of a rock, an edge of a concrete slab or construction, a point of any other unique immovable feature, and if missing, a "targeted or signalized" marker sheet can be firmly nailed to the ground as GCP. [4]

In conclusion, GNSS technology in UASs serves to facilitate the flight process and the initial georeferencing of the captured data. Nonetheless, the ground manual measuring of noticeable GCPs provides an augmentation in the precision of the technique. The points have to be extensively dispersed and cover the main edges of the studied area. The cluster of all defined GCPs consequently constitutes a solid basis that is then used in the photogrammetric process to calibrate the entirety of the map. [4]

[1] *NASA. (n.d.). Discovering the electromagnetic spectrum.*

[2] *Hegarty., E. D. K. and C. J. (2017). Understanding GPS/GNSS: Principles and applications, third edition.*

[3] *Luhmann, T., Robson, S., & Kyle, S. (2014). Close range photogrammetry: Principles, techniques and applications.*

[4] *Linder, W. (2016). Digital Photogrammetry: A practical course.*

[5] *Petropoulos, G. P., & Srivastava, P. K. (2021). GPS and GNSS technology in Geosciences.*

[6] *Leica GS18 T GNSS RTK rover. with Tilt Compensation | Leica Geosystems. (n.d.). https://leica-geosystems.com/*

4. Photogrammetry

Photogrammetry is a process that involves reconstructing the shape of a certain object within location or coordinate parameters from photographs of the object. This reconstruction is a three-dimensional representation of the object employing either digital means (coordinate and geometric data) or graphical ones (images, drawings, schemes, maps).

Subsequently, the process of photogrammetry relies primarily on optical interfaces. Surface properties, brightness, color, contrast, light source, camera, and sensor technology, constitute physical elements of the studied object and the apparatus used. Therefore, every image point - pixel in case digital - maintains unique properties in the form of radiometric data (intensity, grey and color values) and geometric data (position). As a rule of thumb, the higher in definition the photos can be, and the more uniform and less sharp the ambient skylight is - to avoid harsh contrasts between lit and shady zones of a photograph - the higher in quality of the photogrammetric process can be attained.[1]

4.1 Geometric and Mathematical Fundamentals of Photogrammetry

Photographs store qualitative data such as color or age appearance of the subject (aspect, color, old, new). However, when implementing photogrammetry, quantitative data like measurements or coordinates can be extracted. From this point of view, photogrammetry is referred to as the "science of measuring in photos".

Our ability to approximate distances dividing us from other objects, and perceiving the world in a spatial manner where things are near and far is an intrinsic ability of the human vision. Our brain reconstructs two vision fields generated by respectively the right and left eye into one central perspective. In photogrammetry, combining two or even more photographs of the same object follows the same principle referred to as "stereoscopic viewing".[2]

Stereopsis on one hand is the ability of visualizing environments in a three-dimensional appearance.[3] On the other hand, stereo imaging is a technique that aims at generating an illusion of depth in photos. The most recognized way of achieving this is through the use of stereoscopes or binoculars that focus the vision onto two slightly different photos of the same object. Another more modern technique - used as toys for little kids, or in early 3D movie theaters - is the application of the "color anaglyph" method, simply applying red and cyan filters to the display and consequently using 3D-colored glasses...[4]

[1] Luhmann, T., Robson, S., & Kyle, S. (2014). Close range photogrammetry: Principles, techniques and applications.

[2] Linder, W. (2016). Digital Photogrammetry: A practical course.

[3] Russ. (2021, July 21). 3D vision is more important than you think. Optometrists.org.

[4] Guardian News and Media. (2009, August 19). John Patterson: A history of 3D cinema. The Guardian. https://www.theguardian.com/film/2009/aug/20/3d-film-history

February 2023

Illegal settlement to the west of the "Padula Cioca" - Anaglyph effect to be viewed with red/cyan glasses or by slightly shutting one's eyes

Amidst all this, photogrammetry aims at deconstructing the physical process of stereoscopy to create a real 3D model and not an illusion. This is achieved through a geometric and mathematical model of central projection imaging. In the following diagram 1, the designated projection mechanism of an object throughout a camera's lens is expressed. The centrality of the model is symbolized by the small pinhole of the geometric depiction of the camera through which all projection rays pass to imprint on the back canvas. Most important is the fixed parameter D0 which is the known distance from the lens of the camera to its capture sensor plane recognized as "focal length". Accordingly, a scaling property is derived between the size of the real object and its size on the image plane, and that establishes the "photo-scale" principle characterized by a factor m: [1] [2]

$$m = \frac{\mathrm{D1}}{\mathrm{D0}} = \frac{y}{y'}$$

[1] *Luhmann, T., Robson, S., & Kyle, S. (2014). Close range photogrammetry: Principles, techniques and applications.*

[2] *Linder, W. (2016). Digital Photogrammetry: A practical course.*

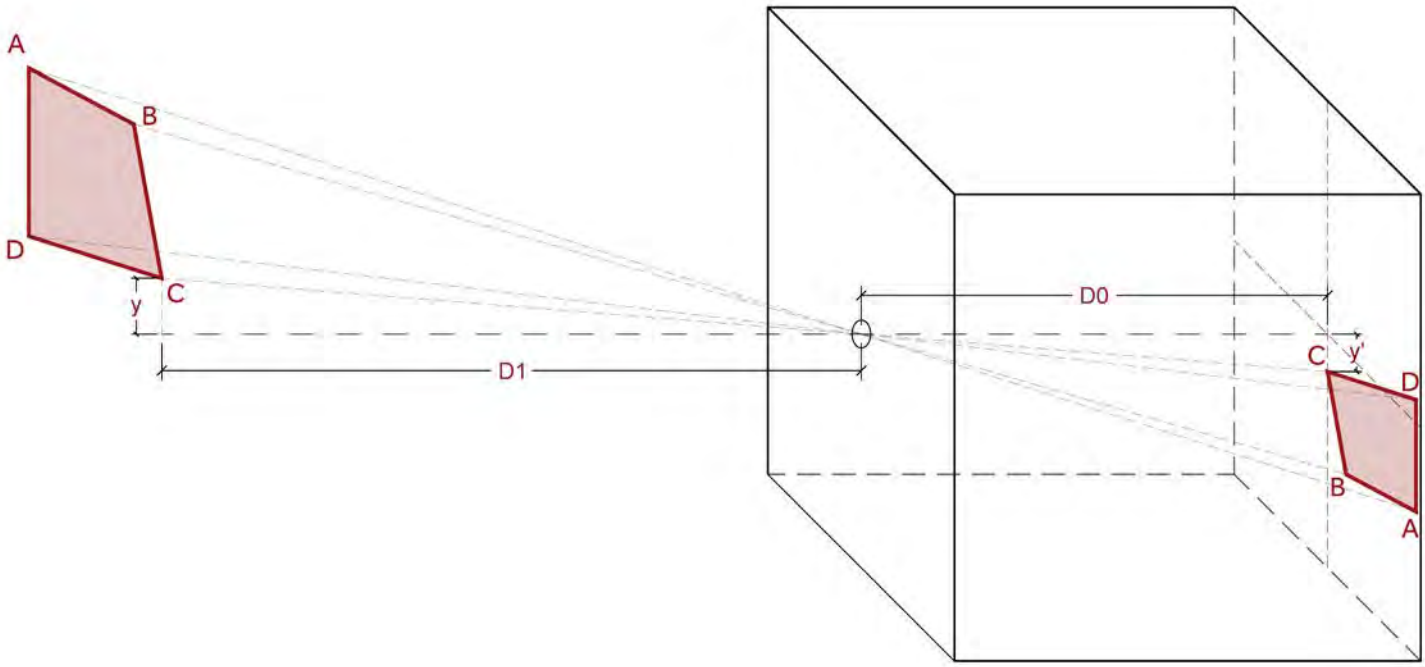


Diagram 1 - Pinhole camera model - Projection of a real object onto a canvas (sheet, film, sensor...)

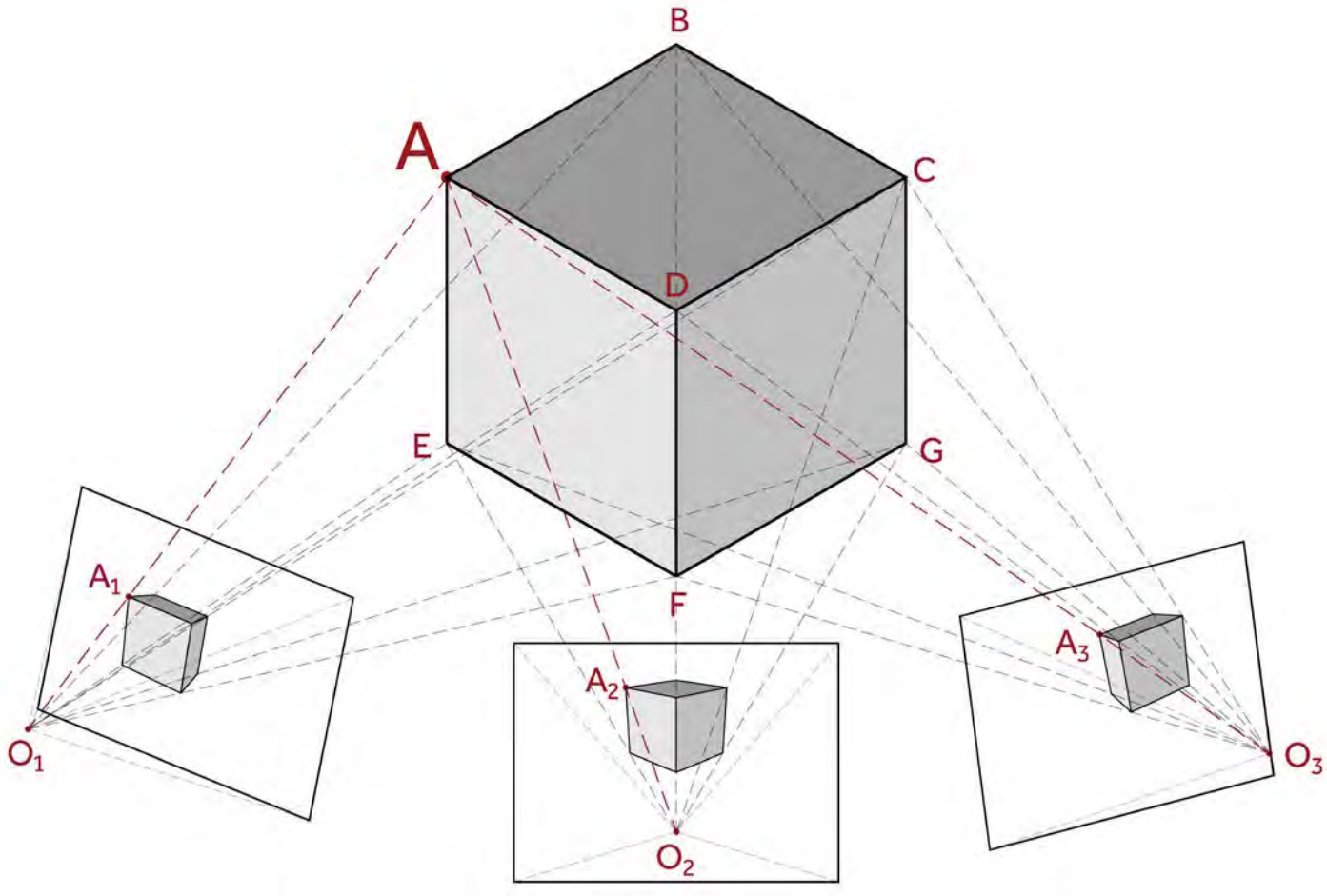


Diagram 2 - Principle of photogrammetric measurement and triangulation - Structure from motion

At this point, the internal camera parameters are being investigated to explore the optical mechanisms occurring inside. Besides "skew" of light rays, and "radial and tangential distortions" due to lens imperfections, the "internal principal points coordinates" of images and exterior orientation parameters are yet the main notions to be reviewed to understand how any point can be spatially traced in reference to others. Diagram 2 describes multi-image photogrammetry in which more than two photos of the same object are used. What is conveyed is the triangulation of a specific point A in order to locate it based on different camera positions. This triangulation is simplified in the subsequent diagram 3 where it is represented as a 2D plane for the sake of a better interpretation, a case referred to as "stereo normal". In this case the cameras are considered to be shifted from each other only in one direction (x), their capture planes identically oriented, and the captured points lie in the same row of the plane. The local coordinates of each projected point (A_1 & A_2) are known based on the respective coordinate system of each camera position, the distance (D) between the two camera centers (O_1 & O_2), and the focal length (H) are also known, which allows through the following trigonometric functions to obtain the real coordinates of point A. [1] [2] [3]

$$x_A = x'_{A1} \frac{D}{-(x''_{A2} - x'_{A1})}$$

$$y_A = \frac{y'_{A1} + y''_{A2}}{2} \cdot \frac{D}{-(x''_{A2} - x'_{A1})}$$

$$z_A = H \cdot \frac{D}{-(x''_{A2} - x'_{A1})}$$

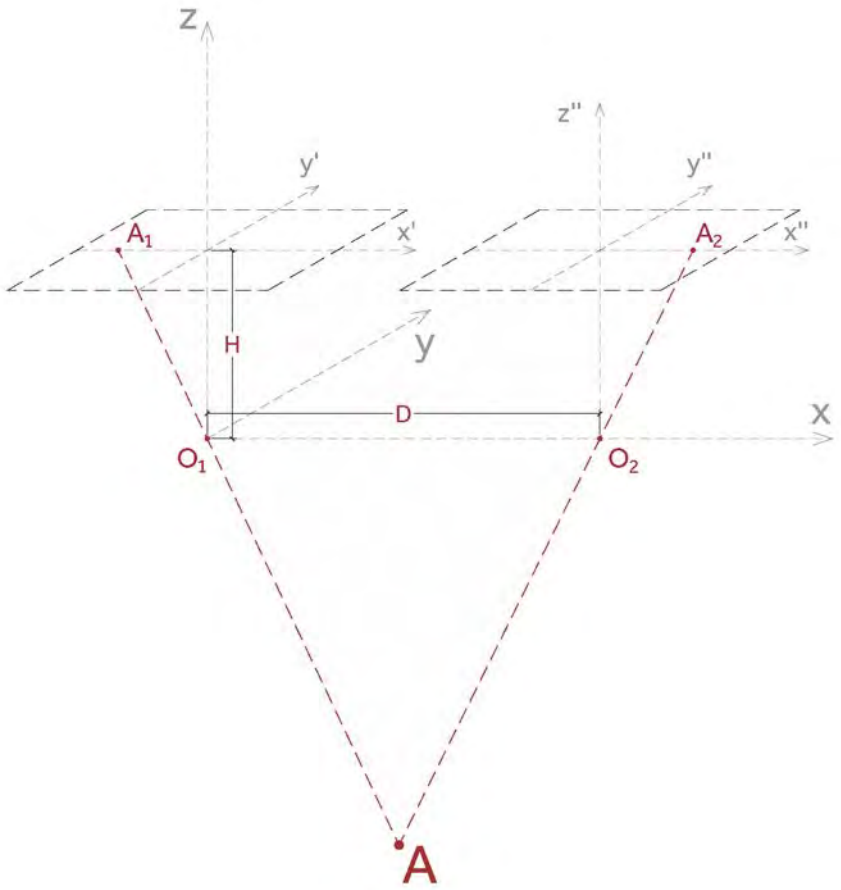
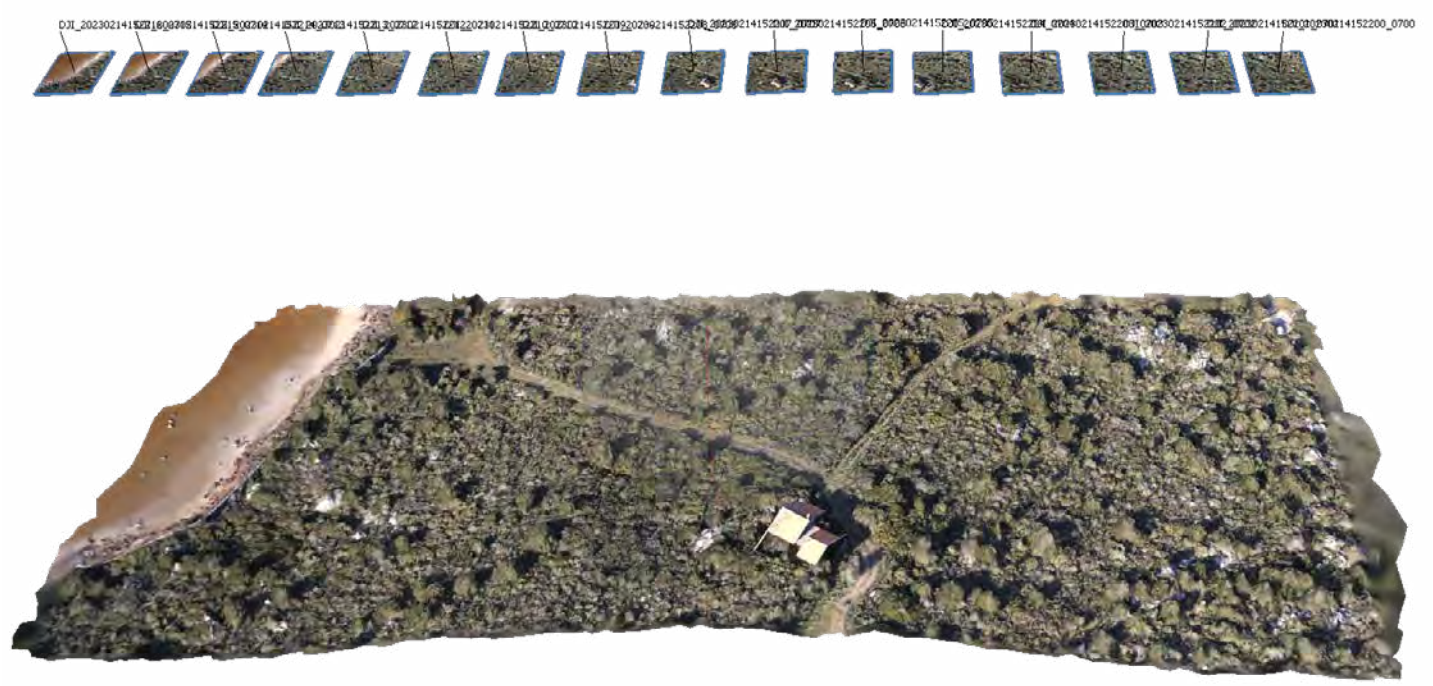


Diagram 3 - 2D "Stereo Normal" case [5] [6]

[1] *Luhmann, T., Robson, S., & Kyle, S. (2014). Close range photogrammetry: Principles, techniques and applications.*
[2] *Stachniss, C. (2015, November 24). Photogrammetry II - 06 - triangulation and absolute orientation (2015/16).*
[3] *Stachniss, C. (2021, June 18). Stereo normal case - 5 minutes with Cyrill.*



Multi-image photogrammetry - 3D model of the illegal settlement area with the respective used drone photos locations

In the end, the perfect stereo normal condition remains an abstract notion since in reality it is quite impossible to reach ideal situations because the camera will always have a certain tilt angle and following one line direction is not enough to scan an entire area. Therefore, photogrammetry relies more specifically on various more complicated sets of scenarios and equations with the most notable being the "collinearity equations". Photogrammetry's aim is to have a desired point georeferenced in real or "world" coordinates system, basically within actual cartographic coordinates (longitude and latitude degrees). Consequently, collinearity works at establishing ratios in relation to the point, the camera, and the global coordinates system. [1] [2] [3]

Accordingly, a unified ratio λ is determined among the coordinate system of the camera's sensor plane x, y, z, the coordinates of point A x_A, y_A, z_A, the coordinates of the optical center O x_0, y_0, z_0, and the focal length H (distance between the optical center and sensor plane) as follows:

$$x - x_O = -\lambda(x_A - x_O)$$
$$y - y_O = -\lambda(y_A - y_O)$$
$$H = \lambda(z_A - z_O)$$

[1] *Luhmann, T., Robson, S., & Kyle, S. (2014). Close range photogrammetry: Principles, techniques and applications.*
[2] *Stachniss, C. (2015, November 24). Photogrammetry II - 06 - triangulation and absolute orientation (2015/16).*

Solving λ in the previous equations yields:

$$x - x_O = -H\frac{x_A - x_O}{z_A - z_O}$$

$$y - y_O = -H\frac{y_A - y_O}{z_A - z_O}$$

Since point A belongs to a global coordinate system different than the one of the camera, its coordinates are subject to rotation and translation on the camera's system. The rotation called "camera transform" is a matrix rotation in which angles are expressed as Rx, global coordinates of point A are X,Y,Z, and global coordinates of the optical center are X_0, Y_0, Z_0. Without further ado, this leads eventually to collinearity equations: [1]

$$x - x_O = -H\frac{R_{11}(X - X_0) + R_{21}(Y - Y_0) + R_{31}(Z - Z_0)}{R_{13}(X - X_0) + R_{23}(Y - Y_0) + R_{33}(Z - Z_0)}$$

$$y - y_O = -H\frac{R_{12}(X - X_0) + R_{22}(Y - Y_0) + R_{32}(Z - Z_0)}{R_{13}(X - X_0) + R_{23}(Y - Y_0) + R_{33}(Z - Z_0)}$$

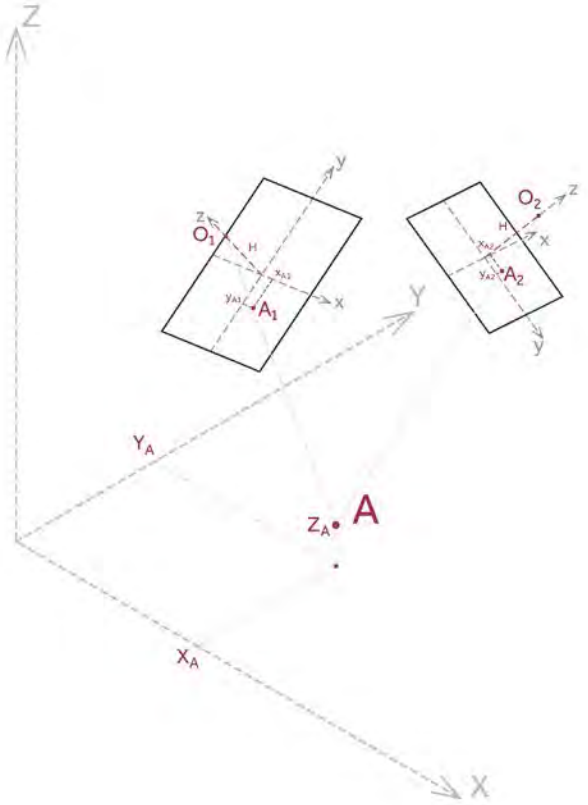


Diagram 4 - "Collinearity" - cameras with different tilt and positions in the global coordinate system

[1] *Luhmann, T., Robson, S., & Kyle, S. (2014). Close range photogrammetry: Principles, techniques and applications.*

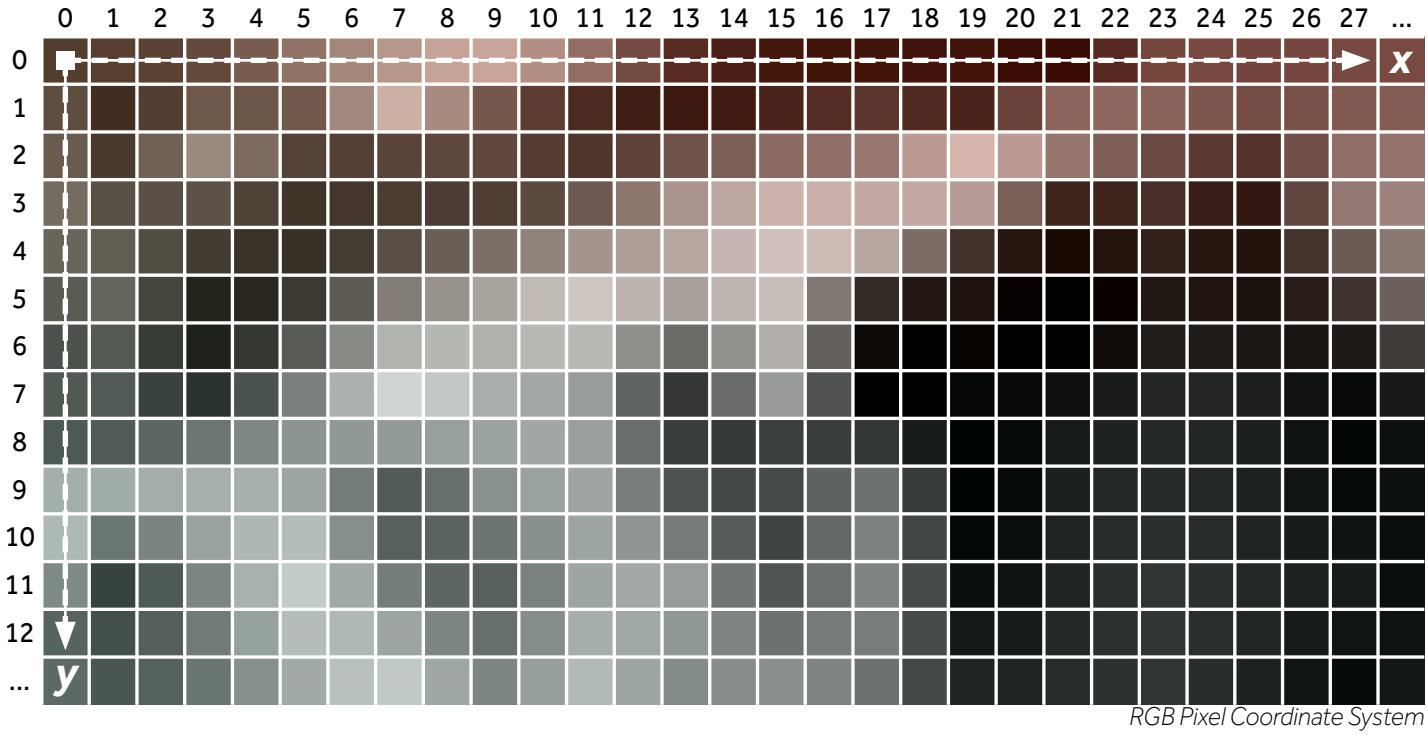
4.2 Digital Imagery and Photogrammetry

February 2023

Surfing shack at the Liscia beach - Pixels as individual squares of a raster matrix with a distinctive color & shade (RGB)

The photogrammetric process has greatly progressed ensuing the convenience offered by digital photography. The once complicated procedures of acquisition, storage, elaboration, and end production became less demanding, more accurate, and quasi automated. To understand how digital photogrammetry works in relation to vectorial or geometric photogrammetry, the raw component or keystone of a digital photo has to be recognized. Digital images also referred to as raster images are composed of "pixels", the smallest elements of a raster matrix that can be manipulated through software. [1] [2]

Since pixels constitute a matrix of individual blocks with radiometric data, then it is also reasonable to be referring to a pixel coordinate system, where typically the x direction is the horizontal row and the y direction is the vertical column, with the origin or first pixel (0,0) located at the upper left corner of the image. Subsequently, each pixel has coordinate values based on its location within the matrix, with one defined brightness level across its specific area. [1]



RGB Pixel Coordinate System

In grey-scale images, pixel brightness values range from full black (0) towards full white (255) for a total of 256 values of grey shades. The human eye can only distinguish up to 60 different tones of grey, however computers can discern the difference of all shades of this system referred to as 8-bit depth system. Moreover, computers can also elaborate much more complex systems like the 10-bit system comprising 1024 grey shades, or the 12 and 16-bit systems. In case of colored images, the true color system of 24-bit depth is implemented or RGB color channels, with 8-bits for red tones, 8-bits for green tones, and 8-bits for blue tones. [1]

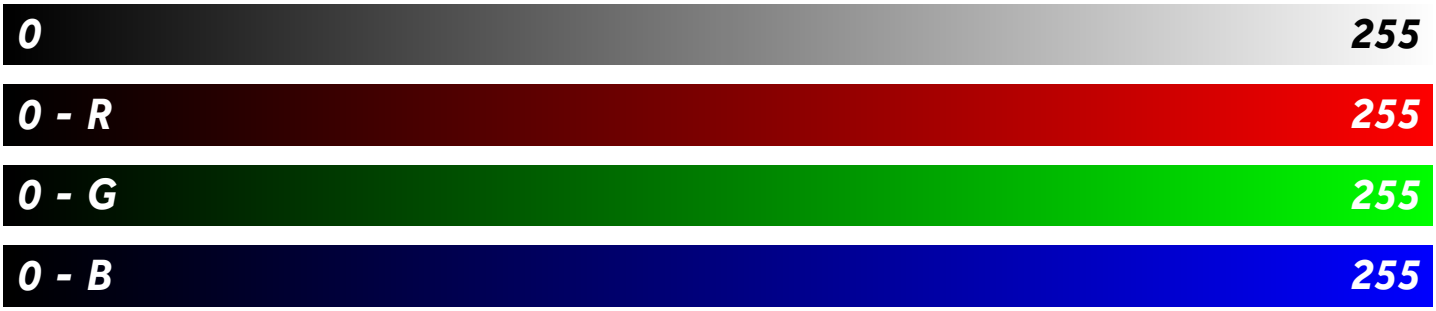
In vectorial photogrammetry, a projected point approximates a real or discernable edge of an object represented in two or more photos. In digital photogrammetry, every point or pixel of a photo with specific radiometric data (RGB) finds its counterpart in another photo. Thus, the adjacent pixels belonging to one object have uniform properties in all the photos capturing that same object, a phenomenon referred to as "connectivity". [1]

Since photos can slightly vary because of angle, external factors, and light source position, connectivity is best achieved in addition to searching for the same pixel in various photos, through the identification of its neighboring pixels as well. When algorithms come into play to achieve connectivity, two assumption models to identify neighbors are applied: N4 & N8. The N4 connectivity assumes that a certain object can be dissected into several unique pixels and treats its surroundings as separate objects. However, the N8 model assumes that a certain object is integral, and the rest of the objects can be separate or joined if they share corner connections. [1]

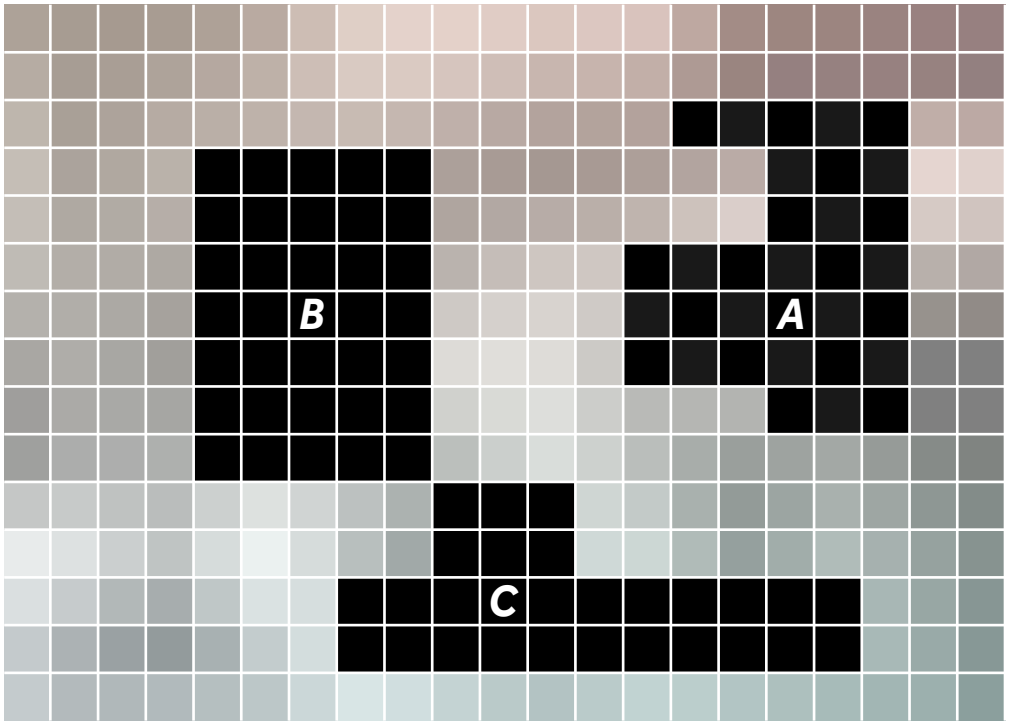
When the change in pixel data is abrupt, the detection of objects' edges is achieved. Therefore, edges are necessary in order to succeed with photogrammetric measurement and recognition. Along with multiple complicated identification mechanisms, the change in radiometric data is fundamentally owed to significant change in brightness of objects in grey scale images or of the same color channel, change in pixel color values (RGB or multi-spectral edge extraction), and change in overall texture of an object (texture analysis). [1]

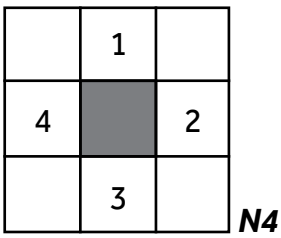
As a conclusion, digital photogrammetry relies on various computer algorithms to interpret and deconstruct raster photographs that are composed of pixels with distinguishable grey or RGB color values. Accurate object recognition relies in the end on finding resemblances among several images through connectivity of pixel data (brightness, color, & texture...).

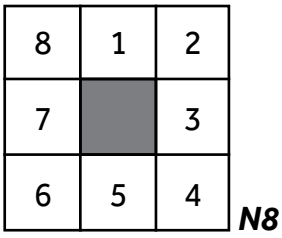
[1] *Luhmann, T., Robson, S., & Kyle, S. (2014). Close range photogrammetry: Principles, techniques and applications.*
[2] *Foley, J. D.; Van Dam, A. (1982). Fundamentals of Interactive Computer Graphics. Reading, MA: Addison-Wesley.*



Greyscale and RGB channels 8-bit depth scales







Connectivity N4 & N8 models
N4: A is an object dissected into multiple pixels, with B & C as separate individual objects
N8: A is a single integral object, with B & C merged together since they share a corner connection

4.3 UAV for Photogrammetry and LiDAR

As previously stated, a UAS system was used to conduct the photogrammetric acquisition of the wetland of Porto Liscia. The role of the UAV or drone is to simply provide a means for aerial transportation, and it is thus the task of other subcomponents to achieve the rest of the mission. Manual control and photography are possible but would constitute an infinite occupation for the pilot, therefore, these technological subcomponents need to be carefully selected to achieve a seamless flow of data procurement. The units specifically used for this survey are as follows:

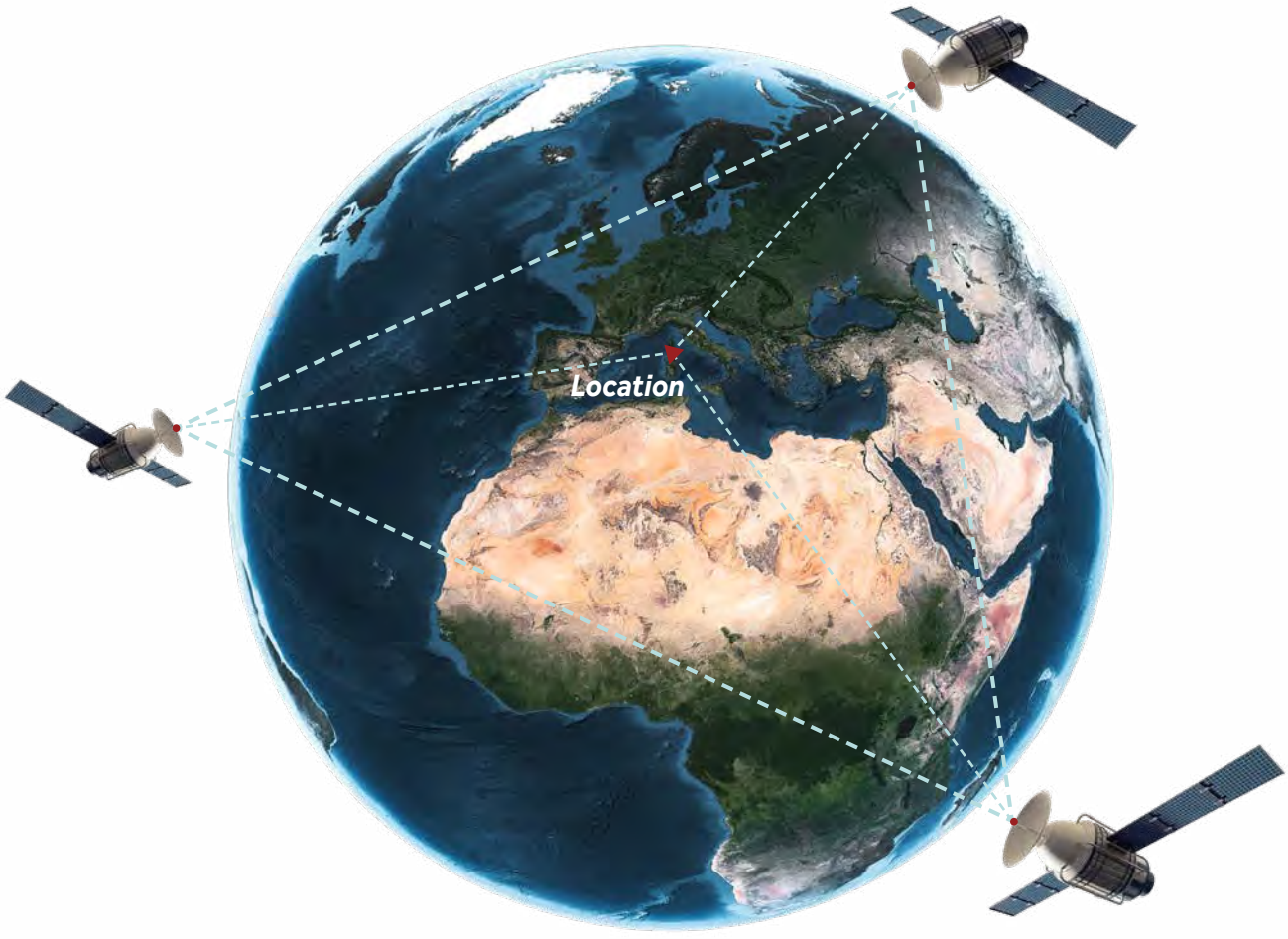
1. UAV: DJI Enterprise MATRICE RTK 300 with remote controller
2. Camera: DJI Enterprise Zenmuse P1
3. GNSS receiver: DJI double antenna that works with GPS (USA) +GLONASS (Russia) + BeiDou (China) + Galileo (Europe)
4. LiDAR: DJI Enterprise Zenmuse L1

While the UAV's and camera's utilities are easily grasped, the functionality of the remaining more complicated set of equipment has to be thoroughly examined. The automation of the whole process lies firstly in the remote controller whose basic role is to emit radio signals to control the drone. A smart controller such as the DJI, has an integrated microprocessor which means it integrates functions of a processing unit of a computer. Equipped with a built-in touchscreen display, it allows for the planification of the flight route and its settings i.e. geographical area to scan and autopilot, elevation, duration, battery health, wind influence, density and frequency of image capture, and the ability to connect to the internet storing data immediately on the cloud. [1 2]

DJI Remote Controller with automated settings and pre-flight route planning

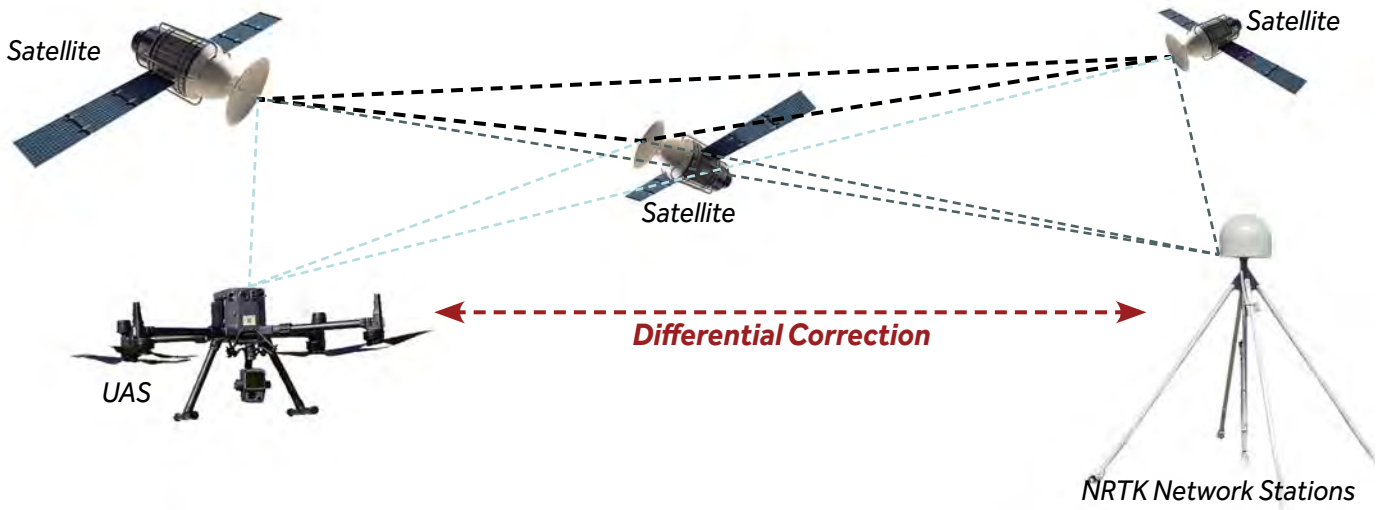
The drone can only accurately geo-localize itself through an incorporated GNSS receiver that communicates through triangulation or trilateration with a constellation of satellites. The concept of triangulation to get the coordinates of a specific point works in this case somehow similarly to what was explained earlier in the photogrammetric process; nonetheless, what is involved now are satellites, a GNSS antenna, radio waves, and of course a different set of mathematics. The whole procedure is referred to as "real-time kinematic positioning (RTK)" that involves firstly the trilateration with satellites, and secondly the correction of the errors in location data relying on a ground reference station or network of stations (NRTK or Network RTK). [34]

Satellites orbiting Earth through a defined trajectory transmit radio waves with known xyz coordinates. The GNSS receiver of the UAV measures the time of the signal's travel time called time of flight of the radio signal from the satellite to the receiver, and thus can calculate spontaneously its distance from the satellite. In vacuum or space, radio waves that make part of the electromagnetic spectrum all travel at the speed of light c=300,000 km/s. The formula of the distance is accordingly $d = c \cdot \Delta t$, where Δt is the duration of time of the moment in which the signal was emitted and then received.[35]



Google Earth photo 29/06/2020

GNSS and Satellite Trilateration



Real Time Kinematic Positioning and Differential GPS Correction diagram

Last but not least, the LiDAR (Light Detection And Ranging) remains one of the most important pieces of equipment in the UAS. It emits electromagnetic (EM) waves belonging to the optical and infrared wavelengths in a constant active behavior, meaning that it produces the EM wave and catches it back like a measuring laser. Unlike a camera that only receives light waves of the visible spectrum, a LiDAR generating its own waves can operate equivalently during day and night, and with high accuracy. The combination of the LiDAR with the camera makes of the former a kind of imaging sensor that measures the "range" or distance between the UAS and the pixels of each image representative of actual points on the field. For the purpose of 3D imaging or modeling, pixels associated with a 3D property are technically referred to as "voxels", foundation material for the upcoming 3D model. [6]

LiDAR L1 and Camera P1 on DJI RTK 300

February 2023

[1] *Specs - matrice 300 RTK - DJI Enterprise. DJI. (n.d.). https://enterprise.dji.com/matrice-300/specs*

[2] *Dukowitz, Z. (2019, September 19). Drone controllers: A look at how they work and important terminology. UAV Coach. https://uavcoach.com/drone-controller/*

[3] *Petropoulos, G. P., & Srivastava, P. K. (2021). GPS and GNSS technology in Geosciences.*

[4] *DroneDeploy. (2022, December 8). What is the difference between RTK, PPK and GCP-and why does it matter?. Reality Capture Platform.*

[5] *The electromagnetic spectrum | iopspark. (n.d.-c). https://spark.iop.org/electromagnetic-spectrum*

[6] *McManamon, P. F. (2019). Lidar Technologies and Systems. SPIE Press.*

4.4 DSM Digital Surface Model

A DSM image is a type of heightmap image that captures all natural features and anthropogenic structures of a studied environment, which in the case of the Wetland of Culuccia, is crucial into receiving data that displays all human intervention on the terrain – unlike the bare earth topography which a typical DEM (Digital Elevation Model) represents by omitting all structures and vegetation.[1]

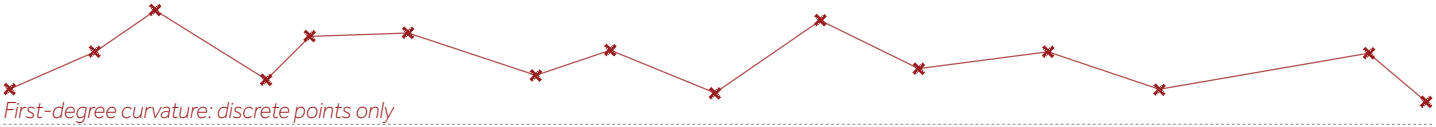
Any 3D point cloud with a sufficient number of points, whether regular in planar spacing ($\Delta X=\Delta Y=$constant) or irregular (ΔX & $\Delta Y\neq$ constant), is adequate for describing the applicate (z axis) information of a studied surface.[2]

Triangulation and interpolation are the two techniques used by software to generate a DSM model out of a 3D point cloud. Worthwhile to recall here is the LiDAR that produces "voxels" or 3D pixels which are employed by digital photogrammetry to generate a DSM image.

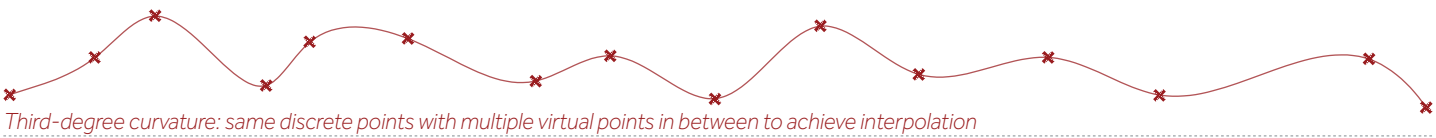
Delaunay triangulation is the simpler technique used to create a mesh triangulation. The mesh is therefore a collection of interconnected 3-point planes, resulting in a polyhedron approximating a wire model of the actual surface.[2]

Interpolation, nonetheless, is a technique that calculates curvature among points in either a planar or three-dimensional point cloud to increase accuracy and reduce computation time.[3] This technique approximates the curvature or points of a mesh that virtually exist in between those of the actual point cloud – finding new points based on the domain of known or discrete points of the survey.[4]

In the case of this study, software Metashape was used to produce the heightmap as seen next which is exported as an image with either a colored or more preferably monochrome gradient, and whose variation indicates the height of each point. This map can be inserted into rendering software as a heightmap which adds a "displacement" feature to a certain object adding more detail and depth.



First-degree curvature: discrete points only



Third-degree curvature: same discrete points with multiple virtual points in between to achieve interpolation

Simplified concepts of triangulation vs interpolation represented in 2D

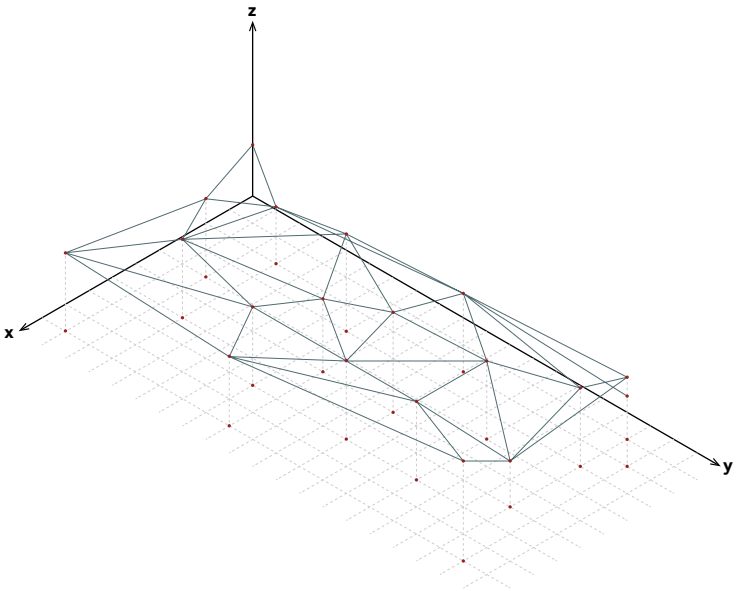
[1] *Gregorius, B. Dem, DSM & DTM: Digital elevation model - why it's important.*

[2] *Luhmann, T., Robson, S., & Kyle, S. Close range photogrammetry: Principles, techniques and applications.*

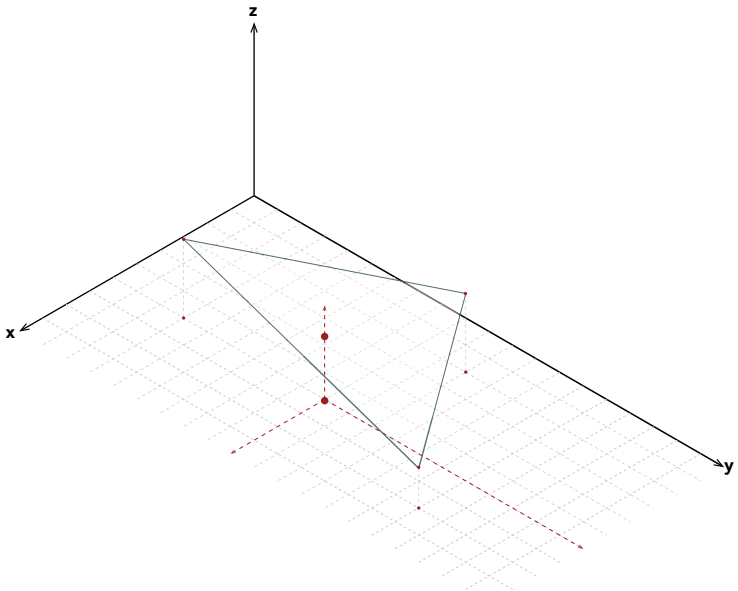
[3] *Cadence CFD. The best methods for mesh interpolation.*

[4] *Steffensen, J. F. (2006). Interpolation (2nd ed.). Mineola.*

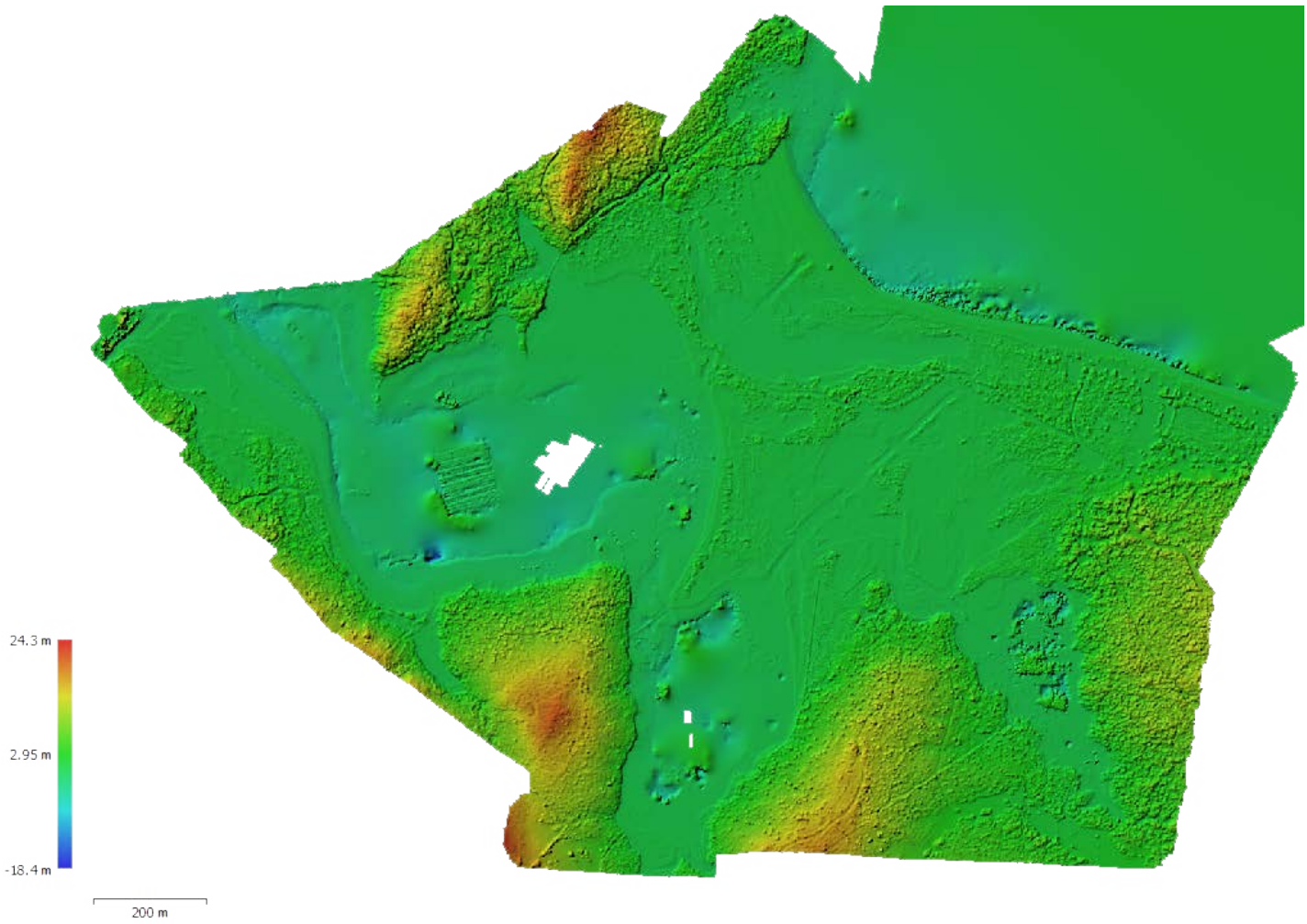
DSM



Concept of a 3D Delaunay Triangulation of a point cloud



Simplified Concept of Interpolation on a triangulated mesh



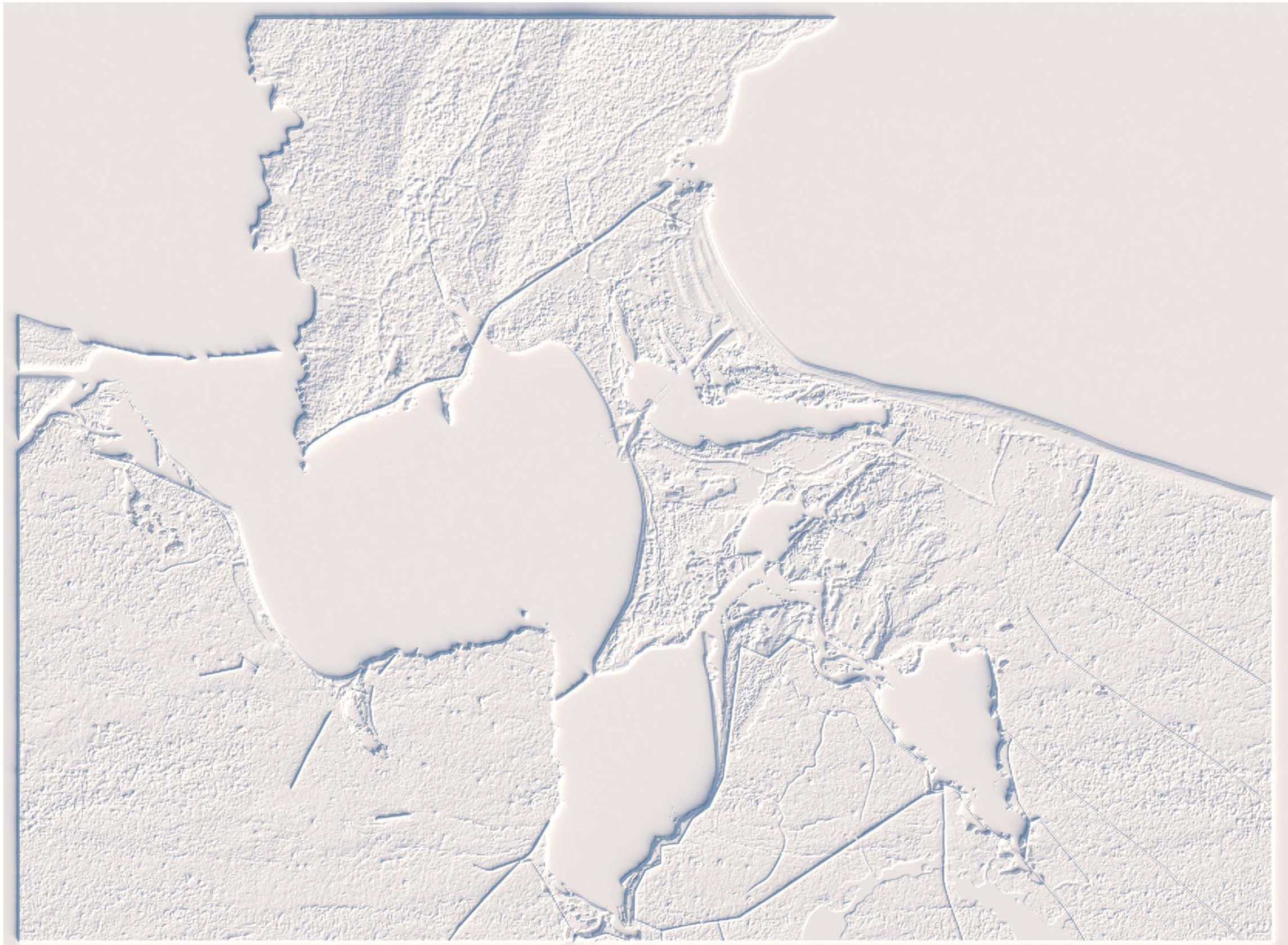
DSM visualized in Metashape with colored gradient

3D MODEL

Entire 3D model as a triangulated and interpolated mesh

Preview 1: Point Cloud (980,626,915 points)

Preview 2: 3D Mesh Model



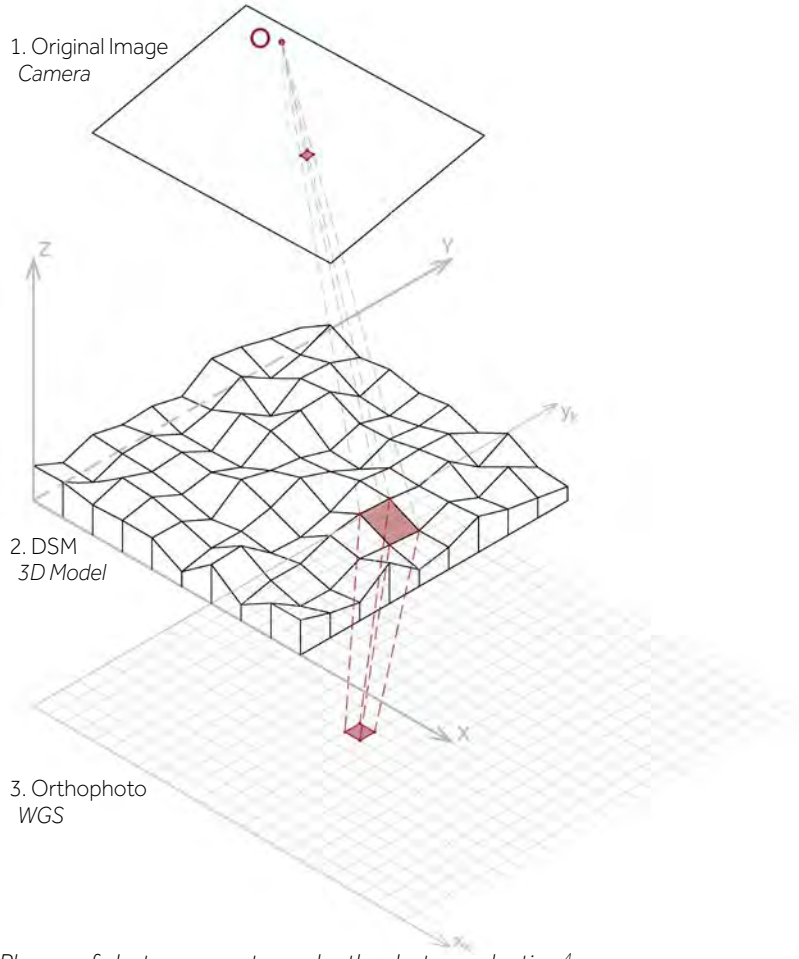
DSM Heightmap rendered with white texture using Autodesk 3DsMax to show elevation variation

4.5 The Orthophoto

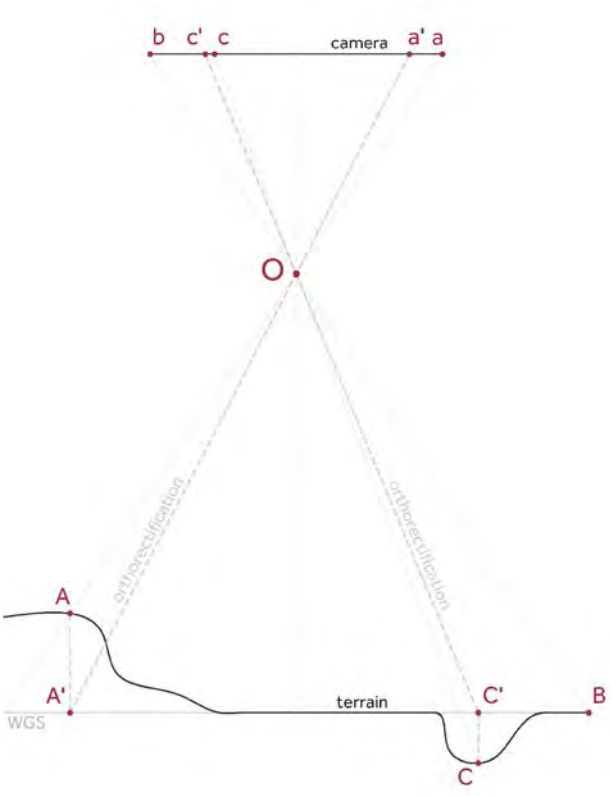
A typical camera captures photos characterized by a certain perspective level based on the lens in use. From this point of view, using a normal aerial image cannot replace a standard map in which coordinates and measurements can be retrieved. Therefore, through photogrammetry a special kind of photo can be generated that possesses first, realistic graphic imagery of a surface, and second, accurate and precise location data. This is referred to as “orthophoto”.

An orthophoto is a photogrammetric creation in which scale is standardized throughout the whole plot eliminating perspective and topographic relief like mountains and valleys. Additionally, in such a photo, X&Y coordinates are assigned to each point allowing for digital georeferencing and the extraction of distances. Furthermore, this means that scale in an orthophoto can only have one value and that is the real scale value. [1]

In order to stabilize different photos into one comprehensive image, a projection system of coordinates has to be selected. The international standard used for cartographic studies, GNSS, and navigation is the WGS or World Geodetic System, with various past versions and a current one referred to as WGS 84 (of 1984). [2]

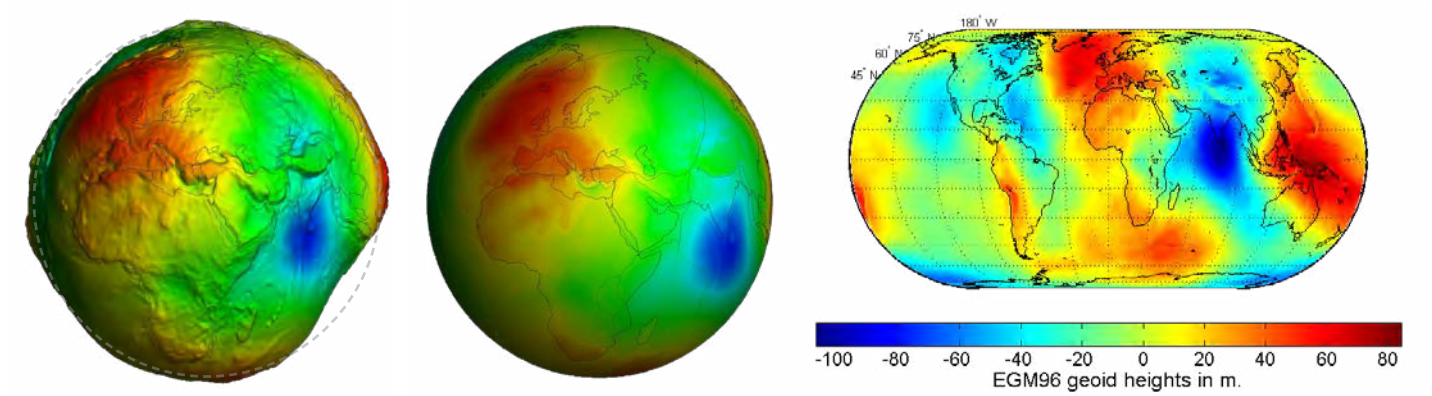


Phases of photogrammetry and orthophoto production [4]



Concept of Orthorectification [1]

Earth is not an ideal sphere, but a geoid with an uneven surface with depressions and elevations. However, in order to create a uniform model of the planet, it is conveyed as an unvarying ellipsoid, mathematically refining the irregular reality. An ellipsoid as such can be geometrically and evenly subdivided into portions covering real areas, and these can be further unrolled or projected on a rectangular orthogonal map like the conventional world atlas. [3]



Left to right: Geoid, to Ellipsoid, to EGM96 map [3]

Consequently, the photogrammetric process implemented at this point reorganizes all pixels of all captured aerial images on the WGS coordinate system that precisely depicts the real distances. In digital photogrammetry, the identification of analogous "pixels" and their "neighbors" requires ultimately a certain degree of overlap among photos. Therefore, "orthorectification" of camera photos requires avoiding gaps or missing regions in between taken photos, and this is accomplished by establishing a certain overlapping percentage of photos - which can be regulated on the remote controller of the UAV. [4]

In the following portions of the thesis, the results of the photogrammetric processing (from software Metashape and QGIS) are displayed. In the initial sections, historical orthophotos have been developed from military aerial photographs taken in 1939, 1940, 1954, 1968, and 1986. In the following sections, a contemporary orthophoto of February 2023 with a precision and definition of 2cm has been developed and traced in the end using CAD software to create a cohesive 3D map.

Three photos displaying "overlap" of similar features - 80% overlap between two successive photos

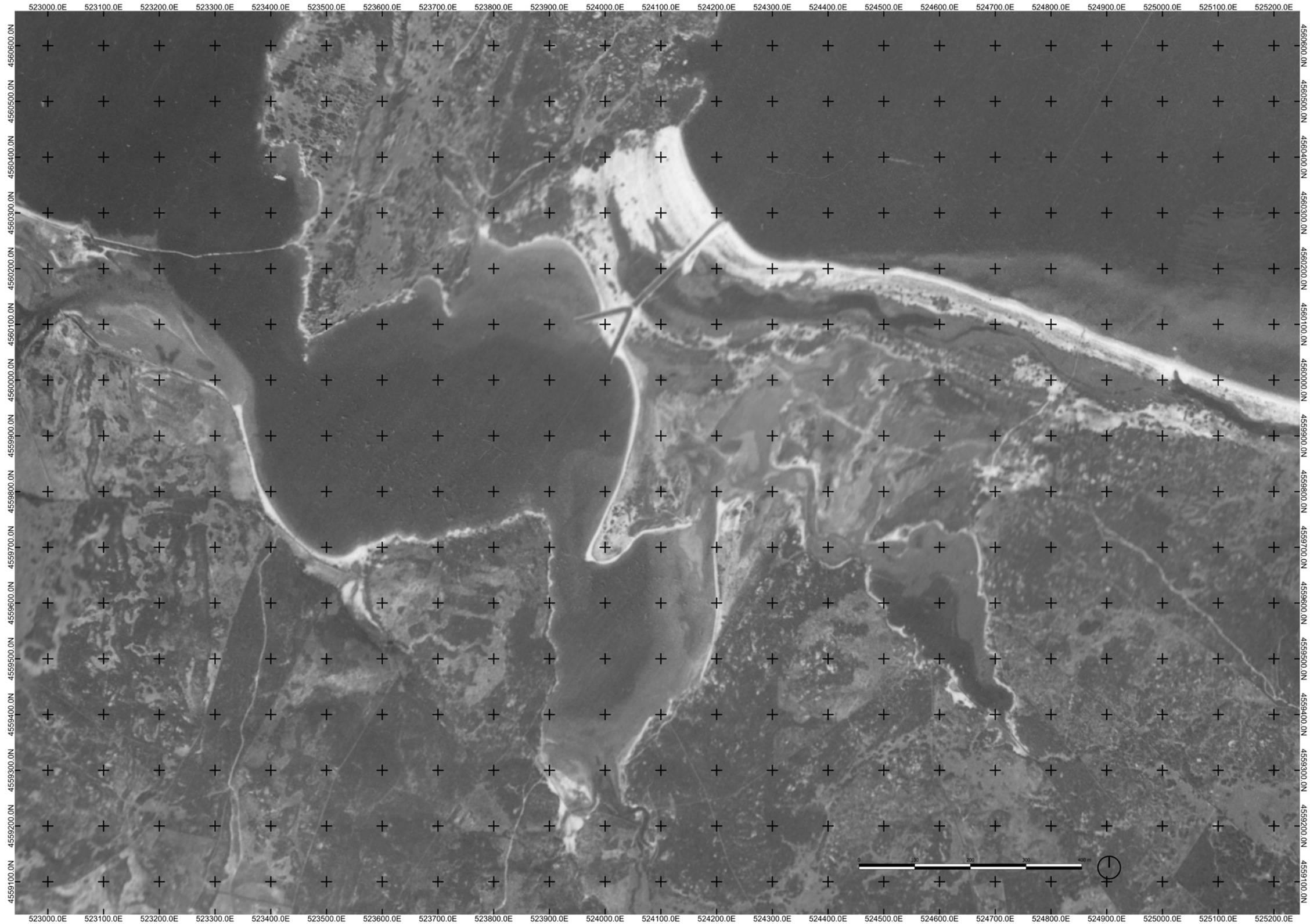
[1] *Digital Orthophotography and GIS. (n.d.). https://proceedings.esri.com/library/userconf/proc95/to150/p124.html*

[2] *"World Geodetic System 1984 (WGS 84)". Office of Geomatics, National Geospatial-Intelligence Agency.*

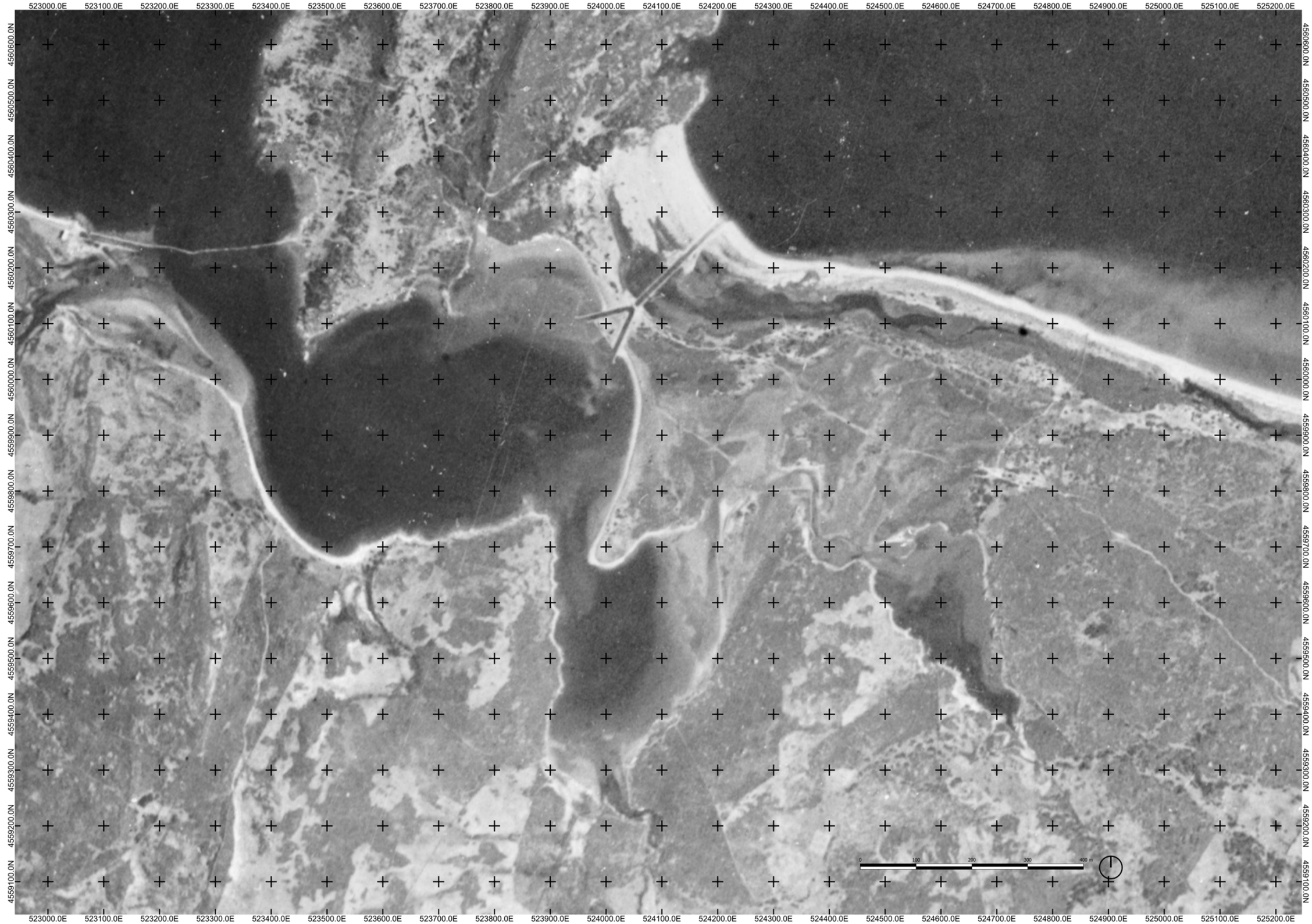
[3] *Franz Barthelmes, E. S. I. (n.d.). International Centre for Global Earth Models (ICGEM). http://icgem.gfz-potsdam.de/home*

[4] *Luhmann, T., Robson, S., & Kyle, S. Close range photogrammetry: Principles, techniques and applications.*

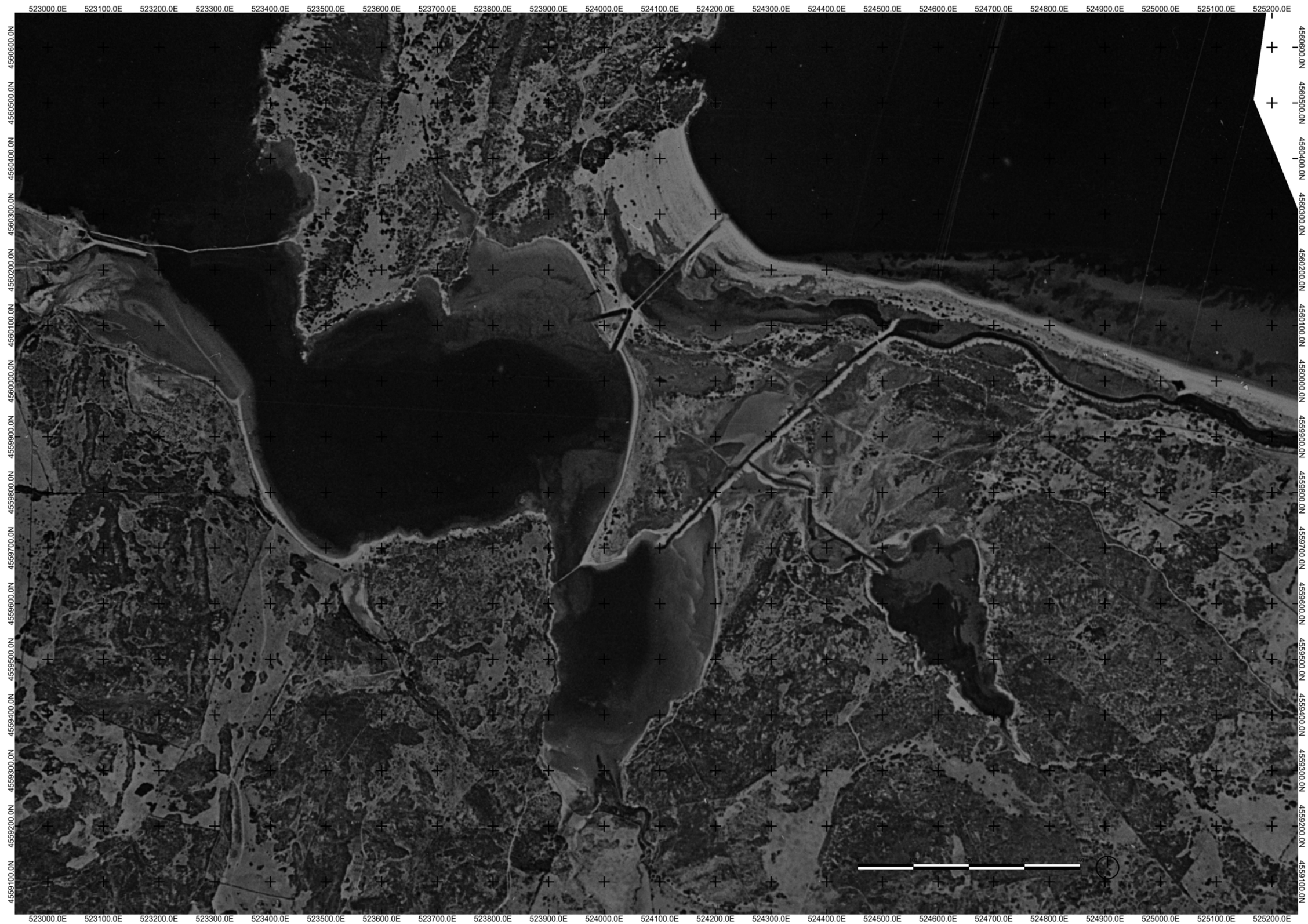
5. Orthophoto 1939 *NCAP National Collection of Aerial Photography*



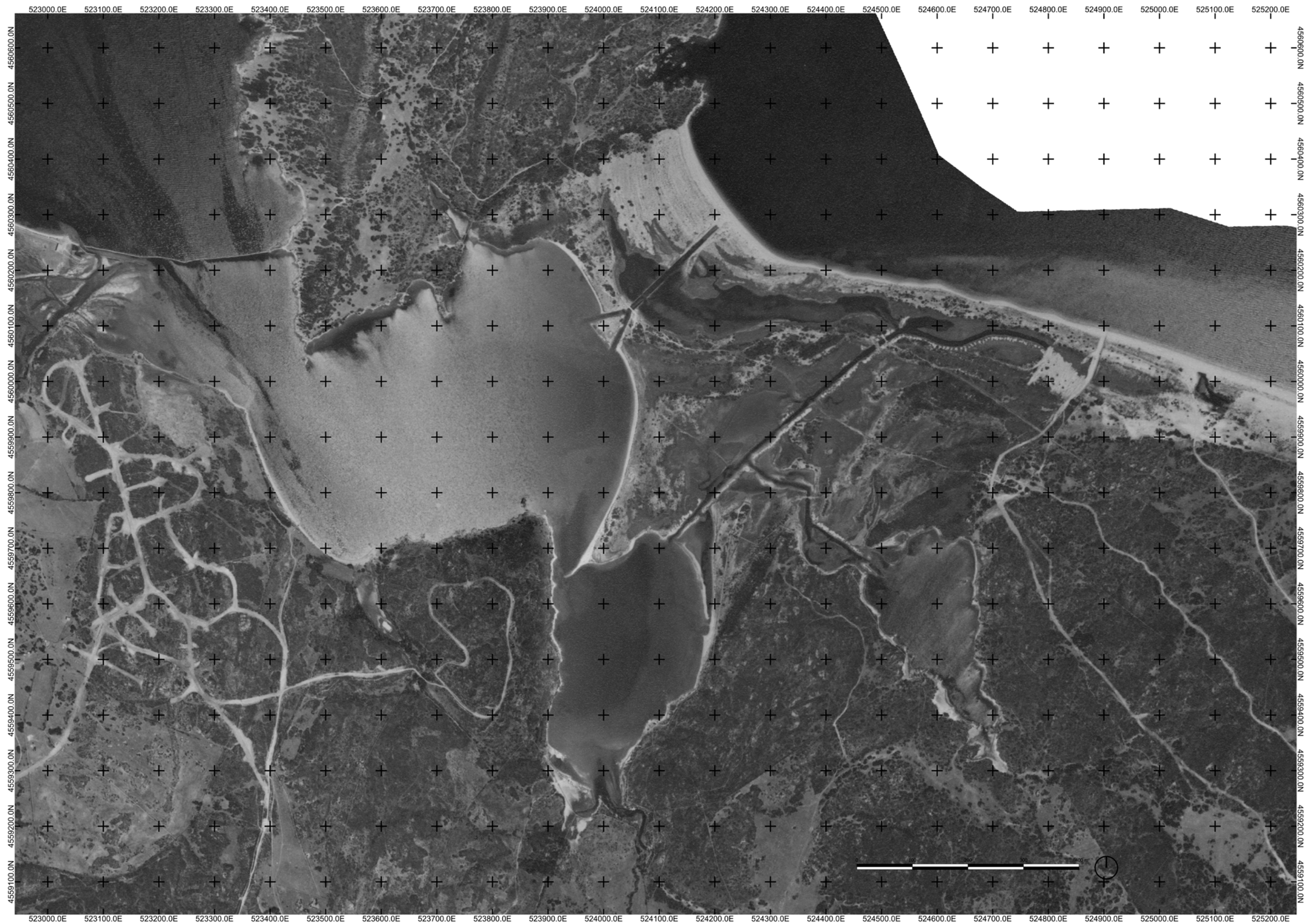
Orthophoto 1940 *NCAP National Collection of Aerial Photography*



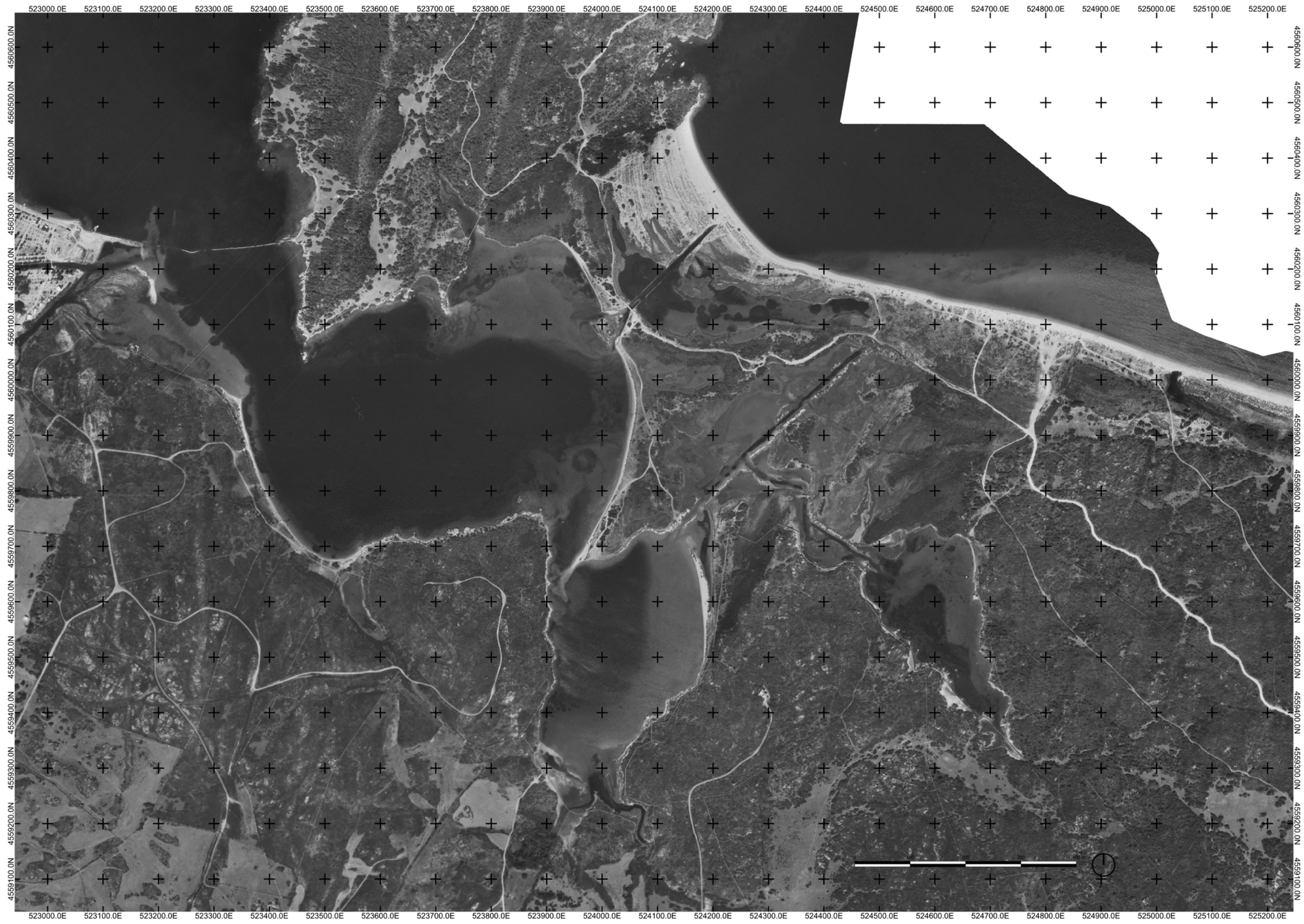
Orthophoto 1954 *IGM Military Geographic Institute*



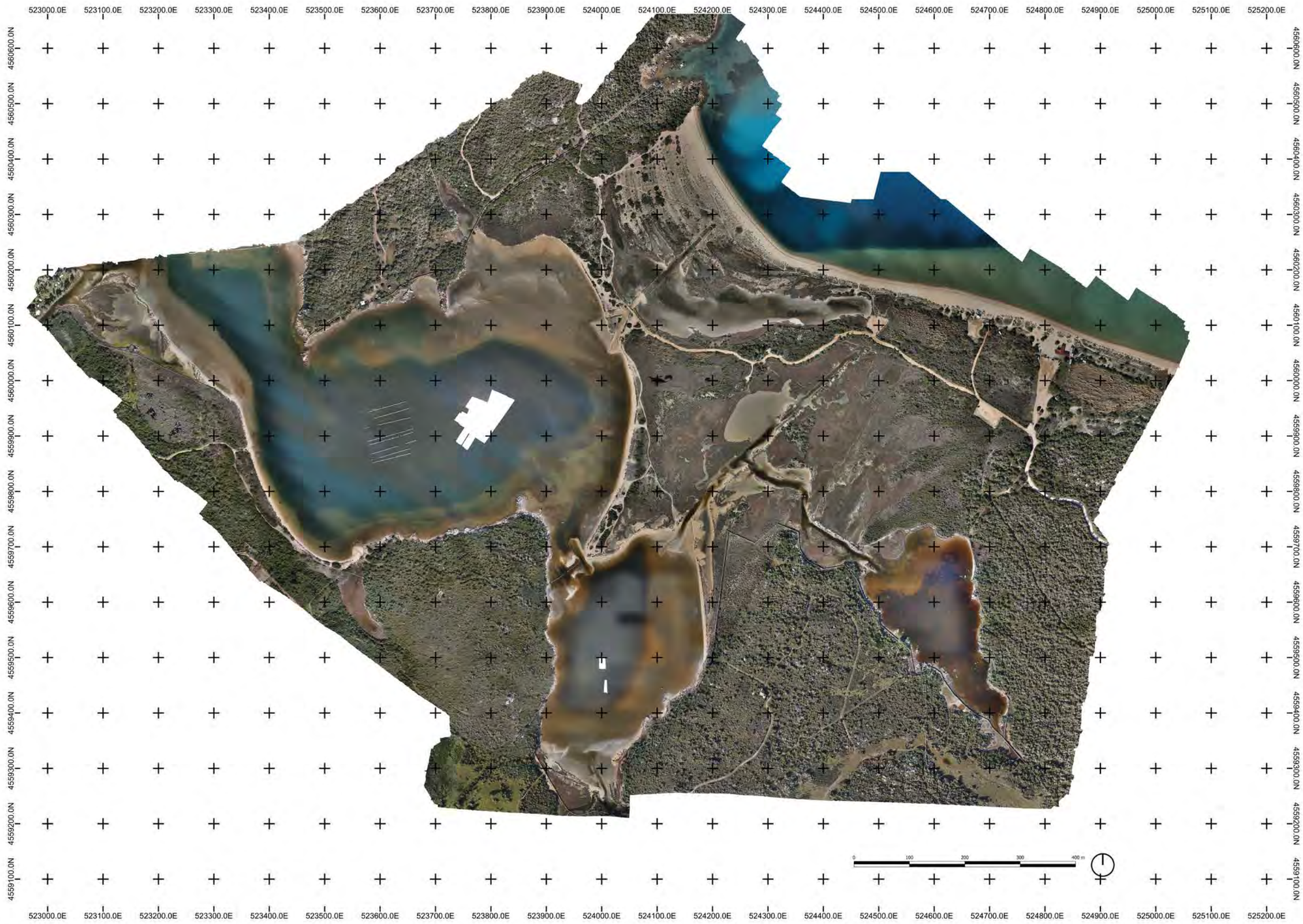
Orthophoto 1968 *IGM Military Geographic Institute*



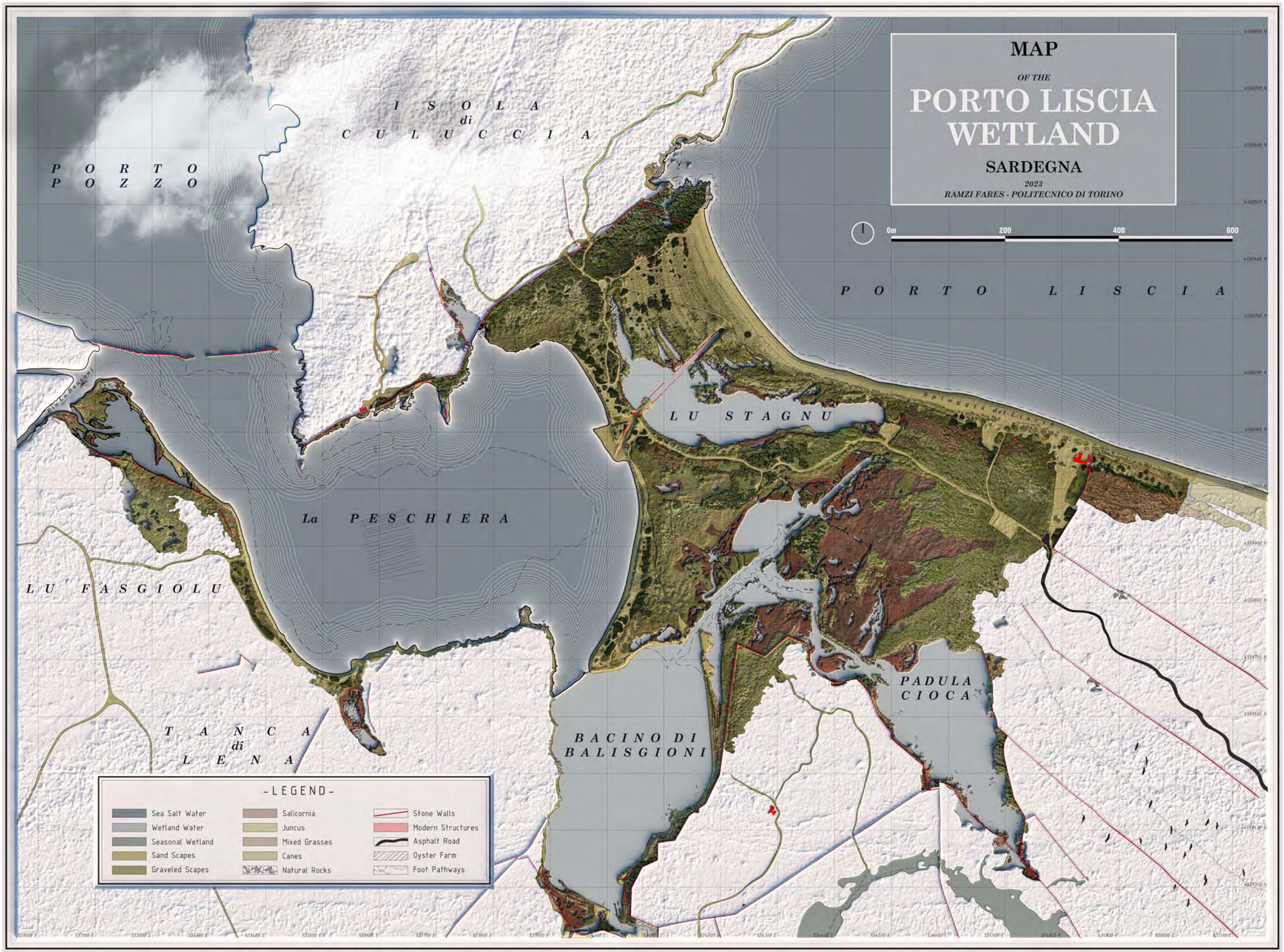
Orthophoto 1986 *IGM Military Geographic Institute*



6. Orthophoto 2023 *Survey of February 2023 - Politecnico di Torino*



7.
MAP



Graphic Texture with DSM Heightmap rendered with Autodesk 3DsMax to create a 3D map of the wetland

- IV -
FISHERMEN INTERVIEW

INTERVIEW

The following script compiles a collection of interviews held over the year 2023 with the fishermen of Porto Pozzo. The consolidated synthetic conversation aims at facilitating the reader's comprehension.

This document's value lies not only in the informative facet it holds but also in the emotional and sensitive side of personal perceptions and opinions. The gentlemen are sincerely thanked for their collaboration, particularly Mr. Gianpiero Mannoni who was born in this area and holds past and present memories of the place, and whose outlook is greatly cherished.

Section 1: Property

. Question 1:

"According to you, let's say, before the current consolidated system of governance existed, before the digitalization of maps, was it difficult to make accurate maps? Were the stone walls that delimit boundaries the only indicator of property?"

Answer:

"Alright, now I have to say something that might contradict itself. First, the mapping techniques were much more of a tedious work than they are now in my opinion, because currently, thanks to aerial photogrammetry and GPS, you don't need to make precise maps anymore in the old-fashioned way (vectorial and pictorial maps). However, formerly, when there was the IGM, the Military Geodesic Institute, the maps were extremely accurate, much more than what people back then were aware of. Nevertheless, these maps couldn't be updated every year, so once the map was made, if there was a modification later on, that modification would be recorded in a document, and that document would become an official record. Then, twenty or thirty years later, you see that the wall that was here now appears to be there. And then people will start to wonder: "Well, it must have been an error from thirty years ago!". And that passes through the bureaucracy and the ignorance of people who did not know exactly what happened.

So, in this sense, you have to consider the factors of time and productivity. An owner might think in this manner: if my wall was here instead of that position, I would have more square meters to build a house, and the municipality would give me authorization to build. Hence, it's better for the wall to be where I want it to be. And for this reason, people used to move these walls bit by bit to enlarge their property when no one was watching, or after the documentation had already been realized."

. Question 2:

"There is a sentiment of very possessive privatization that I can perceive all around this territory. What is in your opinion the root cause of this large-scale phenomenon?"

Answer:

"...Well historically speaking, if you look all around the landscape, you have these contraband hidden enclosures, near rocks and such. I am sure you have seen some of them at Culuccia, they were very active during WWII. But long before that, Corsican inhabitants, for reasons I'm not aware of, couldn't stay in Corsica and came here. A new population was thus formed, characterized by isolationism, each building their own "stazzu" (typical rural type of settlement in North Sardegna).

Each defended their small territory, and within it, they were kings, but also ruthless. These settlers survived by relying on illicit trade, what we call smuggling, as they knew the seas and could reach anywhere along the coast, even up to Vignola (province of Modena) and beyond, about 20 km beyond Santa Teresa, where there was a continuous row of smuggling ports.

Historically, we know from documents that the last family to manage this smuggling was the Mannoni brothers, who lived in a natural fortress called Giunchizza, the last of the Cinque Denti mountains, which extend from Luogosanto to Lientu. The hills surrounding this territory were where this family had taken refuge. They could consist of around 400 people, just to give you an idea.

During this time, captain Pietro Francesco Maria Magnon, a Frenchman in the service of the Kingdom of Savoy, was sent here because they realized that this smuggling, which wasn't economically beneficial to the government, needed to be stopped. However, attacking the smugglers directly would not be effective, as they would just reclaim the territory after a battle. So, they came up with a different idea: urbanizing the area and inviting settlers to form a new village."

February 2020 - Azienda Agricola Culuccia

Stazzu "Biru" - Culuccia Island

Section 2: Network of walls

February 2023

. Question 1:

"When retracing the whole area I noticed peculiarities regarding the stone walls that are sometimes delimiting water from land, or different plantations from each other, or even linking several larger ground-embedded rocks with each other... Could it be that one reason behind them is to contain the wetland, so it no longer grows, or perhaps in opposition, to shield the wetland with its different species like the edible Salicornia?"

Answer:

"This beautiful ecological perspective did not exist; so, if there were walls, they were probably built to contain livestock, to prevent them from moving. We know that cows can calmly swim across the basin, so when someone had livestock grazing in these areas, they tried to build boundaries; otherwise, they would in reality escape. In the past for example, when cows from here went for reproduction, the bulls from Conca Verde escaped, reached them, and then the owners had to go around to recover the bulls that mated with cows of lesser value. Here, brown Alpine cows were born...

The former owner of the Culuccia island (more precisely peninsula) "Ziu Agnuleddu", was always concerned that his animals wouldn't go to the Salicornia of the wetland and then disperse, thus not being able to find them. So, when he closed the whole perimeter of the peninsula with walls, he did so to avoid losing the livestock.

Most probably, some other walls are not containers. They could be edges of a road or an ex-embankment of a road; the walls would be built in a manner to prevent the road from collapsing because the stones hold the sand..."

Question:

"And what about the interesting feature of walls linking several large bed rocks together?"

Answer:

"Ahh! I remember a surveyor from this region will tell you that he used to roam in the countryside with his father. He always recalls the words of his grandfather who used to go into the field; imagine walking in the midst of meadows or forests, opening a path with a pickaxe to reach a round stone. From that stone, looking in the direction where you see another significant one lies the wall. That's how the boundary between one land and another was achieved."

Question:

"This is very important for me because I noticed that most walls are like... let's say, a larger stone linked to another, a connection between two large unmovable visible points, and that made me question why most walls pass through a significant piece of bedrock, now I have an answer to my observation."

Answer:

"Yes, but not only that; sometimes the boundary is not a physical link between two rocks, but it is also the virtual line that exists between the two. When the owner of a land died, you should learn that when these lands were divided, they gave each child for example 100 hectares. Then one of these people passes away, and let's say had two children, each child gets 50 hectares. Then the two children have four children each, but four of them in total are going to study, and they don't care about the land and above all are not going to invest in erecting a 2 km wall for example and paying thousands of euros. Here lies the necessity of virtual boundaries between fixed points. Furthermore, you can have one considerable rock as well in the property, on which you can stand and look towards another permanent natural feature like a summit of a mountain or a certain area and within your vision field you will have your boundary line."

Question:

"So, I can conclude from your discourse that in the cadastral management of lands, the safest way to erect a wall that cannot be moved later on was about finding large natural soil-embedded rocks and linking them together either actually doing it by placing stone blocks or through a more economical approach by having a virtual cadastral line between two points on the ground?"

Answer:

Yes, yes exactly... Remember that the necessity in the end for walls was most importantly to herd domestic animals like cows from roaming free outside a property or reaching to the sea water.

. Question 2:

"Within the walls' framework as well, I am interested in these two little enclosures that hold an impressive richness in fauna, and it seems to me that a boundary of walls was erected to try to enlarge the property by reclaiming land from the sea? However, it seems to me that this did not work well so far since the water still intercepts the 2 ponds. Do you have any comment about that?"

P1

P2

February 2023

Answer:

"Well, we had an experimental fisherman who meddled with this wall because the wall (P2), which is now fully rebuilt by the "Curungiu" brothers (family of construction workers in the region), had collapsed earlier. So, what he tried to do was create a lock: when water entered, the fish would gather inside, and he could enter, pick the biggest fish, and catch it. These were quite primitive constructions, but they utilized these areas, which were semi-humid, sometimes filled with seawater and other times completely dry and they could drive on them. The same goes for the other side."

Question:

"So, are they fishing walls here, "lavorieri"? "

Answer:

"No, they didn't build walls essentially for fishing; these walls were dividing the lands. However, it resulted in having fish sometimes, nests for ducks, coots, and other animals. Back in the day, people used to go hunting for these animals, which could be found there, different species of ducks.

These walls around areas where shallow water ponds exist, used to enclose small mullets. When they found schools of young mullets not big enough for sale, they closed them sometimes in these areas for some time to grow before selling them. These were natural pools, natural tanks, basins used by those who fished here. But you'll find very few traces of this because the fishermen

who did this had no written documentation of their work and results."

Question:

"I want to bring your attention back to the subject of Salicornia because you can see that the walls here (P1) in reality engulf the Salicornia plantations. Could they have a protective influence?"

Answer:

"Nobody cared about Salicornia until the late 1990s and early 2000s. This wall you mentioned if I'm not mistaken, was the boundary for a road, yes. That road ran along the entire beach, and in the aerial photos from the '60s and '68, you can see a new road system, but now it's different because around 1968, they built a hut or a small communal building right here near this area. Now there's a house that is not finished off, because I think it was being built without any legal permit, so it stayed there for years in an incomplete condition..."

August 2023

Wall dividing the sea from pond of previous P2 zone

Section 3: Land Reclamations "Bonifica Integrale" and the "Costa Smeralda"

. Question 1:

"What was in your opinion the main driving force after the land reclamations that shaped this area and what happened after?"

Answer:

"I can start by saying that after the fascist regime collapsed, there was an explosion of surveyors roaming the area, trying to acquire land to build model areas for the Costa Smeralda. There were hundreds of them going from Badesi to beyond San Teodoro, all claiming lands for the founding of the Costa Smeralda, even though all of Costa Smeralda is a pastureland. So, there were these economic groups trying to acquire large portions of territory to create villages and develop real estate.

The entrepreneurs who acquired vast territories, of whom a huge portion were international individuals, due to various circumstances had their projects fall one by one. If I remember correctly, the son of one of the developers fell ill with something incurable. It didn't kill him, but he remained sick for his entire life. They lost interest in that area. Something similar happened to another, so he said he didn't want anything to do with that area anymore. Thus, they handed it over to managers, and the first one I remember was a lawyer named "Fonnesu" from Maddalena who tried to make these areas productive..."

Question:

"What kind of gestion did these managers envision for the territories they were responsible for besides the establishment of the pearly image of the "Costa Smeralda"?"

Answer:

"Let me give you a personal example from a time when an Italian businessman came to us claiming he would like to collaborate. "I wanted to cultivate olives" he said. You see, here we have a saying: "olive trees do not bear chestnuts." It means olives, walnuts, and chestnuts take 40 years to become productive, so if you plant them, you'll hardly benefit from their produce. I looked at this man - he was 65 years old or more - and asked him: "Excuse me, is this your job, and do you want to proceed with it?" "No, he said, I am a bank owner."

"Do you wake up at 65 and start olive production? Okay, I understand, but surely your goal isn't just to produce oil; you have other interests."

Their interest, if I remember correctly, was to create a residential area behind this hill, but it also had a productive area on the ground, things we weren't interested in, and obviously the

municipality never granted them permission because they were encroaching on the territory with unnecessary things. If you look at the exit of Porto Pozzo, coming towards Palau, they created a new development with 19 houses and a swimming pool: 19 houses in one hectare, a very small area. Many houses clustered together, and it's an activity that the municipality has never been interested in. So, all these endeavors eventually died because their goal was not to make the area productive but to profit from construction. Since this goal constantly clashed with the municipal administrations of this territory for 30 years, they couldn't get any permits, and in the end, they gave up."

. Question 2:

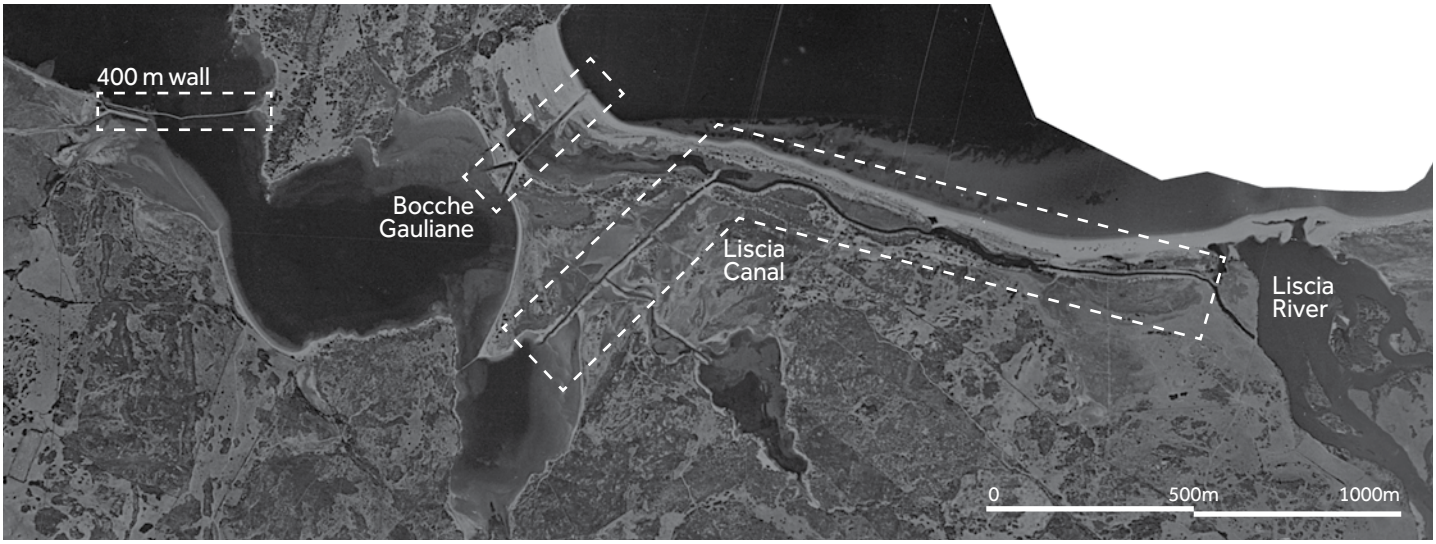
"What were the main activities happening in the wetland especially around the canals that were dug during the "bonifica integrale" period?"

Answer:

"There were families in the region living off by gathering mollusks, fishing, and so on, collecting juncus to make traps that they took to Maddalena, Santa Teresa, etc...

With around 400 meters of marine walls, the "Bocche Gauliane" (triangular canals of a fish trapping system), and here, they go towards the channel that connects to Liscia, and following all the water paths, you can still find the remnants of three or four facilities for catching eel, which were very valuable in the 1970s and 1980s, but there were probably many more...

In the 1970s, the Spiga family had set up two mussel farms, one here and one in Balisgione, with seven-meter poles, and they moved with stretched ropes through the water, so instead of using engines and oars, they took these ropes, pulling themselves from one side to the other, moving."



IGM - Ortophoto 1954

. Question 3:

"Were there any mining or excavation activities in this wetland, since most wetlands worldwide are raked for their natural resources?"

Answer:

"As far as I know, no, it's not easy to dig where there's water..."

Question:

"Was there anything valuable like minerals or metals?"

Answer:

"No, as far as I know, none of those who were here were interested in such things. Coal is the only product basically for all of Sardegna; as I mentioned before, a forest once existed here around the wetland, but it was transformed; a forest of oak that covered all of Sardegna for 270km, you could traverse all of the island from North to South under a canopy of large oaks that were all used for building the train tracks, roads and the production of charcoal. But to have a special resource of the wetland, it did not exist...

There were all sorts of trees in the region before: if you go further searching for "Corbezzolo" or strawberry tree, there's a bush nearby, but in the past the Corbezzolo trees were over a meter wide. So, all this was cut down and turned into coal. The coal was piled up on the beach of Porto Pozzo, and if you walk along the shoreline, you can still see the traces of the coal that was piled there in the 1890s."

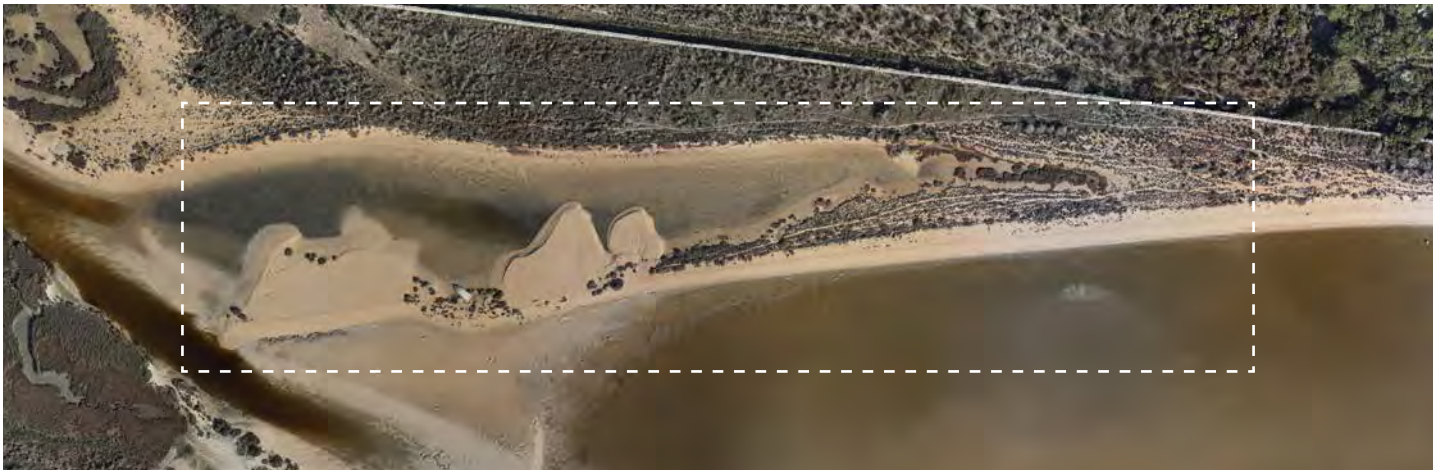
August 2023

First canal of the Bonifica with concrete borders, used to link Porto Liscia beach with the "La Peschiera" basin

Section 4: Geography and Land Morphology

. Question 1:

"I am interested in areas of the wetland that seem to me have naturally changed over time. For instance, what is the role of that area where the new natural bridge has formed in the "Peschiera"? Noting that before the aerial photo of 1968 it did not exist."



February 2023

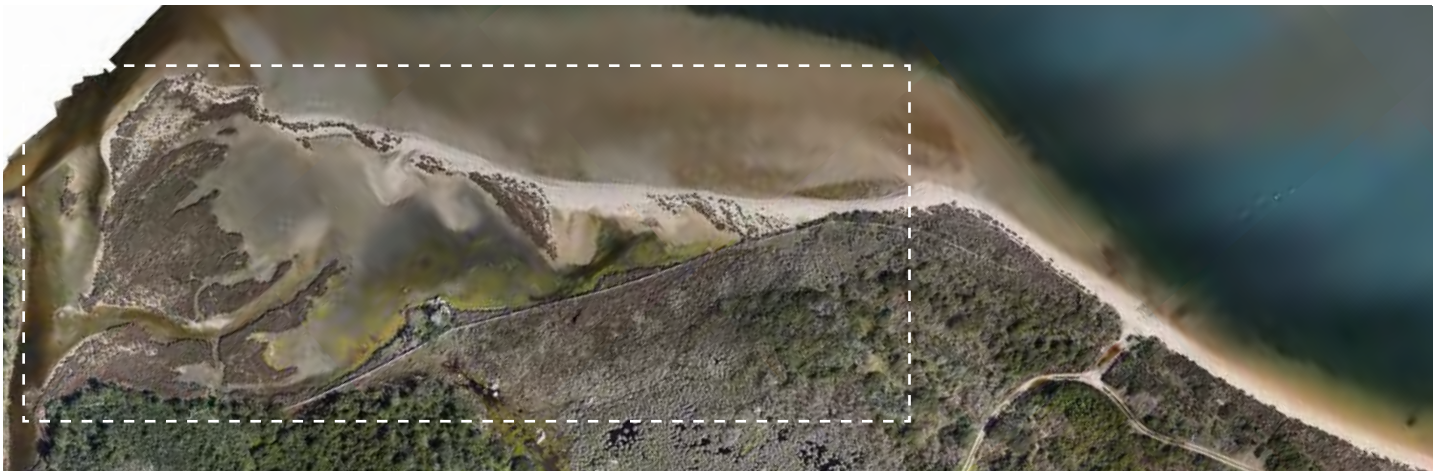
Answer:

"This wetland was always known to be an area of hunting, raking and juncus cultivation. In July, during the blooming of the juncus, the harvesting process involved carefully gathering the female part. It was essential to use a straight pulling technique to prevent any bending that could result in damage to the plant. The edible and prized white roots, slightly below the surface, would be gently detached. The tall thorny reeds instead were then gathered in bundles of approximately 100 pieces and set aside for drying. When unfavorable sea conditions persisted for a month or two, marked by strong winds preventing fishermen from venturing out, they spent their time weaving and building fish traps or "lavorieri" from these tall reeds.

I've seen traps with lengths of 2 and a half to three meters, even things that wouldn't fit here (in his workshop), and they were used to catch lobsters, sea breams, and mullets. They were made with reeds of Juncus, more resistant than the ones made with canes, lighter, and more convenient to carry. Also, they were more precise in size, so you could load the boat with a huge number of traps. You could remove the lid part of the boat and stack them one on top of the other, ending up with a pile of 20, 30, or even 50. The excessive raking occurring in that area in search of mollusks and clams, and the juncus ''lavorieri'' production resulted in a mobile soil that with currents led to the formation of this little internal peninsula."

. Question 2:

"What about the other peninsula that was formed near the Riu Lu Banconi in the peschiera, is it natural or due to anthropogenic influences as well?"



February 2023

Answer:

"This area I can inform you about from direct knowledge and it is called "Lu Fasgiolu". When we first discovered it, there was a drain opening of the sewage water of Porto Pozzo before they closed the sewer pipeline that connected all the drains from San Pasquale and Santa Teresa. Before this line was closed about twenty years ago, Porto Pozzo had its own small wastewater treatment plant. When the water filled up, it flowed down creating an impressive waterway and also a significant flow of water. This water pushed the sand and sediment, and the area was gradually formed.

There was water here, but not as thick as it is now, because when it flowed down, it penetrated through a dense cane thicket that was so intricate that even wild boars couldn't pass through. You can imagine, the common reed grows with the water, you give it water all year round, and it becomes a block of canes, which acts as a natural filter. It blocked everything, leaving only the purified water."

Question:

"So, all of this was canes?"

Answer:

"I think the canes have dried up since they closed the sewer line and the water stopped. The shape it took is that of a bean, hence everyone called it ''F A S G I O L U".

The younger generation say it was because it has the shape of a bean. The old ones say otherwise that there was a bean field nearby, and this bean field was placed on top of an ancient Santa Maria cemetery."

. Question 3:

"In the evolution maps we can notice that diverse shorelines, especially the Liscia shoreline, have dramatically changed their boundary, is this natural or anthropogenic, because I hear many contradicting stories?"

Answer:

"Yes, it's entirely natural. Back in the 1930s, the beach was thinner and now it has extended. The currents and winds push the sand; there's a lot of sand for hundreds and hundreds of meters. The currents, I can't explain it in detail, but it's the movements due to the tide and the wind. When the west and northwest winds lift the water, they also lift what's on the bottom. On the other hand, the northeast and east winds press the water down and press what's on the bottom.

If you put yourself faced with mistral winds (strong, cold, northwesterly wind that blows from southern France) you see the foam rising, the foam above the crest of the waves, while if you place yourself in front of the east with the same intensity of wind you see the sea choppy but smooth, there is no foam because the pressure is squashing the water on the surface...

This area holds over a hundred years of history. Some stories are true and verifiable, some are legends difficult to verify, and others are just intuitions. You see something and sense that something might have happened, but searching for the truth is tiring and not easy..."

. Question 4:

"After consulting with the Naturalistic Observatory at Culuccia and other experts, I came to learn that the "Padula Cioca" the most retreated basin into the landscape is the wildest part of the wetland, since it is far and hard to reach. From an ecological perspective, do you believe there are any threats or particular anthropogenic interference that happened in this part of this wetland?"

Answer:

"What I can say is that it's been lowering in level over the years due to the dead mud, completely useless, about 60 cm or 1 to 1.2m towards the center. This mud is due to the fact that the water temperature rises in the summer to a point where everything in the water comes out. What causes this? It's because this little basin has been isolated due to these walls that were built in the early '70s to catch eels in the area.

Question:

"I see, so the walls prevented sufficient water exchange, and the water inside was boiling..."

Answer:

"And in winter freezing..."

Question:

"You remember where the walls were?"

Answer:

"They were scattered all over the place here and there causing disruption, with small bridges sometimes, canals and roads, before they slowly disappeared... The water level inside rises and falls due to the tides. There will always be mud there because no matter how much you dig in the center it is 17 meters in depth, and you can't move the mud at that depth.

Question:

"So, do you think there is no solution for the mud problem?"

Answer:

"The solution is quite sad, but it involves excavating all that dead mud with machines and using it for something like growing reeds and other plants. In fact, the reeds grow rapidly, about 13 centimeters per day. The mud gets compacted, and the reeds form a structure like a wall..."

February 2023

Entry point of the Padula Cioca seen in the background

Section 5: Malaria and its Consequences

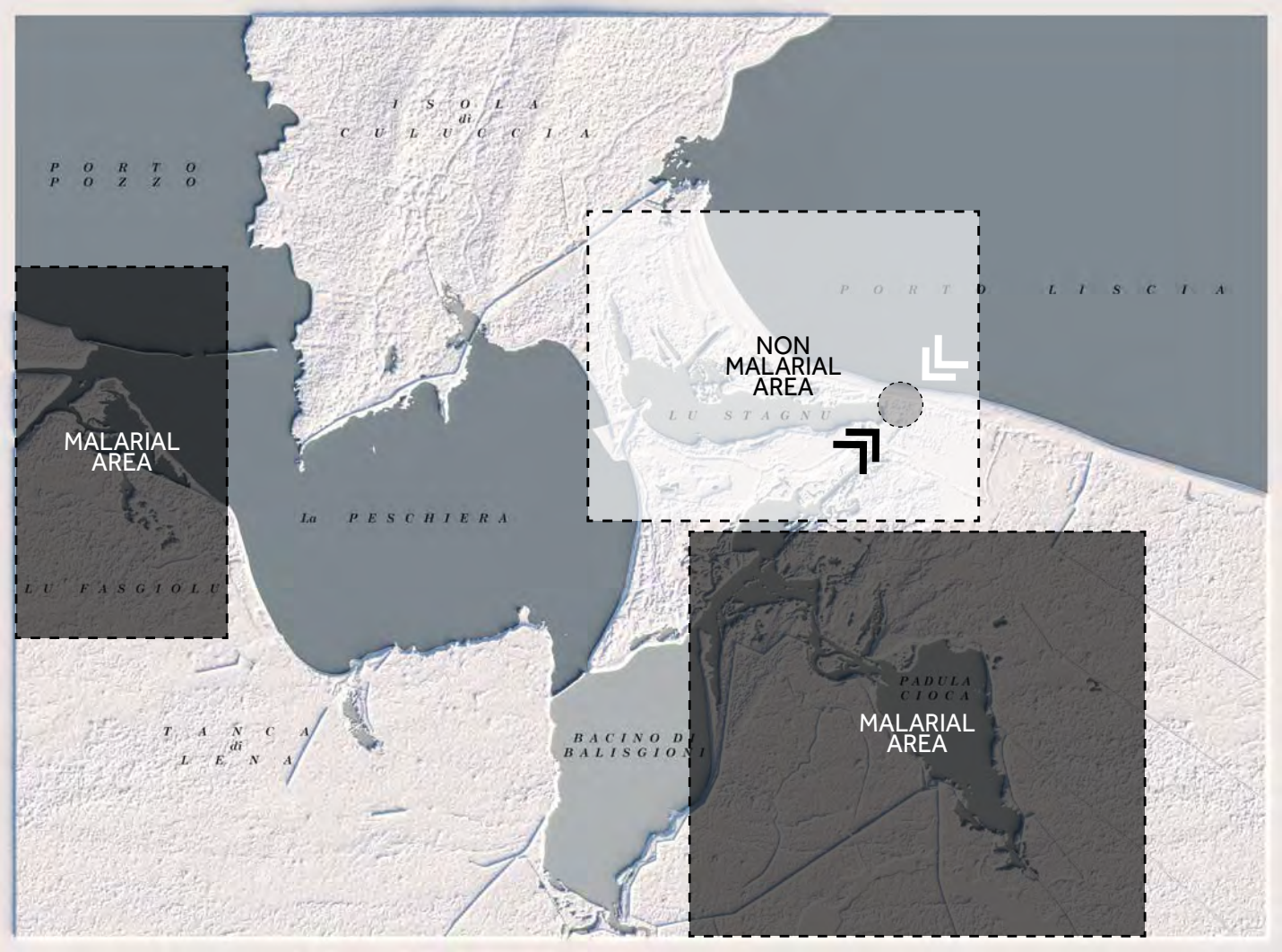
. Question 1:

"Do you recall any memory of your childhood regarding mosquitoes or malaria?"

Answer:

"I can point out for you on the map the previously malarial areas from what I can try to identify. The area beyond Lu Fasgoliu at Porto Pozzo and the eastern side of the wetland were highly malarial.

Porto Pozzo fell into the hands of too many administrators with different ideas and opportunities, and each tried doing something to improve it. Now, this isn't traceable anymore, but the beach across was originally another marshy area. The landlords of the hills nearby made attempts for a dock, a landing place for those who rented their houses... There was no beach; it was a wetland! Moreover, there were clouds of mosquitoes that were frightening... Over time, the beach was "built" with very fine industrial sand..."



Question:

"So, the sand they used is not dug up natural sand from another beach?"

Answer:

"No, it is not from here, however between the Rio Porto Pozzo and the Rio Lu Banconi, there was a bit of natural sand. The reeds of Juncus and Salicornia all vanished there because of the dumping of sand they transported from a quarry at Porto Liscia. Thanks to the laws of the 1970s, if I remember correctly, many landowners' activities here were overlooked for moving their boundaries without anyone noticing.

People are oblivious to this, but when I was a kid at sunset, from this area, clouds of mosquitoes would rise up and darken the sky, millions of them. It wasn't a matter of how many; you needed flamethrowers to get rid of the mosquitoes. I can't describe it! Imagine the leaves of these trees around us, each leaf represented a swarm of mosquitoes that would attack you fiercely at sunset.

Obviously, in a marsh you can't control the multiplication of mosquitoes because the water is confined. However, if there's a beach, the water is directly drained from the river; it flows instead of stagnating, and in flowing water, it's harder for mosquitoes to breed.

They were a problem 30-40 years ago, but now they almost don't exist anymore, still, it was not a comfortable situation in the past before the construction of the beach. Of course, they created a productive activity here and provided jobs for hundreds of people, giving prestige to the place. In the end, yes, they did something that might not be ethically correct, but it was done from a business and sanitary perspective. It's alright I guess because they didn't devastate the area for profit; they also contributed something to the territory, and that saved them."

Remarks:

While Mr. Mannoni was observing the map we were examining, he indicated a point between the Lu Stagnu and the Porto Liscia beach (specified on the diagram) that serves now as a vacant parking area. Previously in the past, the pond would open up to the sea at this point and close naturally with the seasons – exactly what still happens at the mouth of the river Liscia. The fact that he mentioned as well later on that this area was not malarial raises the inquiry about whether there is a connection between the two.

The interesting mechanisms about this place are that the pond's water used to move naturally with the seasons, and it was where the first canal in the wetland was dug. These factors likely discouraged mosquitoes that prefer still water from breeding there.[1]

[1] *Centers for Disease Control and Prevention. (2022, May 27). Where mosquitoes live.*

February 2023

River "Liscia" mouth open to the sea in winter

August 2023

River "Liscia" mouth closed to the sea in summer

August 2023

Porto Pozzo - Eucalyptus trees planted to dry up marshes

August 2023

Porto Pozzo - Beach artificial sand and basin for boats

Synopsis

The series of interviews carry immense importance as they hold the potential to unveil crucial insights. This conversation provides a unique window into key elements that constitute the physical and cultural fabric of the wetland of Porto Liscia and its surroundings.

These could be assembled as follows:

1. Architecture of Isolationism: this can be observed in the dense privatization of landscapes and property, which subdues nature to either the visions or whims of the landowners.

2. Architecture of Seclusion: vast properties become detached one from the other due to a very intricate network of stone walls that stretches beyond what the eye can reach. Seclusion in some cases weakens the place it is suffocating but may shield it in other cases from external influences.

3. Spacious Urbanism: characterized by the need to occupy as much land as possible with a non-expanding population. This stems from the need for safety and early settler subjugation to the throne.

4. Vernacular Landscape: human activities like raking for mollusks, or the presence of a significant natural disruptor like a sewage drain or anthropogenic water canals, can lead to the formation of small new islands and integrated ecosystems.

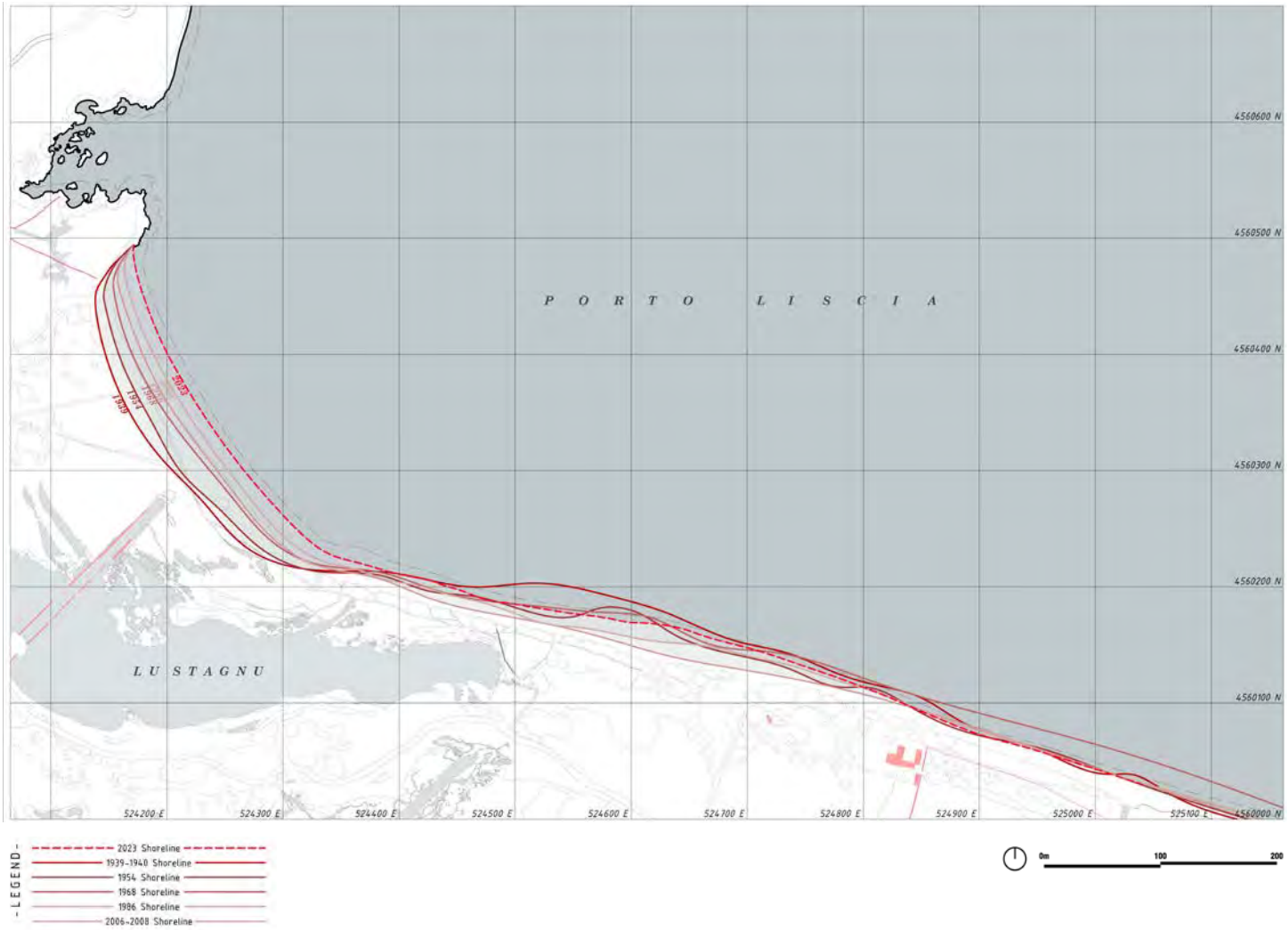
5. Resource-based economy: activities such as fishing, raking, harvesting, foraging, and hunting are all primitive activities that tend to extract what nature supplies. The fact that more significant economic mining entrepreneurship is lacking is solely due to the fact that those kinds of resources are absent.

6. Utilitarianism: which is already partially covered in the preface, that seeks in brief at domesticating a wild setting to render it useful. Since this land is squeezed by surrounding sea water, this makes it unfavorable for agriculture. Therefore, it has always been and remains to this day a place for gathering and fishing, as explored in the previous point.

7. Disease and Sanitarianism: these are obviously due to the past presence of Malaria and mosquitoes. The motives behind the bonifica integrale into reclaiming as much Italian land for agriculture or combatting the lethal insects translated in action into the carving of straight canals that stir the stagnating waters of the marshes. From a broad perspective, they colligate different water bodies which facilitates movement, and from a more obscured perspective they lead to a permanent agitation in the waters which makes it unpreferable for mosquitoes to breed.

- V -
ANALYTICAL EVOLUTION SCHEMES

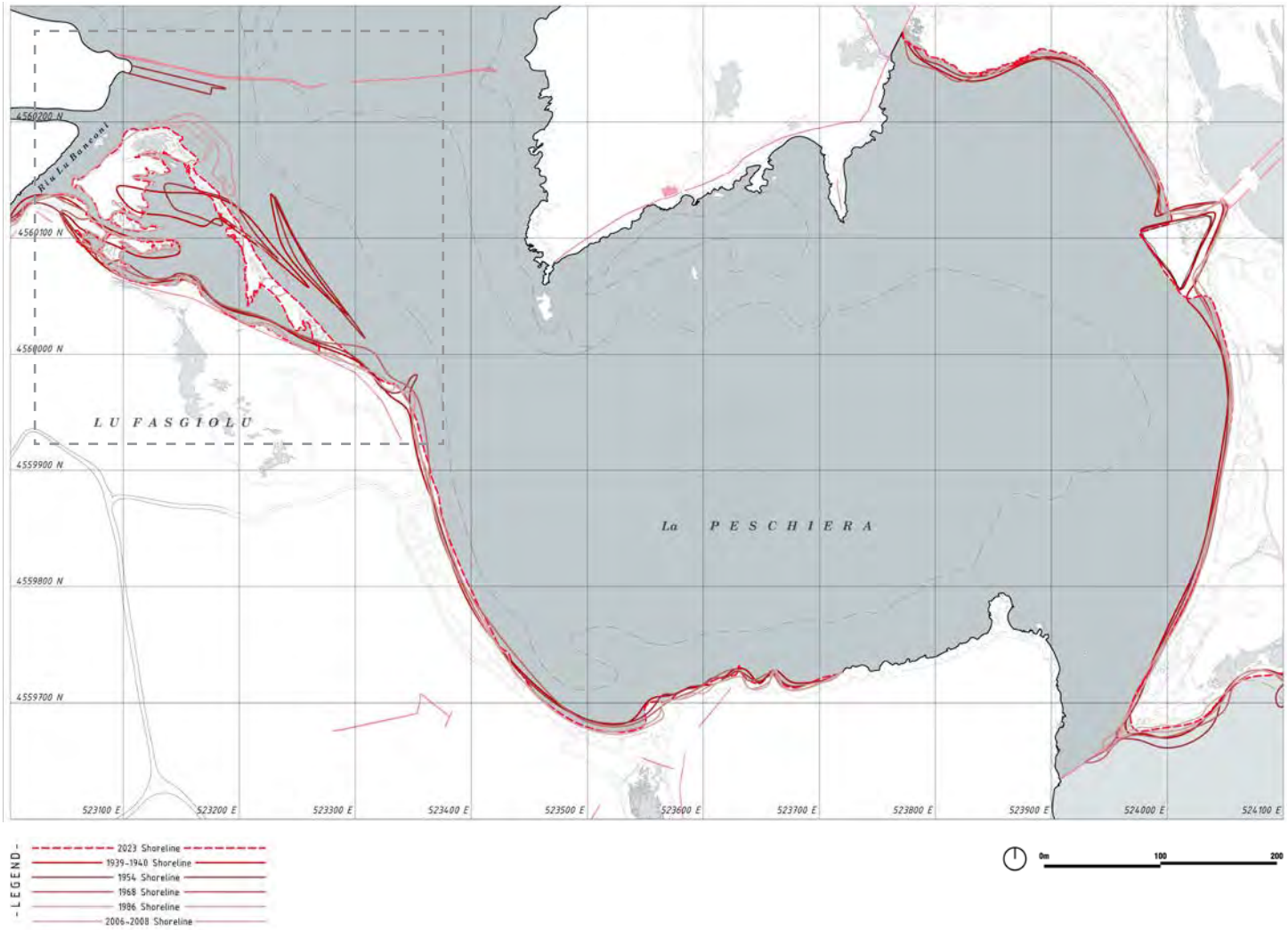
Section 1: Porto Liscia Beach Evolution Scheme



What can be noted from this scheme is that the beach width increased with the years from the oldest orthophoto in possession that dates back to 1939. In particular, the sand in front of the "Lu Stagnu" was expanding towards the sea following steady intervals approximating 10m each, and for a total of a 50m average.

Most residents agree that since the sand is of natural quality, it must have all happened through natural tidal movements. However, few think that some people could have been secretly transporting sand from neighboring beaches to increase the size of this one in particular.

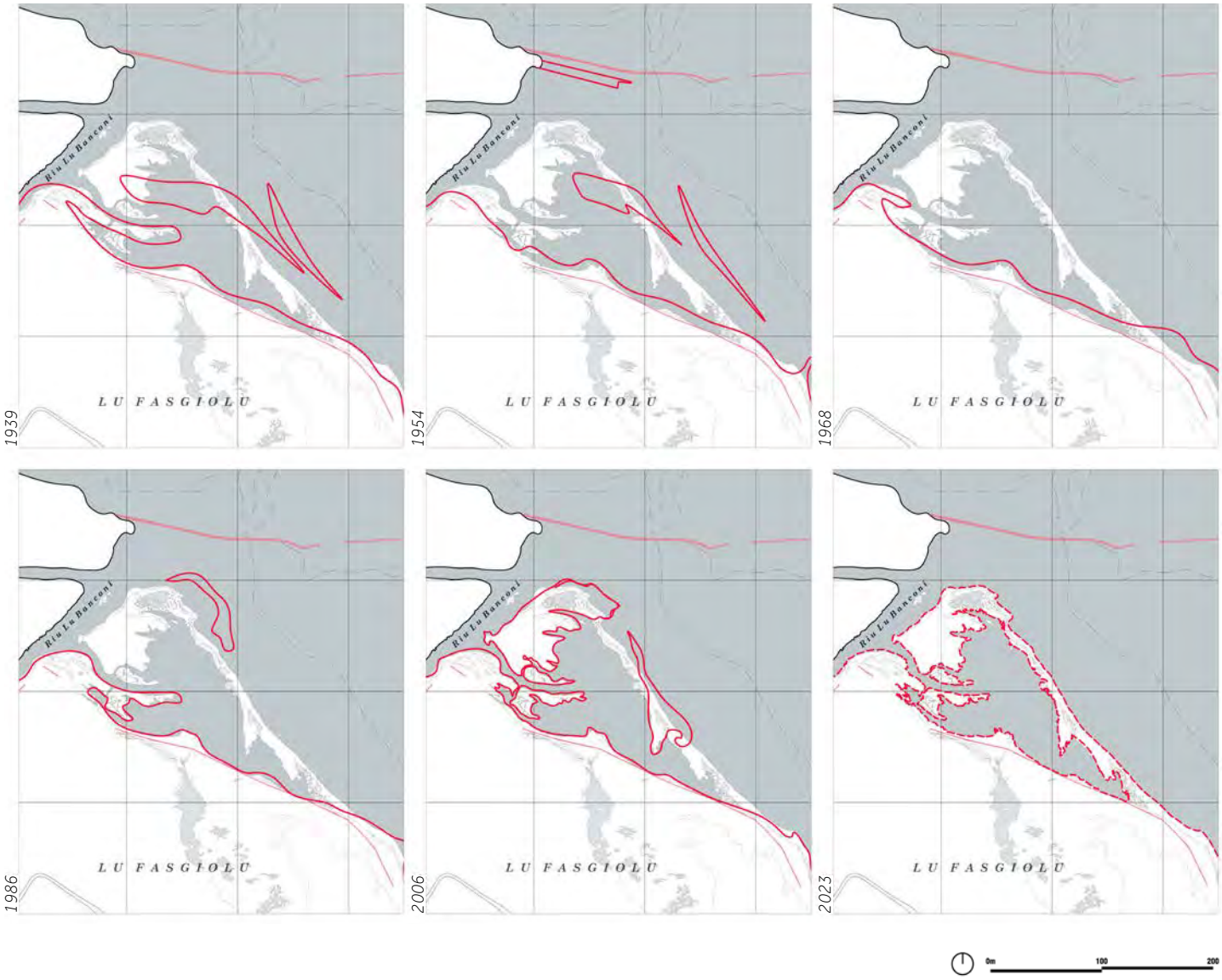
Section 2: La Peschiera Evolution Scheme



This area exploited chiefly as a fishing basin, presents little remarkable changes in its shorelines. Nevertheless, it holds the "bocche gauliane" which were dug with the canal linking it to Porto Liscia. These features (bocche gauliane) are the triangular system of waterways seen on the east of the basin which were used by fishermen to lead fish from one side and trap them from the other.

The most notable area of change however in this basin is the area called "Lu Fasgiolu" at the west, near the "Riu Lu Banconi" river opening. It was a mass of sediments that were constantly swirling throughout the years to finally take the shape of a bean (fagiolo in Italian). According to the previous interviews, besides being at the mouth of a river, a municipal sewage drain was discharging its waters in that position, which was causing all the disturbance at that spot.

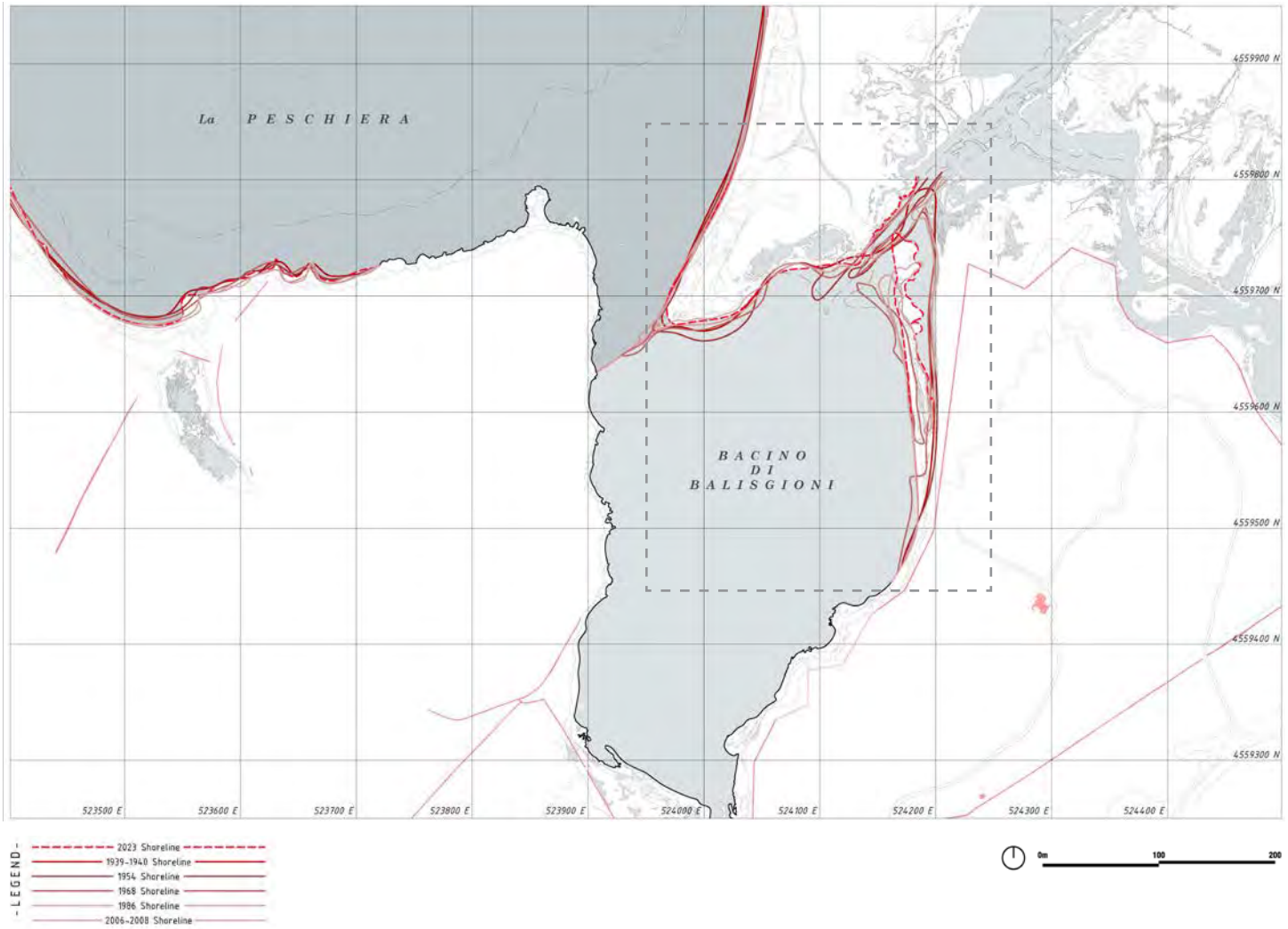
Section 3: La Peschiera " Lu Fasgiolu" Evolution Scheme



The diagrams directly above portray the outline the sediments were taking since 1939 in comparison to the base map of 2023. Besides taking at the end the shape of a bean, another interesting feature which fell into place is the natural bridge that began to form recently starting from the scheme of the orthophoto of 2006, linking the bean to the land section of "Lu Fasgiolu".

It is also worth noting that in the scheme of 1954, north to the "Riu Lu Banconi" outlet, an attempt at a small pier for boats was constructed with little to no observable present traces. It also hosted a cubic "camera di morte" literally translating into "death room" for trapping fish, according to Mr. Mannoni.

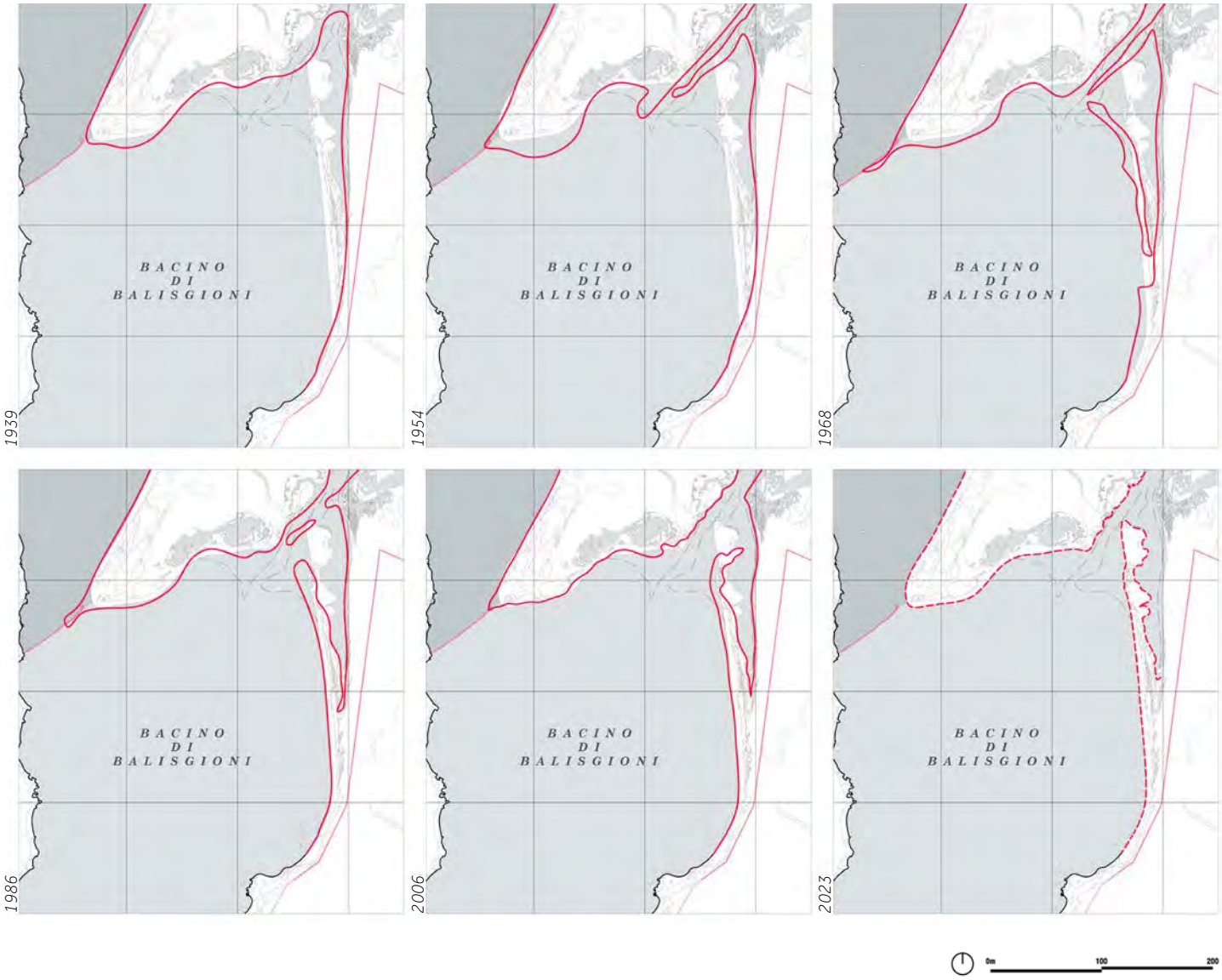
Section 4: Balisgioni Basin Evolution Scheme



This retracted basin shows absolutely no evidence of morphological change in its central and southern part, mostly due to its withdrawal within the landscape and its perimeter that holds fragments of embedded rocks.

In contrast, its northern eastern section, the closest to the heart of the wetland, is where a sequence of variations can be witnessed. According to the previous interviews as well, this area was always high on raking and foraging activities which resulted in mobile sediments that deposited in a manner following the movements of the water to form the thin natural peninsula.

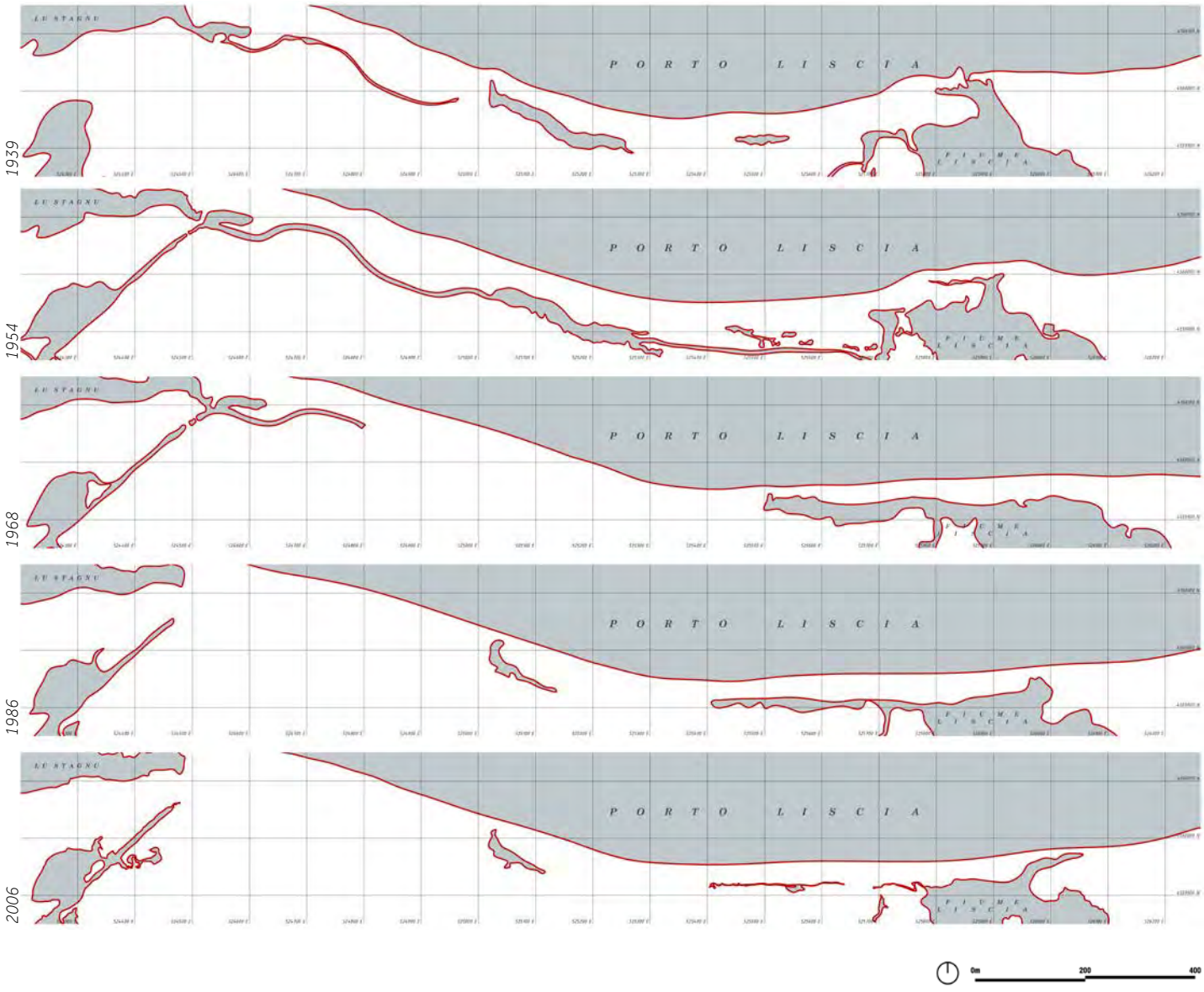
Section 5: Balisgioni Basin "Artificial Peninsula" Evolution Scheme



The artificial peninsula can be observed beginning from the orthophoto of 1968. The justification of the fluid sediments is previously covered. However the inclined shape it took, taking its distance at the top and approaching the land from the south, is owed to the second canal that was unevenly bending the residues with greater force at the top.

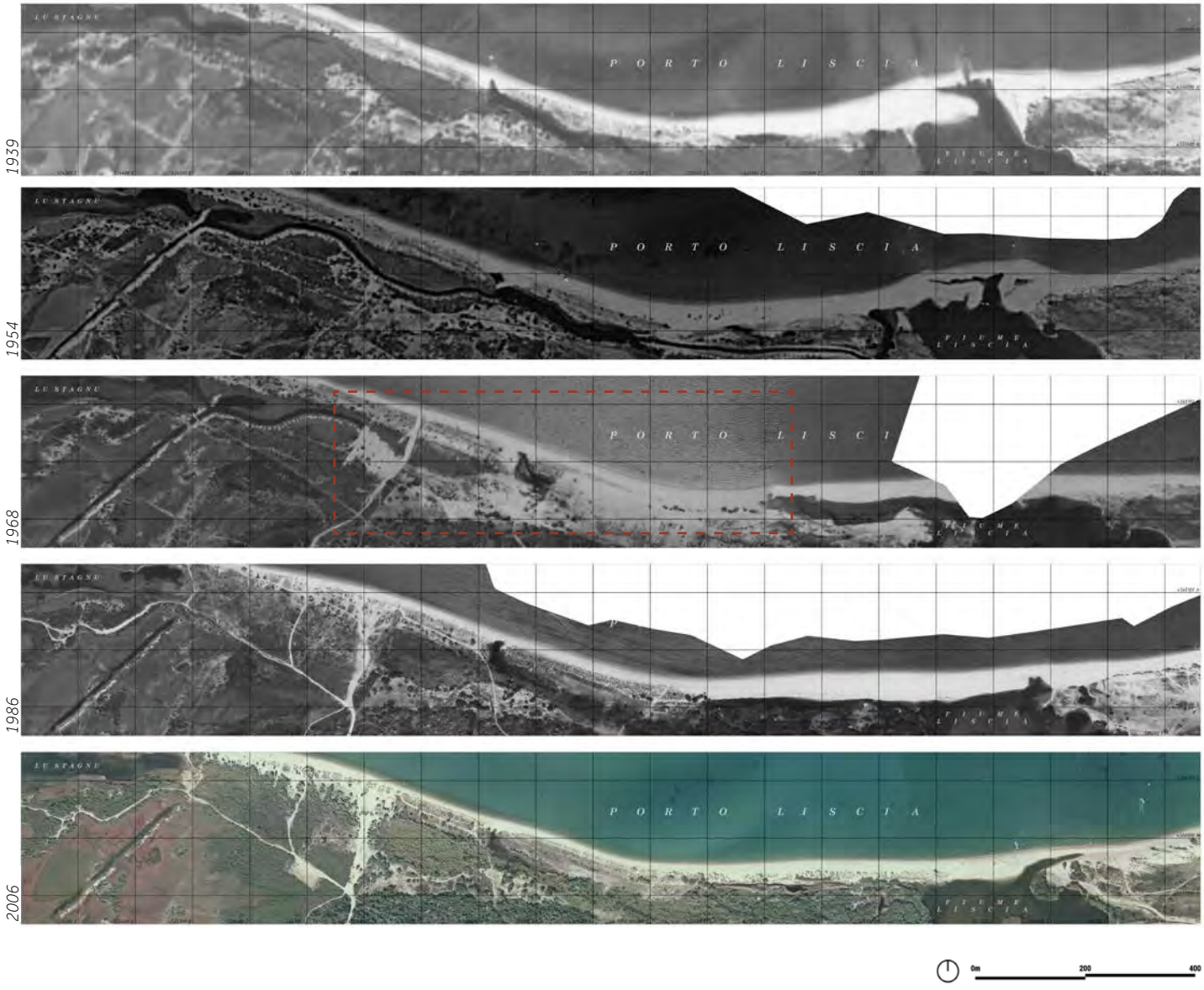
The evolution of the second canal is examined in the next scheme.

Section 6: Liscia Sweet Water Canal Evolution Scheme



Initially, "Lu Stagnu" was connected to the river Liscia by a series of natural canals and small ponds highlighted in the first scheme and which can be observed in the orthophoto of 1939. These canals were widened as seen in 1954 adding a second straight canal that pierced through the wetland connecting all basins together and streaming sweet river water into the marshes.

What happened next was a series of abrupt closures observed in the following diagrams and orthophotos. Particularly in the orthophoto of 1968, traces of an anthropogenic layout of sand can be noted. The arrangement these sands took is comparable to that of the work of construction sites. According to locals, the seaside was widened to allow more people to pass through.



However, according to the "Consiglio Regionale della Sardegna" the canal filled up with sediments after the construction of a dam on the river around 1960, which reduced the water supply of the river into the ponds of the wetland. They mention as well that if these vents were to be reopened, it would increase the salinity at the mouth of the river making it preferable for juveniles and valuable species of fish.[1]

[1] *Consiglio Regionale della Sardegna. Lagune in Sardegna: una Risorsa, 1981*

February 2023

Canes growing on the previous site of the canal behind the dunes of the Liscia Beach

Canes or cane grass only grow in damp soils of either fresh water or of moderate salinity.[2] After conferring with the Naturalistic Observatory at Culuccia, most probably a decent amount of underground fresh water is most likely still seeping through all along the old canal allowing these canes to thrive.

[2] *CABI, 2020. Arundo donax (giant reed). In: Invasive Species Compendium.*

- VI -

DESIGN INTERVENTION WASTELAND TO WETLAND

1. Introduction

For the closing section of the thesis, this part is dedicated to developing an adequate design solution in the light of the body of data that was collected and analyzed, and notable design or landscaping theories. Thus far, sufficient information has been gathered to start formulating hypotheses. However, the significance of the material in relation to conceptual rationale is still missing. Consequently, the introductory portions of this section shall deal with theoretical notions in relation to the natural object under study being the wetland, and the user approach to the site be it previous, current, or future.

For the sake of categorization, noting this study as a time-defining reference, the past attitude of users is thus related to all notions of previous philosophical & operative currents that directly or indirectly affected people's interpretation of nature, and in particular a disregarded wetland. These currents can chiefly be summarized under the umbrella of utilitarianism and sanitarianism. However, when the user-object relationship is mediated (person-nature connection), the proposed design can try to alter or improve this relationship in order to advance with a contemporary vision that should safeguard the wetland and ensure its future survival.

2. Utilitarianism & Sanitarianism

Jeremy Bentham, philosopher of modern utilitarianism, defined "utility" as follows:

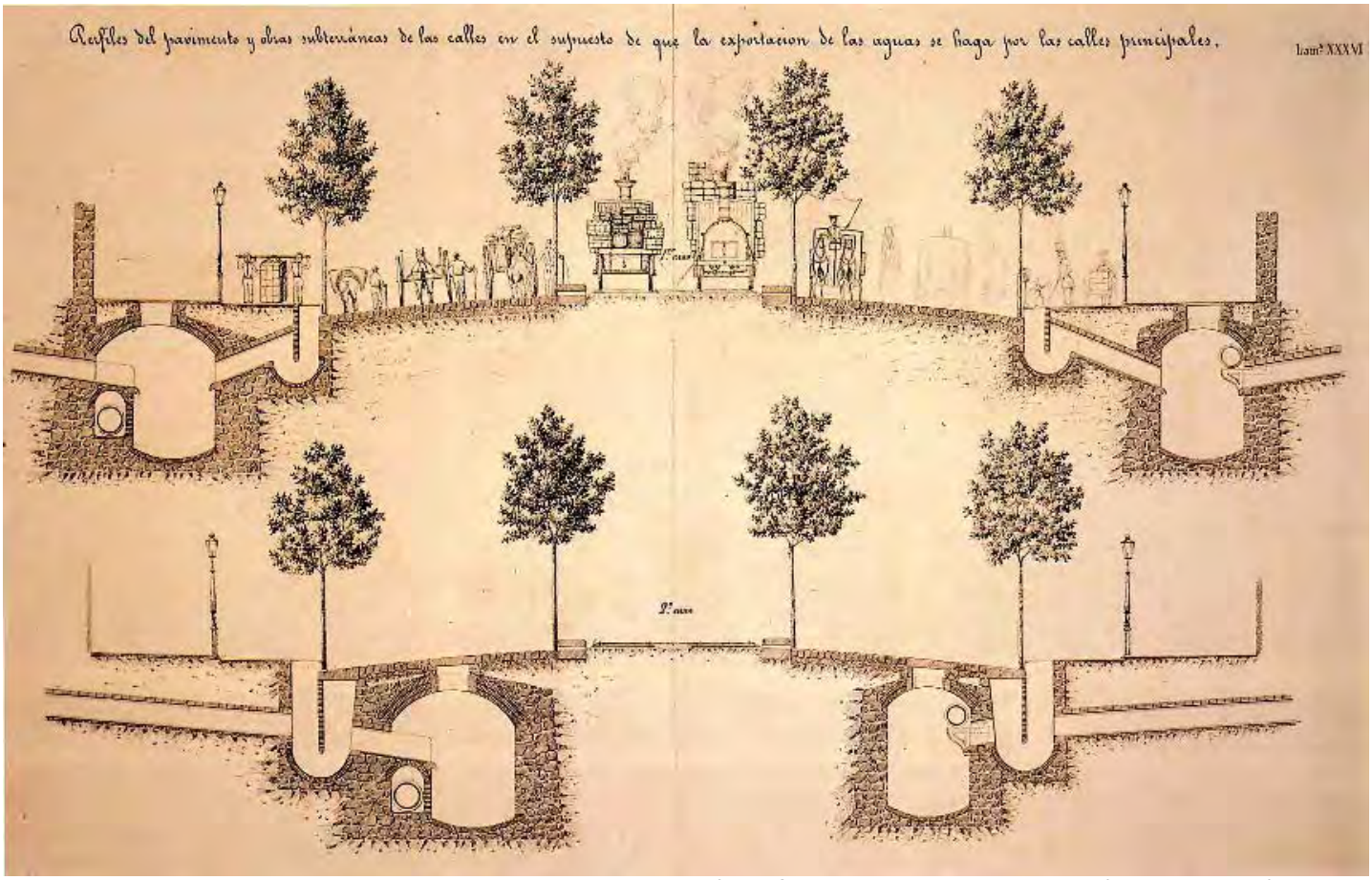
"That property in any object, whereby it tends to produce benefit, advantage, pleasure, good, or happiness ... [or] to prevent the happening of mischief, pain, evil, or unhappiness to the party whose interest is considered." [1]

This statement would imply that actions are judged by their validity based on the consequences they produce. According to Bentham, nature as a chaotic entity, subdues people to either pain or pleasure and in our ruling, we group objects or living things following this categorization. [2] [3] For example, bees are regarded positively because we can perceive the outcome of their pollinating endeavor leading to the production of highly nutritious honey. However, wasps that are not as efficient are in fact pollinators to the ignorance of many.[4] Even night moths have proved to be singularly more efficient than bees in conducting that kind of work at night. [5] The intention here is not to dwell much on the effect of terror or disgust of particular insects on humans, but to instill the idea that in nature, as Spinoza says, nothing is "contingent" (as in nothing is accidental) and the "order of causes" behind a creation is "hidden" from us. Thus, whether following a rule of chaos or a rule of order, everything in nature is

determined for a certain purpose, irrespective of our ability to observe the phenomena or not. In other words, we may observe various phenomena in nature without essentially understanding or perceiving their contributing impact on our presence:

"In nature there is nothing contingent, but all things have been determined from the necessity of the divine nature to exist and produce an effect in a certain way." [3]

Hence, the utilitarian movement with all its sub-ramifications, reasonably aims at reducing the amount of apparent pain and increasing direct pleasure.[2] Regarding the wetland, the pain of malaria had to be exterminated to allow for a more pleasurable living. Malaria and mosquitoes had a severe impact on various populations that folklore beliefs of the 16th century recount of witches and creatures of the dark that can transform into various insects to kill people and little babies. [6] The liberating agent of such distress was the emergence of the Sanitary Movement in the 19th century which had a profound improvement on the cleanliness of people, homes, public spaces, infrastructure, and cities entirely. The movement accentuated the importance of having more spacious streets, wider sewage networks, well ventilated domestic units, and access to clean air and water to promote healthy individuals... [7]



https://upload.wikimedia.org/wikipedia/commons/9/9b/Cerda-

Ildefonso Cerdà, sanitarian urban designer of the extension of Barcelona
Scheme depicting wider streets adapted for carriages, larger sewage networks, and integrated vegetation

The sanitarian principle based on utilitarian creed, in the absolute, insinuates that the desired end justifies the means used. However, within our ignorance of the interplay of all natural factors, the elimination of one undesired element could cause a chain reaction of other undesired outcomes.

According to Spinoza:

"...this doctrine concerning the end turns Nature completely upside down. For what is really a cause, it considers as an effect, and conversely [NS: what is an effect it considers as a cause}. What is by nature prior, it makes posterior. And finally, what is supreme and most perfect, it makes imperfect." [3]

In other words, every element by the laws of nature is playing a symbiotic role with another; the removal of a certain element "causing" an "affect" could possibly lead to other unwanted "affects" and flip the role of several entities.

In the end, perhaps the utmost danger that the utilitarian doctrine can induce is the transformation of a world solely based on production and use. And in order to maximize this association, the tendency of this movement is ultimately to also treat people as objects for use. This was documented during the bonifica integrale period in which the dream of the ideal fascist landscape regarded peasants and farmers as agents, eventually serving the state under the guise of combatting disease and achieving a better future. Even in Stalin's 5-year plan of the Soviet Union, nature was stripped from its fundamental sacred property and rendered an object in servitude of the "master race".[8]

"Utilitarianism is a civilization of production and of use, a civilization of things and not of persons, a civilization in which persons are used in the same way as things are used." Pope John Paul II [9]

[1] Encyclopædia Britannica, inc. (n.d.). Utilitarianism.

[2] Bentham, J. (1986). An introduction to the principles of morals and legislation: Printed in the year 1780, and now first published. Legal Classics Library.

[3] Spinoza, The Ethics

[4] Naturalistic Observatory of the Island of Culuccia

[5] Moths are more efficient pollinators than bees, new research shows. Butterfly Conservation.

[6] Lisai, G. (2022). Sardegna esoterica: Il volto misterico di un'isola ancestrale, Sospesa Tra Sacro e Profano. Newton Compton.

[7] Wilson, Frances; Mabhala, Andi (19 November 2008). Key Concepts in Public Health

[8] McGrath, A. E. (2003). The reenchantment of nature: The denial of religion and the ecological crisis. Doubleday/Galilee.

[9] Pope John Paul II (1994) . Letter to families. https://web.archive.org/web/20110405033300/https://www.vatican.va/holy_father/john_paul_ii/letters/documents/hf_jp-ii_let_02021994_families_en.html

3. A Chronological Scheme of Variations

Landscape architect Gilles Clément established in a written manifesto the technical term "third landscape" referring to the importance of regenerating nature and its biodiversity after originally being altered by human intervention. Approaching the wetland of Porto Liscia borrowing from such notions makes way for three main separate threads of reasoning in regard to the typology of a landscape: [1]

1. The first landscape: is about nature in its most native untouched state, wild, original, and autochthonous. The best explanation to such categorization are Spinoza's thoughts in his Ethics about "Natura Naturans" & "Natura Naturata". Concisely on one hand, "Natura Naturans" is the revered divine energy of nature that exists not for anything in particular but for the sake of existing: *"...by Natura naturans we must understand what is in itself and is conceived through itself..."* [2]

On another hand, "Natura Naturata" is the complex interaction of free natural elements, a Latin term meaning exactly nature that is born in contrast to nature that is created. It is the slow and long-stretching movement of nature during which elements are indeed interacting altogether producing certain effects without any anthropogenic interference.

2. The second landscape: it is during which a disruptive element is introduced to the original order of the first one. Undoubtedly, it is when for the existence of a certain civilization, a landscape has to be consumed in a certain manner i.e., direct management, agriculture, control, farming, and urban settlements...

This has a severe impact on the biodiversity and endemism of a landscape, constituting a mutilating wound that requires artificial maintenance that does not in reality bring about any better substitute for the original state. To understand it better, it is enough to contemplate the difference in biodiversity between a forest and a razed land for agriculture, or a large natural park and a city garden. In the wetland of Porto Liscia, fortunately the land was not levelled for any particular reason, however, external factors of the mediterranean and direct factors linked to the "bonifica intergrale" and "costa smeralda" periods resulted in an alteration in the natural symbiosis of the wetland. Here, through the digging of the canals and the change in the water's flow, two direct factors are induced being the levels of salinity and overall turbidity of the water – not to mention the destruction of its western part during the "costa smeralda" period.

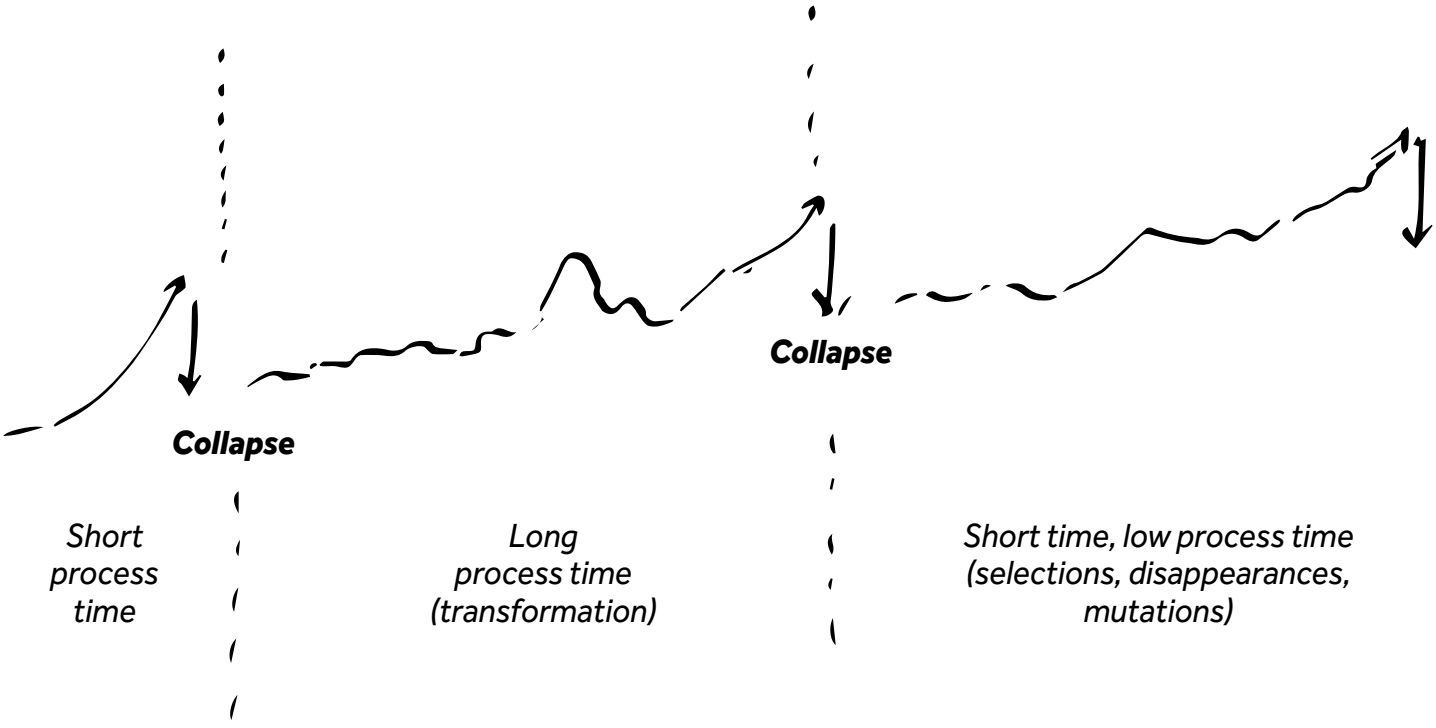
[1] *Manifesto of the Third Landscape - Trans Europe halles. (n.d.).*

[2] *Spinoza, The Ethics*

3. The third landscape: it is the current state of the wetland in which it was able to readjust itself to the indefinite changes of the previous period. The changes in the levels of salinity and the water's turbidity (flow and movement) brought about several "affects" to the wetland and its vicinity thus being unmonitored fluctuations in temperature, distribution of fauna and flora, and overall primary productivity including opportunities in fishing and mollusks raking.

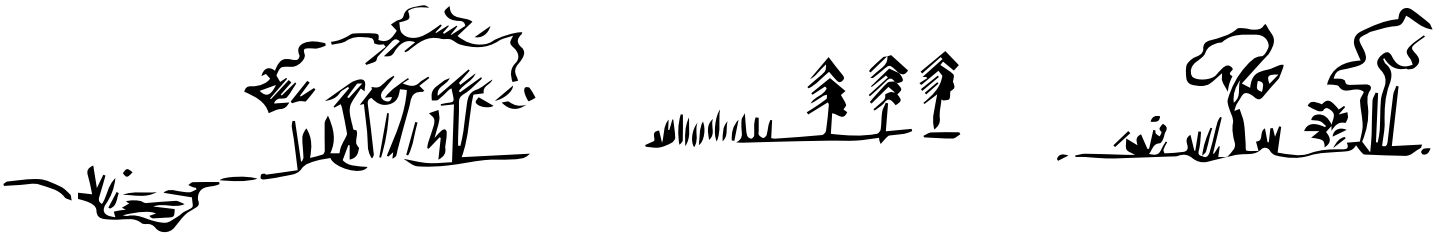
It is currently somewhat of a neglected land still holding a rich indigenous character, in which factors are not fittingly studied and subject to oblivious interference by authorities, locals, and tourists.

The design intervention that will be proposed shortly after, shall bring about a program that deals with finding out the unknown, still unobservable factors, to determine whether this wetland is in a steady state of regeneration or sluggish perishment.



"The general process of evolution can be understood as a succession of short and slow phenomena (Darwinian and Lamarckian) concerning (biological) systems...." [1]

Sketches by Gilles Clément from the "Manifesto of the Third Landscape"



First Landscape:
. High diversity and endemism
. Stable species / slow dynamics

Second Landscape:
. Managed land
. Very low diversity and no endemism
. Artificial maintenance

Third Landscape:
. Neglected land
. Acceptable diversity, unstable species
. Low endemism

4. Possibilities of intervention in a fragile environment

At this point, the wetland of Porto Liscia can be referred to as a sensitive biological system in which biotic life exists even in hidden crevices and in underground nests. To actually try to introduce more anthropogenic structure is a challenge by itself and therefore the best intervention is the least intrusive and the most emancipating, making of the selection of the area of interference an utmost necessity. Thus, two methodologies are taken into consideration for this analysis: the Duvigneaud and Sukkop approaches.

Botanist Paul Duvigneaud relied in his study on urban wastelands, being leftover and abandoned green sites of a city, on the enormous primary productivity of such habitats. He implemented laboratorial analysis and climatological measurements, installing devices and instruments, as well as referring to municipal data of waste, pollution, traffic, and population...

However, botanist and ecologist Herbet Sukkop highlighted the difference and importance of each wasteland based on the degree of species diversity. His most notable work is the study of wastelands in Berlin in which he depicted the city as a mosaic of 57 "biotope types" of green areas. He also worked on the map of Brussels, dividing it into zones of "greenness" using a scale from grey to green highlighting the total density of "biomass" in each habitat. [1]

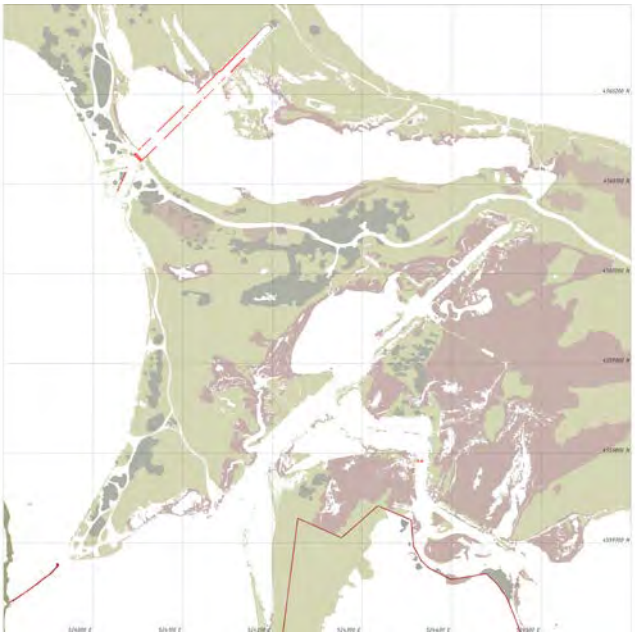
For an architectural thesis, this kind of profound supervision is quite impossible, nevertheless with a parallel attitude, a similar kind of study can be developed to understand where and how the project is best fitted. Therefore, the next "mosaic" schemes highlight areas of productivity and their significance following the approaches mentioned above.

[1] *Gandy, M., & Jasper, S. (2020). The botanical city. Jovis.*

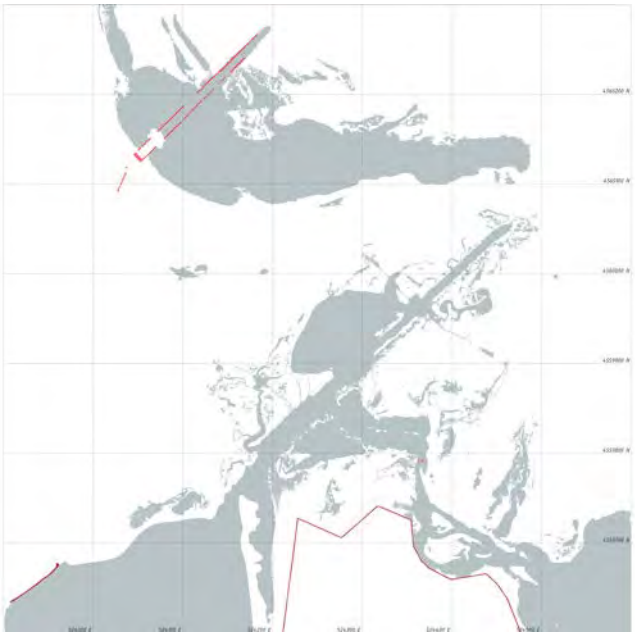
1. General Area Selection: This large area is the heart of the wetland in location but not in importance. It holds all anthropogenic structures being canals, accessible roads, parkings, and bridges, making it the easiest accessible of all and not necessitating further implementation of mobility and networking structures. It is also one of the most picturesque zones with adequate influx of animals and birds, and a strategic position for visitation and distance observation.

Salicornia *Sand* *Sea*

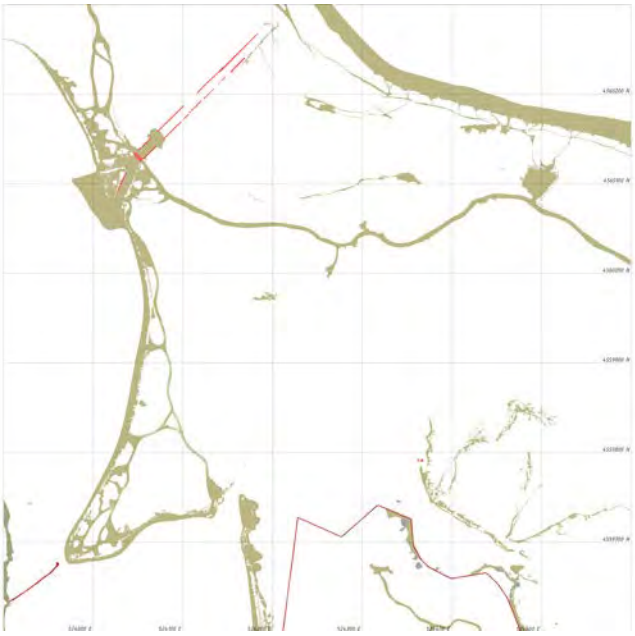
Juncus *Shrubs* *Wet areas*



2. Areas of 100% primary production: Since vegetation is a living compound, these areas are fully covered with vegetation making them areas of extreme importance and sensitivity.



3. Areas of minimal seasonal levels of primary production: In summer the whole wetland is flooded, and these are the overflooded muddy areas that do not interfere directly with the vegetation.



4. Areas of minimal stable levels of primary production: these are the beaches and dug sandy roads on which no biological life exists except sparsely in underground form (mollusks, insects).

5. General Areas for non-intrusive intervention: areas of overall minimal levels of biological production adequate for a certain small-scale intervention (sand and waterscapes).

5. Proposed Design

An indispensable primary product of this thesis is employing advanced geomatic cartography techniques to accurately depict the complex constituents of the wetland of Porto Liscia and understand them on all influential and significant levels of decision-making. Previous maps failed to capture essential aspects of the wetland, reducing it to a simplistic representation of land and water networks. As historian Bhavani Raman observed in the context of an illegal encroachment on a creek in North Chennai, the absence of water features on official maps can lead to the destruction of the ecosystem, illustrating the profound impact of accurate cartography: "if the paper map does not bear any trace of water then the creek does not exist." [1]

Building on this foundation, the proposed design intervention seeks to enhance visitors' awareness and connection to the wetland in a direct, experiential manner. It aims to enrich the visitor experience by adding layers of perception to the natural environment, encompassing elements such as wildlife, flora, bird watching, seasonal changes, water dynamics, activities, and most importantly provide a means to unearth what is still unknown.

The physical components of this program, illustrated in the following maps and photos, comprise firstly a steel-mesh pathway that weaves through the natural networks of the landscape, gently suspended above the vegetation to protect plant life and to prevent users from stepping on the plants. This choice of material and elevated platform design facilitates the unobstructed flow of sunlight, rain, water, wind, and small animals, and provides a multi-level year-round experience for visitors.

The second component involves an intricate pathway of granite blocks in vast empty regions where large animals can be freely roaming [2] - a sturdy material highly diffused and native of the region, and not requiring any maintenance. This pathway allows for the observation of seasonal changes and offers the same adaptable periodic feature.

The third element, an instrument of knowledge, consists of several artificial ponds where water's turbidity and salinity can be monitored under open-air conditions. This mimics laboratorial conditions however, in the actual exterior setting where the numerous natural factors and their impact cannot all be calculated and fathomed. This will allow for rapid understanding of the effect of change in natural factors on the overall survival of the wetland; if certain continuous factors show unfavourability then they should be limited in the general context and vice versa. Once the need for further study subsides, these ponds can seamlessly integrate into the wetland.[3]

The fourth constituent is an underground granite enclosure for bird watching at ground "grasshopper" level, reminiscing of disguised hunting blinds. The concealed unit ensures an unobstructed view for both visitors and animals, particularly birds sensitive to unfamiliar extrusions and objects like predator-mimicking surf kites. The aim is to keep everything at a shallow level. The underground portion can also exhibit a transparent section along one or more of its walls to contemplate the stratigraphy of the soil.

August 2023

Successful trial of canoeing the entire wetland during high tide

Notably, the program respects the untouched eastern side of the canal, preserving its natural, unspoiled beauty, and leaving its faraway most savage parts intact. Instead of introducing additional infrastructure, the design complements existing road and beach networks. A rope line, supported by wooden bollards, delineates the canal, acting as both an abstract barrier and a perching station for birds, particularly ospreys that require elevated platforms for hunting. This design also includes two wooden decking platforms at the canal's northern and southern extremes, enabling canoe trips during high tide while pulling the rope – an ancient traditional practice employed by fishermen in the absence of motorized boats.

The design intervention serves as a sophisticated network of "technical objects" that seamlessly integrates various elements within the environment, including humans, nature, animals, culture, and science. It adeptly regulates user behavior to safeguard the integrity of the interconnected ecosystem, imposing restrictions when necessary, but also encourages more profound interactions for enhanced observation and assessment. Despite its unobtrusive, low-level, and camouflaged presence, this design possesses a noteworthy strength to reshape perceptions, influence behaviors, raise environmental awareness, and most importantly, foster a reciprocal relationship between people and nature, emphasizing understanding over attempts to control or manipulate a marginalized natural world.[3][4]

[1] *Gandy, M., & Jasper, S. (2020). The botanical city. Jovis.*

[2] *Trælvikosen. Trælvikosen – Snøhetta. (n.d.). https://www.snohetta.com/projects/traelvikosen*

[3] *Bijker, W. E., & Law, J. (2010). Shaping Technology/Building Society: Studies in Sociotechnical Change. MIT Press.*

[4] *Goh, K. (2021). Form and flow: The Spatial Politics of Urban Resilience and Climate Justice. The MIT Press.*

General plan of the intervention

Path part I: Steel decking, and wooden platform as port for canoes

Path part II: Steel decking, and granite detached blocks

Path part III: Steel decking, granite blocks, and scientific research artificial ponds

Path part IV: Steel decking, and granite underground bird-watching unit

Path part V: Steel decking, wooden bench, and second port for canoes along the canal

Camouflaged design with scenic stops

Path's natural integration and adaption to different seasonal changes

- VII -
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CREDITS

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