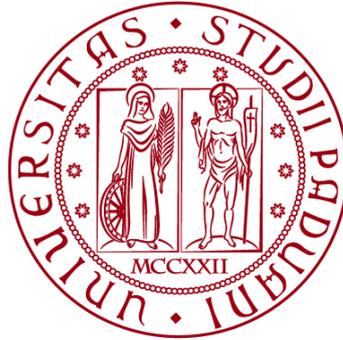


**UNIVERSITÀ DEGLI STUDI DI PADOVA**

**DIPARTIMENTO DI BIOLOGIA**

**Corso di Laurea magistrale in Marine Biology**



**TESI DI LAUREA**

**Environmental features and macrozoobenthic  
communities of climatic micro-niches in salt  
marshes of the Venice Lagoon**

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**ANNO ACCADEMICO 2023/2024**



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## **ABSTRACT**

Aquatic vegetation, once died, is converted into detritus that drift in the water. In coastal habitats, seagrass and algal detritus is frequently stranded on the shore by waves and wind action; in the Venice Lagoon, this detritus can be stranded on the salt marshes. These vegetation wracks can offer to the organism's food, shelter and habitat, since salt marshes, and in general marsh bare soil is subjected to extreme and variable environmental conditions. These dead vegetation wracks can be preferred by organism to live and feed for their environmental characteristics acting as thermal and humidity micro-niches.

Due to these features, these micro-niches are important to study to underline environmental parameters but also the faunal communities present, for conservation perspective, since these microhabitats are part of salt marshes ecosystem, and in a future perspective can increase organisms' protection against climate change providing more livable environmental conditions, under a global change threat of temperature rising and heat waves.

The goal of this thesis is to study these micro-niches in natural saltmarshes of the Venice Lagoon, in particular seagrass, algal wracks and marsh plant meadows, compared to bare salt marsh soil kept as a control. The work described here is focused on sampling physical characteristics of wracks, especially humidity, temperature and granulometry.

Together with the sampling of environmental variables, the work has focused on the taxonomic identification and quantification of macro-invertebrates living inside the wracks, to be compared to macrozoobenthos of the bare soil and marsh plant vegetated area, to study any difference in terms of fauna between these micro-niches.

The selected study site was a salt marsh in the southern Lagoon of Venice, Ca' Manzo, investigated in spring-summer 2024.

# 1. INTRODUCTION

## 1.1 Thermal micro-niches and global change

According to NOAA's (National Centers for Environmental Information) 2023 Annual Climate Report, ocean and land temperature were increasing by 0,2 C° every decade since 1982, three time faster than the period between 1850 and 1982 (0,06 C°) and 2023 has been the warmest year by far (<https://www.ncdc.noaa.gov/cag/global/time-series>). Every year, in the atmosphere, 11 billion tons of carbon are released by fossil fuels burning and forest clearing, leading to a carbon dioxide increase in the atmosphere every year (Lindsey and Dahlam, 2024). Following this trend, by the end of the century average global temperature will be at least 5 C° and at maximum 10,2 C° higher than those in the first half of 20<sup>th</sup> century (<https://science2017.globalchange.gov/chapter/executive-summary/#fig-3>). Climate change is an ongoing and future process caused by humans (IPCC, editor, 2014), that is leaving a footprint on air, land and water (Morelli *et al.*, 2016). This extreme climatological event is eroding biodiversity worldwide (Lenoir *et al.* 2017) and is challenging stakeholders and scientists to better understand organism adaptations to it (Morelli *et al.*, 2016).

An increase in temperature can exceed thermal tolerance of organisms that can adapt to it using mechanisms like niche shift acclimation or micro-evolutionary processes (Wasof *et al.* 2013), or they can track it following the shift induced by climate on the modified climate of that region (Lenoir *et al.*, 2017). If high temperatures exceed physiological tolerance of organisms, it is possible to see local extinction and high mortality events (Strachan *et al.*, 2014). High temperatures can influence eggs incubation, hatching and resting stages (Oliver, 1971; Alekseev *et al.*, 2007), metabolic rates, sex ratios (Terblanche *et al.*, 2005), food webs, and behavior (Rosenzweig *et al.*, 2008). Climate change adaptations can be achieved by organisms throughout behavioral, physiological, or morphological adaptation or life history adjustment (Strachan *et al.*, 2014). A behavioral adaptation can be the use of climate change refugia or climatic micro-niches (Strachan *et al.*, 2014) described by Morelli *et al.* (2016) as: "areas relatively buffered from contemporary climate change over time that enable persistence of valued physical, ecological and socio-cultural resources". Also, Hylander *et al.* (2015) define refugia as: "mechanism for increased resilience of species to climate change".

Ecological niches have a different conceptualization from different authors in history (Sales *et al.*, 2021). They were defined considering: species place in nature (Darwin, Linnaeus; 19<sup>th</sup> century), factors affecting species existence (Grinnell, 1904, Elton, 1927), space occupied by species (Hutchinson, 1944), resource utilization (MacArthur and Levins, 1967), requirement and impacts of species (Chase and Leibold, 2003), ecological models (Hubbell, 2001) and interaction between biotic, abiotic factors and species movement (Soberon and Peterson, 2005) (Sales *et al.*, 2021). Niches could be also considered

environmental entities modified by constructor species to enhance their own fitness (Sales *et al.*, 2021).

Environmental niches can be fundamental, defined by physiology, or realized, also defined by biotic interactions like competition, predation and dispersal (Pellissier *et al.*, 2013). Either realized and fundamental niches are shifted by abiotic and biotic factors that shape the ability of species to live under certain environmental conditions (Pellissier *et al.*, 2013). These factors change across geographical regions, but only realized niches can be quantified and ecologically interpretable (Pellissier *et al.*, 2013).

Climate change refugia are characterized by stable climatic conditions over time, as an example vegetation or moisture content can act as climate change refugia, creating livable conditions under climate change and need to be managed to enhance the survival of organisms (Morelli *et al.*, 2016; Hylander *et al.*, 2015). Following these considerations, wetlands and coastal areas themselves are considered climatic refugia (Morelli *et al.*, 2015). The stress gradient hypothesis states that under physical stress, positive interactions (like habitat amelioration induced by climate change refugia) increase, thus reducing stress and providing food, refuge or substrate to organisms (Qiu *et al.*, 2019). Refugia can be big or small, and in the second case we should refer to micro-refugia like algal mats, stones, or leaf litter (Strachan *et al.*, 2014). Water content loss is one of the worst factors affecting intertidal aquatic animals (Strachan *et al.*, 2014). Moisture content is important to reduce air and soil variability of temperature, having buffering and decoupling capacity (Lenoir *et al.*, 2017). The first mechanism has a spatial dynamic (buffering) while the second a spatio-temporal dynamic (decoupling) and together reduce temperature of micro-niches compared to regional temperature (Lenoir *et al.*, 2017).

Climate refugia can buffer the action of fluctuating and extreme temperature, droughts, and sea level (Morelli *et al.*, 2016), can provide shelter also for a long time (Lenoir *et al.*, 2017), and can be colonized in the future by species that leave places with unfavorable environmental conditions (Morelli *et al.*, 2016; Lenoir *et al.*, 2017). Species can also use refugia only for a short unfavorable period and then go back and expand enhancing their survival and maintaining biodiversity (Hylander *et al.*, 2015; Morelli *et al.*, 2016). Refugia provides climatic condition stability, so local climatic conditions are decoupled from regional climate variations (Lenoir *et al.*, 2017) and they can be good enough to sustain small populations or meta-populations from exposure and disturbance (Morelli *et al.*, 2016). For their role in buffering climate change conditions and enhancing biodiversity and, so, in maintaining resilient ecosystems with diverse communities in different landscapes and waterscapes (Haight and Hammil, 2020), climate micro-niches should be understood, protected and conserved (Haight and Hammil, 2020).

## 1.2 Aquatic and vegetated intertidal ecosystems conservation in the Venice Lagoon

### 1.2.1 Venice lagoon ecosystem

Lagoons coastal semi-enclosed coastal areas in communication with the sea with a shallow average depth (Guadagnin, 2021). Due to these characteristics, they are very vulnerable to the impact of human activities (Boutoumit *et al.*, 2021) such as tourism, mining, industry (Boutoumit *et al.* 2021), pollution, fishing, resource harvesting, dredging of channels and infrastructure constructions (Boscolo Brusà *et al.*, 2022). Semi enclosed coastal systems (SECS) are also subjected to storminess, droughts, floods and increased temperatures (Boutoumit *et al.*, 2021).

Worldwide, coastal lagoons are among the most productive marine habitats, and they provide many goods and services (Boutoumit *et al.*, 2021; Franzo, 2012). These include nursery habitat and shelter for fish (Guadagnin, 2021), carbon and nutrient cycling, water purification and biodiversity support (Franzo, 2012). Coastal lagoons also provide a sense of place thanks to their waterscape, enhance ecotourism, protect the coast against erosion and act as natural carbon sinks buffering climate change (D'Alpaos and D'Alpaos, 2021). Lagoons act also as organic matter accumulators and as reservoirs able to fertilize nearby coastal environments through export of organic and inorganic nutrients (Franzo, 2012).

The Lagoon of Venice is situated along the northern Adriatic Sea coast (Oselladore *et al.*, 2022). It is the largest lagoon system in the Mediterranean Sea (Sfriso *et al.*, 2009, Flindt *et al.*, 1997), in which it represents one of the most important transitional water bodies (Oselladore *et al.*, 2022). The lagoon is around 10 km wide and 50 km long (Flindt *et al.*, 1997) and its origin dates back 6000 years during the last Glacial period (Flindt *et al.*, 1997, Guadagnin, 2021). Northern Adriatic Sea is a shallow basin, with an average depth of 40 meters and has a high freshwater input, a limited water circulation and a higher productivity compared to the rest of the Mediterranean (Mancinelli and Rossi, 2001).

The lagoon is divided into three main basins; central, northern and southern divided by Petroli and Malamocco-Marghera channels (Bonometto, 2014; Oselladore *et al.*, 2022) and communicate with the Adriatic Sea through three inlets: Chioggia, Malamocco and Lido (Flindt *et al.*, 1997). Through the inlets there is the exchange of sediments from the sea to the lagoon and vice-versa thanks to reflux currents (Guadagnin, 2021). The total surface of the lagoon is 549 km<sup>2</sup>, including marshes and various islands (Sfriso *et al.*, 2009), and the average depth is shallow, less than 1 meter (Oselladore *et al.*, 2022).

Transitional waters are the transition between freshwater and marine waters (Oselladore *et al.*, 2022), they show strong gradients and variability of chemical-physical parameters like: salinity, temperature, pH, nutrient content, particulate and dissolved organic matter, turbidity and dissolved oxygen (Oselladore *et al.*, 2022). The lagoon of Venice is influenced by the

freshwater runoff of rivers like the Dese that discharge sediment and detritus and is limited by the Brenta river on the south side and the Sile river on the northside (Guadagnin, 2021). The lagoon of Venice is an ecotone (Guadagnin, 2021): an area in between two different ecosystems, with specific physical, biochemical and ecological features (Beltran *et al.*, 2020). Streams, wetlands, lakes and coastal shores are considered ecotones (Beltran *et al.*, 2020). The Venetian Lagoon can be considered micro-tidal, since the average tidal range is about 60 cm, reaching a meter during syzygy, and few centimeters during neap tides (Tagliapietra *et al.*, 2016) and is a mesotrophic ecosystem that uses detritus from the river runoff and the sea input (Guadagnin, 2021). “Venice and its lagoon” belong to the UNESCO world heritage sites since 1987 (D’Alpaos and D’Alpaos, 2021) and are one of the most studied urban and natural ecosystems in the world (Ivajnsič *et al.*, 2018).

The Venice Lagoon has also experienced local threats in the past centuries from human inhabitants living in Venice, that diverted the main rivers that used to get into the Lagoon (Piave and Sile in the north, Brenta and Bacchiglione in the south) (Boscolo Brusà *et al.*, 2022) causing a strong reduction in sediment supply (Tognin *et al.*, 2021). The construction of jetties and navigable channels inside the lagoon caused hydrodynamic changes and a loss of morphological heterogeneity in the Lagoon homogenizing the habitat (D’Alpaos and D’Alpaos, 2021). Other stressors were sediment resuspension due to manila clam harvesting, especially in the 80s (Facca *et al.*, 2014) and the Mo.S.E. (Experimental Electromechanical Module), a system of walls that is operating since October 2020 in the inlets helping to prevent very high tides called “*acqua alta*” closing water fluxes. The activation of the Mo.S.E. affects the accumulation of sediment on salt marshes since it blocks sediment supply from storm surges (Tognin *et al.*, 2021). These natural and anthropogenic processes act together, exacerbated by climate change, and can lead to the deterioration of the lagoon with a consequent decrease in ecosystem functions and services provided (D’Alpaos and D’Alpaos, 2021), loss of native species, eutrophication and changes in community structure (Boutoumit *et al.*, 2021).

The northern part of the lagoon has a lot of drainage from basins rich in agriculture activity that transport nutrients and fertilizers (Oselladore *et al.*, 2022). The central lagoon is the most influenced by industrial activities receiving drainage from Venice, Mestre and Marghera (Oselladore *et al.*, 2022), while the southern is affected by urban activities from the touristic cities of Chioggia and Sottomarina (Oselladore *et al.*, 2022).

Salt marshes and aquatic angiosperms were endangered by human activities since the 20th century (Boscolo Brusà *et al.*, 2022), so different projects for ecological restoration were put in action over the years in the Venice Lagoon as part of the Natura 2000 network (Barausse *et al.*, 2015). These restoration projects include: LIFE SERESTO, for aquatic angiosperms (Oselladore *et al.*, 2022); LIFE VIMINE, for salt marshes (Barausse *et al.*, 2015) and LIFE Lagoon

Refresh, aimed at partially restoring the salinity gradient present in the lagoon before river diversion (Boscolo Brusà *et al.* 2022).

### 1.2.2 Salt marshes

Salt marshes are the studied intertidal ecosystem of this thesis, they are typically found in temperate zones in protected shoreline, geographically delimited by ice from polar upward expansion and mangroves from tropical downward expansion (Silliman, 2014; Pennings and Bertness, 2001). Salt marshes grow in shallow water, since they are threatened by wave action of beaches, so they are found in lagoons, bays, and estuaries (Bonometto, 2014). Marsh plants are outcompeted by cattails and sedges in the uptake of nutrients, preventing their migration up to rivers (Silliman, 2014). They can undergo wide temperature, salinity and inundation oscillations (Bonometto, 2014), they are partially flooded during tidal cycles and completely flooded under pronounced high tides (Barausse *et al.*, 2015). Marsh plants are halophytic, and they are adapted to cope with salinity variation (Guadagnin, 2021). They have succulent tissues, can excrete salt from salt glands present in leaves, can lose leaves with high salt concentration (Guadagnin, 2021; Silliman, 2014) or increase osmotic pressure in their cells using amino acids to become isosmotic (Silliman, 2014).

Halophytic vegetation has also some adaptations to cope with oxygen soil depletion: adventitious roots to favor oxygen supply, aerenchymatous parenchymatous tissue for oxygen transport and anaerobic metabolic pathways (Guadagnin, 2021; Silliman, 2014). Salt marsh halophytes follow a zonation, with the lower boundary set by physical stressors like anoxia, and the upper boundary set by competition with other species for nutrients (Silliman, 2014). In this competition, stress tolerant plants occupy the lower zone, while the dominant competitor species occupy a higher elevation (Silliman, 2014). Marsh plants trap sediment transported by the tides and contrast erosion of salt marshes margins due to subsidy, wind, currents and waves (Guadagnin 2021; Bonometto, 2014), they also filter water cleaning it, maintain soil humidity and slow down tide energy (Bonometto, 2014).

Salt marshes are inhabited by both terrestrial (like birds, mammals, terrestrial angiosperms, insects) and aquatic organisms (like algae, seagrasses, molluscs, crustaceans and fish) (Pennings and Bertness, 2001; Chapman and Roberts, 2004). Heterotrophic aquatic organisms like invertebrates and fish living in the marshes have developed adaptations in osmoregulation to cope with salt variation (Guadagnin, 2021), most of them can also move during low tide in the main basin and then come back in the marsh creeks during high tide (Guadagnin, 2021). Organisms have also to cope with thermal stress using different strategies: snails can climb up the substrate; crabs can burrow into sediment and bivalves can adopt cooling evaporation (Silliman, 2014). Salt marsh plants also act as shades for organisms from high temperatures thus reducing temperature stress and changing communities' structure (Ludlam *et*

*al.*, 2002). There can be mutualism between marsh plants and burrowing organisms, like crabs that enhance oxygen availability and nutrients to plants (Silliman, 2014). This ecosystem has both top down and bottom-up controls: marsh plants are affected both by grazing of herbivores and soil biogeochemistry that decrease nitrogen concentration (Silliman, 2014).

Salt marshes are highly important habitats since they provide ecosystem services like: coastal flooding mitigation and protection thanks to storm buffering; carbon sequestration through taking up atmospheric carbon; mediate nutrient and pollutant fluxes improving water quality; protect endangered species and support fisheries (Tognin *et al.*, 2021; Wasson *et al.*, 2017; Pennings and Bertness, 2001). Salt marshes are usually nitrogen-limited habitat: nitrogen enhances above ground productivity but decreases below ground production impeding the elevation and tracking of sea level rise (Wasson *et al.*, 2017). Salt marshes are habitats with high primary and secondary productivity, and they undergo a high level of natural stress like tide submersion, that together with organic matter decomposition favor the development of anoxic soil (Guadagnin, 2021). In these ecosystems plant-plant facilitation phenomena have also been observed, for example primary colonizers of bare soils can facilitate growth of other species shading or reducing salt accumulation, and these interactions are very important to enhance resilience from disturbance (Silliman, 2014). Salt marshes can expand in terrestrial habitats as sea level rises or can occupy subtidal habitats by trapping sediments or colonizing sediments transported by storms or rising coastlines (Pennings and Bertness, 2001). Salt marshes are well very studied by ecologists since they are good model systems, due to their simple communities, their patterns across stress gradients and the ease with which they can be experimentally manipulated (Pennings and Bertness, 2001).

In the Venice lagoon, in areas with smaller fetches and lower wave energy there is a higher sedimentation rate (Guadagnin, 2021), and above the sediments can grow angiosperms that develop salt marshes habitat (Guadagnin, 2021; Silliman, 2014; Pennings and Bertness, 2001). Main marsh plant species in the Lagoon of Venice are: *Puccinella palustris*, *Halimone portulacoides*, *Limonium serotinum*, *Aster tripolium*, *Salicornia fruticosa* and *Salicornia veneta* (Guadagnin, 2021; Bonometto, 2014).

Venetian salt marshes are called “*barene*” in Venetian language (Bonometto, 2014), they are crossed by natural creeks called “*ghebi*” (Bonometto, 2014). From the edge of the salt marshes are degrading mudflats and are called “*velme*” (Bonometto, 2014). The *velma* is characterized by mostly bare muddy soil sometimes vegetated with a sparse mixture of halophytes and seagrasses that emerge during particularly low tides (Bonometto, 2014; Guadagnin, 2021). Marshes in the Venice Lagoon are high around 25 cm in the inside portion, while they are higher in the marginal part, around 45 cm, on the open lagoon side, since here the plants trap bigger sediment amounts and detritus

from the tide. This higher side is compact, undergoes strong salinity fluctuations, and is more resistant to erosion (Bonometto, 2014). The inner surface of marshes has humid muddy soil with constant salinity (Bonometto, 2014).

Climate change and anthropogenic activities are imposing a lot of threats on salt marshes (Barausse *et al.*, 2015). These threats include erosion by tidal currents and waves induced by wind, among natural causes (Barausse *et al.*, 2015); sediment loss due to jetties and deep channel construction; riverine sediment absence due to river diversion; soil subsidence either natural or artificial, erosion by motorboat activity (Barausse *et al.*, 2015). But also, sea level rise and erosion promoted by storm surge protection barriers (Tognin *et al.*, 2021). These stressors can act synergistically or additively leading to salt marsh deterioration (Silliman, 2014). Due to these threats between 30% and 40% of salt marshes and seagrasses can be lost in the next century (D'Alpaos and D'Alpaos, 2021) since every year the lagoon loses 1.100.000 m<sup>3</sup> of sediments due to anthropogenic activities (Bonometto, 2014; Guadagnin, 2021).

Ecosystem services and functions provided by aquatic vegetation in the Venice lagoon are considered economically important (Ivajnšič *et al.*, 2018). Salt marsh conservation is recognized in Europe (Ivajnšič *et al.*, 2018) throughout Natura 2000 network for coastal protection (protecting over around 15 % of European coasts) and its Directives Bird and Habitat (Barausse *et al.*, 2015). Habitat Directive (Directive 92/43/EEC) recognize salt marshes as “habitat of Community interest for nature conservation” (Guadagnin, 2021) because they are endangered; or priority habitats on annex I (Ivajnšič *et al.*, 2018; Boscolo Brusà *et al.*, 2022; Barausse *et al.*, 2015). European Water Framework Directive (WFD, 2000/60/EC) set goals for improving ecological status of transitional waters through restoration ecology (Boscolo Brusà *et al.*, 2022) while Birds Directive (Directive 2009/147/EC) set measure for birds’ protection (Barausse *et al.*, 2015). In the past decades, “Magistrato alle acque” (Bonometto, 2014), the former Venice Water Authority, now called “Provveditorato Interregionale per le Opere Pubbliche per il Veneto, Trentino Alto Adige e Friuli Venezia Giulia “(Brigolin *et al.*, 2021; <http://provveditoratovenezia.mit.gov.it/>) acted to restore Venice lagoon salt marshes, creating more than a hundred artificial salt marshes for a total are of 10 km<sup>2</sup> (Bonometto, 2014). Salt marshes were restored also using “integrated approaches” in projects like LIFE VIMINE, that worked between 2013 and 2017 in the northern Lagoon of Venice using soft technologies and biodegradable materials (Tagliapietra *et al.*, 2018; Barausse *et al.*, 2015). The main objective was to protect and restore the eroding margins of natural marshes (Tagliapietra *et al.*, 2018; Barausse *et al.*, 2015).

### 1.2.3 Seagrass meadows

Seagrasses are flowering and vascular (phanerogams) coastal aquatic plant of the group Magnoliophyte found everywhere except Antarctica (Vance *et al.*, 2022; Costa *et al.*, 2021; Tagliapietra *et al.*, 2018). They have a life cycle completely submerged in brackish or marine waters (Tagliapietra *et al.*, 2018). They are ecologically important since they provide different ecosystem services like carbon sequestration, coastal protection and habitat and food for invertebrates and fish sustaining biodiversity and complex food webs and water oxygenation (Vance *et al.*, 2022; Costa *et al.*, 2021; Beltran *et al.*, 2020). Seagrasses provide shelter and/or living space for animal communities and can increase habitat complexity (Tagliapietra *et al.*, 2016). Seagrass meadows have a higher number of animal species, abundance and diversity compared to nearby bare sediments, due to both the aboveground part of the plant that favor recruitment and belowground part that favor sediment stability and habitat complexity: for this they are considered “ecosystem engineers” (Tagliapietra *et al.*, 2016; Magni and Gravina, 2023). Seagrasses have morphological and physiological adaptations to cope with salinity and submersion like horizontal rhizomes for swell resistance, hydrophilic pollination and dissemination (Tagliapietra *et al.*, 2018)

In the Venice Lagoon there are different species of seagrasses: *Zostera noltii* that grows in the intertidal belt around the low neap tide water level in pelitic sediments, while *Zostera marina* and *Cymodocea nodosa* grow in the deeper part of the lagoon and are strongly affected by anthropogenic threats (Tagliapietra *et al.*, 2016). These three species are particularly present in the southern basin of the lagoon (Oselladore *et al.*, 2022). Another well studied species in the Mediterranean Sea is *Posidonia oceanica* (Linneus), which forms wracks in the Mediterranean sandy beaches (Lepoint and Hyndes, 2022). Seagrasses have declined in the second half of the past century (around 7% coverage loss per year worldwide since 1990) (Tagliapietra *et al.*, 2016; Costa *et al.*, 2021; Vance *et al.*, 2022) due to anthropogenic pressures such as eutrophication, invasive species, urbanization, extreme climatological events and sediment resuspension (Costa *et al.*, 2022; Oselladore *et al.*, 2022). Some projects were put in action for seagrass restoration (Oselladore *et al.*, 2022), one of them was the Life SERESTO - abbreviation of seagrasses restoration - (Oselladore *et al.*, 2022) project in the Northern Lagoon of Venice that worked for the restoration of two important aquatic angiosperm meadows: *Z. marina* and *Z. noltii* (Oselladore *et al.*, 2022). In the European Union seagrasses are protected thanks to policies like the Marine Strategy Framework Directive (MSFD, 2008/56/EC) (Marbà *et al.*, 2013; Vance *et al.*, 2022) and Water Framework Directive (EU 2000/60) (Vance *et al.*, 2022; Tagliapietra *et al.*, 2018) considering them as good ecological status indicators (Tagliapietra *et al.*, 2018). In coastal lagoons, one of the main signs of habitat degradation is the loss of seagrass beds and changes in fauna and flora composition (Oselladore *et al.*, 2022). In the Lagoon of Venice, stressors

and pollutants caused the regression of aquatic angiosperms thus affecting flora and fauna communities during the years (Oselladore *et al.*, 2022), but in the last few years this trend has changed, and seagrass meadows are increasing again (Sfriso *et al.*, 2024).

#### 1.2.4 Macroalgae

Marine macroalgae, called also seaweed, have a vital importance for the primary productivity of marine ecosystems (Simul Bhuyan *et al.*, 2021). Worldwide, there are around 8,000-10,500 species grouped in three main categories: brown, green and red algae (Simul Bhuyan *et al.*, 2021). They are primary producers of seas and oceans supporting food webs (Simul Bhuyan *et al.*, 2021). They support also a big amount of ecosystem services like nutrient cycling, biodiversity, carbon sequestration, shore protection, nursery grounds and feeding habitat and removal of nutrients (Simul Bhuyan *et al.*, 2021). The habitat provision is very important since they provide shelter, food, shading and physical structure for organisms (Simul Bhuyan *et al.*, 2021). Seaweed, like seagrasses, can also export detritus in other habitats thus increasing productivity of these habitat (Simul Bhuyan *et al.*, 2021).

The lagoon of Venice has seen an increase of *Ulva rigida*, *Enteromorpha* and *Cladophora* as main algal blooms, since around 1970 (Sfriso *et al.*, 2001), especially *Ulva rigida* was predominant with biomasses of 10 kg ww/m<sup>2</sup>. (Tagliapietra *et al.*, 1998). This trend changed in the last few years, showing a decrease in macroalgal blooms, especially *Ulva rigida* and an increase of seagrass meadows, as said above (Sfriso *et al.*, 2024). Blooms of *Ulva rigida* particularly affected the central and northern basins of the lagoon in summer and their decomposition leads to anoxia, causing dystrophic crises and changing nutrient cycle and macrofaunal communities (Oselladore *et al.*, 2022). For example, in the 80's, the Lagoon of Venice experienced a bloom of Diptera *Chironomus salinarius* due to anoxia caused by *U. rigida* (Oselladore *et al.*, 2022; Sfriso *et al.*, 2001). Blooms of macroalgae occur when there is an increase in salinity, nutrients, light penetration and decrease in current velocity (Harris *et al.*, 2020). These blooms are linked to coastal eutrophication (Harris *et al.*, 2020) and when are washed in the shore, they create catastrophic disturbance events of kilometer or meters scale (Harris *et al.*, 2020). Seaweed fix carbon dioxide and take up nitrogen and phosphorus to grow and produce energy storage products (Simul Bhuyan *et al.*, 2021). Eutrophication is a worldwide anthropogenic-mediated problem often caused by the bloom of macroalgae (Cardoso *et al.*, 2004; Baldrighi *et al.*, 2019). Macroalgae bloom is associated with an increase in nutrient load from fertilizers of agriculture and increased coast-population density (Cardoso *et al.*, 2004; Baldrighi *et al.*, 2019). Jones and Pinn (2006) define eutrophication as “the process of natural or man-made enrichment in nutrient element, mainly nitrogen and phosphorus, beyond the maximum critical level of the self-regulatory capacity of a given system for a balanced flow and cycling of nutrients “. Green tides (GT) were a problem of Europe, Asia and America in

the past three decades, they're called green since they are dominated by green algae, especially *Ulva* sp. (Baldrighi et al., 2019). They enhance problems for the environment (Baldrighi et al., 2019), *Ulva* can be found from temperate to tropical areas (Harris et al., 2020) and its grow is limited by grazing of amphipods (Harris et al., 2020).

### 1.3 Seagrass wracks and algal wracks as micro-niches

Salt marshes are subjected to macroalgae and seagrass wrack strandings (Wasson et al., 2017) (as showed in figure 1), which are the micro-niches of interest in this thesis, especially when aquatic vegetation increases in biomass due to eutrophication, and drifts from the lagoon or sea till the marsh edge (Wasson et al., 2017).



Figure 1. Wracks stranded in two Venice Lagoon salt marshes.

#### 1.3.1 Seagrass wracks

Seagrass primary production is comparable to aboveground biomass production of forests and mangroves (Costa et al., 2022). A considerable part of this production does not enter the food web, and so is not eaten by grazing herbivores invertebrates and fish but is converted into detritus that can be consumed in the meadow itself or transported to the shoreline through wind and wave action (Costa et al., 2022). Here the drifting detritus is stranded and called with different synonyms like seagrass wracks or beach-cast or banquettes or exported litter (Costa et al., 2022; Vance et al., 2022; Lepoint and Hyndes, 2022). Stranded wracks will deposit alongside the coastline forming a semi-stable ecosystem (Beltran et al., 2020) and will be locally redistributed thanks to wind and wave action creating a mosaic of bare sediments and seagrasses wrack patches (Ruiz-Delgado et al., 2015).

Production of detritus is enhanced by the senescence process of the leaves: they die and are released from the plant controlled by the plant physiology, to eliminate epiphytic fauna and to allow nutrient uptake from shoots (Lepoint and Hyndes, 2022). It is estimated that around 15 to 25% of carbon fixed by seagrasses is exported to adjacent systems but this number can vary between few percent to 100% depending on the local system and environmental conditions, like seascape and hydrodynamics (Lepoint and Hyndes, 2022). Since seagrasses have high lignin and cellulose and low nutrient content, seagrasses wracks present a slow decomposition rate, persisting in the environment from weeks to years and forming wracks up to two meters high that change coastal geomorphology (Beltran *et al.*, 2020).

Wracks are an example of spatial subsidy event, since they transfer energy (of the wrack itself) from a donor habitat to a recipient habitat (Ince *et al.*, 2007). Usually, this mechanism examines transfer of energy from marine to terrestrial environments in which there is high fauna abundance despite the low terrestrial primary productivity (Ince *et al.*, 2007). Wracks accumulating in the intertidal zone can also limit erosion of beaches, but usually, especially in summer, municipalities remove the stranded wracks from the beach to avoid odors of decomposition or for the visual impact, using the mass as bioenergy source or compost production (Vance *et al.*, 2022). This can affect the beach ecosystem, since wracks can reduce erosion threats of intertidal areas against storms enhancing coastal protection and provide ecosystem services like biomass and nutrients back to the sea as food for organisms (Vance *et al.*, 2022; Cucco *et al.*, 2020; Beltran *et al.*, 2020).

The main pathway of organic material on both terrestrial and aquatic environments is the transfer of carbon from primary producers to herbivores and decomposers (Poore and Gallagher, 2013).

Wracks can be used as food, habitat, or shelter by bacteria, fungi, diatom microalgae and benthic macro and meio-fauna invertebrates like small crustaceans and molluscs (Costa *et al.*, 2022; Mascart *et al.*, 2015), that are the most important organisms in shredding, degrading and decomposing wracks (Mascart *et al.*, 2015). There are different species that colonize the detritus, like crustaceans peracarids (amphipods, isopods, tanaidaceans) and gastropods molluscs (Costa *et al.*, 2021), animals can also be attracted from nearby areas depending on the feeding, locomotion ability and chemical clues (Costa *et al.*, 2021). All these organisms can feed higher trophic levels in the trophic chain, including vertebrates like fish and birds (Herman *et al.*, 1999). Some detritivores crustaceans like *Gammarella fucicola* Leach, 1814 and *Gammarus aequicauda* Martynov, 1931, can feed on the detritus of the wrack or on the microbial community on the detritus itself during the decomposition process (Costa *et al.*, 2022). In general wracks seem to support a unique macroinvertebrate assemblage (Mascart *et al.*, 2015). Wracks in the upper shore are colonized mainly by terrestrial species while deposits in the middle or lower shore are colonized mainly by marine species (Ruiz-Delgado *et al.*, 2014). Wracks can be consumed by animals between

less than 1% to more than 70% (Poore and Gallagher, 2012). Moving away from the wrack to the bare sediments, assemblages reduce their resilience and resistance to environmental threats, due to worsening of environmental conditions (Magni and Gravina, 2023). It is largely reported higher abundance and species richness of invertebrates macrofauna in wracks patches compared to bare soil sediment (Ruiz-Delgado *et al.*, 2014; Mascart *et al.*, 2015) since wracks support diversity and function increasing species richness and biomass on coastal ecosystems (Ulaski *et al.*, 2023). There can be also other organisms living in the wracks like spiders, beetles and flies (Lowman *et al.*, 2019), but usually there is a succession of organisms colonizing the wrack for shelter depending on microhabitat conditions and grade of decomposition (Poore and Gallagher, 2012). For example, talitrid amphipods, that are one of the main taxa inhabiting wracks worldwide with presence up to 90% of the total macrofauna (Poore and Gallagher, 2012), tylid and oniscoid isopods are usually the first colonizers, while they succeed to Coleopterans and Dipterans insects when the wrack dries out (Ruiz-Delgado *et al.*, 2014).

Wrack colonizers depend also on the stranding position of wracks along the shore from landside, since the inhabitants can be different on different wrack positions (Ruiz-Delgado *et al.*, 2014).

Wracks can also release nutrients due to microbial degradation, altering sediment biogeochemistry but also acting like fertilizers for nearby vegetation (Orr *et al.*, 2005). Seagrass wrack can also emit greenhouse gases (GHGs) like CO<sub>2</sub> and CH<sub>4</sub> (Vance *et al.*, 2022).

In some salt marsh ecosystems, wracks can enhance plant biodiversity affecting positively the ecosystem providing nutrients, structure and avoiding erosion (Chapman and Roberts; 2004). Decomposition rate of wracks depend on both biotic and abiotic conditions: biotic regards litter quality, invertebrate and microorganism activity, abiotic conditions regard mainly hydrodynamic conditions (Costa *et al.*, 2022) and geographical region (Lepoint and Hyndes, 2022), but also chemical composition of refractory and phenolic compounds (Olabarria *et al.*, 2010). Decomposition rates of wracks in tropical areas are faster than the same wrack in the temperate areas (Lepoint and Hyndes, 2022), while deposition patterns are influenced by the physical environment like wave exposure, intertidal slope, morphodynamical state and swash environment (Gomez *et al.*, 2013).

### 1.3.2 Algal wracks

Wracks can be composed also of macroalgae, such as *Ulva* sp., *Sargassum muticum* or *Fucus vesiculosus*, that can form mats (aggregations) in the water (Cardoso *et al.*, 2004), and then can strand in the intertidal zone (Olabarria *et al.*, 2010), in this case we should refer to algal wracks or beach-cast (Olabarria *et al.*, 2010; Ulaski *et al.*, 2023; Wasson *et al.*, 2017). Drifting macroalgae can also mix with dead macrofauna, seeds and seagrasses shoots, roots and rhizomes to form a uniform detritus (Mascart *et al.*, 2015). In many temperate

regions, marine macroalgae are the first source of carbon and organic material for macrofauna (Olabarria *et al.*, 2007), algal wracks can strand either in sandflats, beaches and salt marshes (Olabarria *et al.*, 2007). Once stranded, wracks can be dehydrated, fermented, fragmented, buried and decomposed (Olabarria *et al.*, 2007).

Stranded wracks can not only stay and begin desiccation or burial forming the wrack, but they can also go back to the sea during another high tide or be transported higher in the intertidal (Ulaski *et al.*, 2023). The composition of the wrack depends on different variables, like shore dynamics, decomposition rate and life cycle of the plants (Olabarria *et al.*, 2010). Macroalgae can alter the sediment water interface directly by physically altering sediment properties or indirectly enhancing bioturbation action of benthos (Harris *et al.*, 2020). The presence of mats in the intertidal zone can modify biogeochemical cycles, affect food webs, faunal community structure and ecosystem processes (Jones and Pinn, 2006).

Before detaching, mats can drift for hundreds of kilometers and in the meanwhile, they provide habitat and food for macroinvertebrates and fish foraging in the lost debris (Ulaski *et al.*, 2023).

Availability of algal detritus can facilitate recruitment of deposit-feeders and grazers (Olabarria *et al.*, 2010), and can be inhibited by short term anoxia, reducing diversity of detritus consumers (Olabarria *et al.*, 2010).

In intertidal areas, stranded algal wracks can have two different ecological roles in regulating macrofaunal communities depending on the density of the wracks (Olabarria *et al.*, 2010). At low densities and for restricted periods, it can increase habitat complexity and increase recruitment, providing food for organisms and shelter from predators (Olabarria *et al.*, 2010; Lauringson and Kotta, 2006), or giving a higher dispersal capacity to organisms (Lauringson and Kotta, 2006). At high densities for a long period can negatively affect macrofaunal communities (Cardoso *et al.*, 2004) due to negative effects like hypoxia, reduced escape from predators, and lower predation efficiency (Lauringson and Kotta, 2006). Patchy algal mats may provide better habitat and food conditions than bare sediments (Lauringson and Kotta, 2006) while when mats are abundant and thick, hypoxia and sulfide develop below the mats impoverishing macrozoobenthos communities (Lauringson and Kotta, 2006; Wasson *et al.*, 2017). We can say that thin mats increase invertebrate diversity while thick ones decrease it (Wasson *et al.*, 2017).

Indirectly, algal wracks affect also higher trophic level consumers that feed on macroinvertebrates feeding on the wracks (Ulaski *et al.*, 2023).

Shredder organisms act as a link between wracks subsidy and nutrient cycling (Lowman *et al.*, 2019). Shredders break down detritus enhancing availability of organic matter to microbes that mineralize it producing ammonium that can be used by phototrophs or transformed in nitrate and exported in the sea or in deeper sediment for anaerobic microbes as terminal electron acceptor (Lowman *et al.*, 2019). Like seagrass wracks, algal wracks maintain

biodiversity and function increasing biomass and species richness compared to bare soil, that host poor-species assemblages and low abundant macrofauna (Ulaski *et al.*, 2023; Olabarria *et al.*, 2007).

Wrack-associated macrofauna can process more than the half of the material deposited and remineralize it (Lowman *et al.*, 2019). On algal wracks live flies, beetles, spiders and talitrid amphipods, these can have a large contribution on mats consumption rates (Lowman *et al.*, 2019).

Some invertebrate consumers prefer kelps over seagrasses due to lower phenols concentrations and more mucus secretion, this preference can affect macrofaunal communities and wrack persistence over time (Ulaski *et al.*, 2023).

There can be also a preference based on nutritional value, secondary metabolites, refuge value, relative availability, that are traits of the algae (Poore and Gallagher, 2013), but also herbivore traits like size, phylogeny and mobility (Poore and Gallagher, 2013). On the other hand, some detritivores are indiscriminate and feed mainly on microbes associated to wracks instead of wracks itself and do not discriminate between seagrass or algal wracks (Poore and Gallagher, 2013).

Successions of macroinvertebrates communities are seen throughout wrack decomposition, since aging wracks result in microclimatic changes (Ulaski *et al.*, 2023). Talitrid amphipods are the primary colonizers and most important consumers (Olabarria *et al.*, 2007), talitrid amphipods, tyloid isopods and tenebroid insects show a different distribution pattern due to environmental variables such as air temperature, moisture and relative air humidity (Olabarria *et al.*, 2007). Decomposition of algal mats and wracks can have a negative effect on macrofaunal benthic organism increasing sulfide concentrations, nutrients and microphytobenthos grow, and decrease sediment oxygen (Harris *et al.*, 2020).

Algal wracks can also be buried and release nitrogen and phosphorous, enhancing reproduction of microalgae, growth of bacteria and nearby vegetation (Olabarria *et al.*, 2010; Ulaski *et al.*, 2023). There is also a different turnover time of the detritus depending on the species, for example *Sargassum muticum* decomposes faster than *Fucus vesiculosus*, while ephemeral species like *Ulva sp.*, due to their low content of phenolic and refractory compounds, show a faster decomposition rate (Olabarria *et al.*, 2010).

There are also morphological differences in seaweed that can affect habitat complexity (Ulaski *et al.*, 2023), while wrack supply variability may depend on wave exposure, substrate characteristics and seasonality of seaweed growth (Ulaski *et al.*, 2023).

In salt marshes, marsh edges in contact with the main channels are exposed to wracks more than other areas (Wasson *et al.*, 2017). Algal wracks stranded on salt marshes can negatively affect growth of marsh plants through reduction of light, releasing harmful compounds like ammonia or sulfides and organosulfur, or an excessive release of nutrients throughout decomposition

(Wasson *et al.*, 2017). These effects are exacerbated by inundation rate increase and trampling (Wasson *et al.*, 2017). The effects of these stressors can be either a decrease in canopy height, percentage cover, flowering and vegetation retreat (Wasson *et al.*, 2017). The impact of algal wrack can decrease resilience of marshes against erosion threats and can negatively affect carbon sequestration of marsh plants (Wasson *et al.*, 2017; Bonometto, 2014).

#### 1.4 Sediment-water interface

Since in this work, the organism's community and environmental features of sediment underneath micro-niches of interest will be studied, it is important to introduce the concept of sediment-water interface. The dynamics of many marine ecosystems depend on the link between benthic and pelagic organisms (Snelgrove *et al.*, 2000). Sediment-water interface (SWI) is: "one of the most clearly defined ecological boundaries on Earth" (Snelgrove *et al.*, 2000). Here gradients, both physical and chemical, are steep, transitions occur in some millimeters scale and abundance of organisms like crustaceans or Polychaetas and nutrients is higher in sediment than the water column (Snelgrove *et al.*, 2000). Organisms living in sediments are also denser than ones living in the pelagic domain, since they do not need to cope with sinking, body forms are also more robust to permit burrowing of sediments (Snelgrove *et al.*, 2000).

There are connections across the sediment-water interface (SWI): life cycles, particulate and dissolved organic matter (Snelgrove *et al.*, 2000). Main ecological process link biodiversity above and below SWI (Austen *et al.*, 2002), including primary productivity, recruitment, decomposition and sediment stabilization (Austen *et al.*, 2002). Sediment mixing is controlled by biological activities like burrowing or feeding and they are defined as bioturbation (Snelgrove *et al.*, 2000). Phytoplankton both alive or dead cells, carcasses of fish and other animals but also fecal pellets of zooplankton sink to the bottom providing detritus for benthic organisms (Snelgrove *et al.*, 2000). In contrast, benthos helps nutrient recycling through decomposition (Austen *et al.*, 2002) fueling primary pelagic productivity (Snelgrove *et al.*, 2000).

Microbes are responsible for ammonium nitrate regeneration, denitrification, aerobic respiration, sulphate and metal reduction and phosphate release (Austen *et al.*, 2002). These actions are facilitated by meio and macrofauna and protists shredding (Austen *et al.*, 2002). In this case, bioturbation and bio irrigation affect the exchange of fluids (bio irrigation) and materials (bioturbation) through the SWI (Bertics and Ziebis, 2010; Austen *et al.*, 2002). Also, the life cycle of some benthic organisms, especially macrofauna, can be spent between the SWI, living above the boundary as eggs or larvae while adults migrate into the water to spawn or feed (Austen *et al.*, 2002). These movements occur seasonally and fluctuate annually (Austen *et al.*, 2002). More in general we can say that some species have a pelagic reproductive

dispersal stage while others have a below-SWI phase or life cycle (Snelgrove *et al.*, 2000).

In salt marsh ecosystems, fauna tends to be associated with different kinds of vegetation (Snelgrove *et al.*, 2000). The high organic load that causes anoxic events can also depress below SWI species richness (Snelgrove *et al.*, 2000). Since habitat complexity enhances biodiversity, infauna species richness in vegetated areas, such as seagrass and algal wracks, is higher compared to nearby bare sediments (Snelgrove *et al.*, 2000), due to actions like predation that tend to depress diversity in bare soils, and vegetated areas protect organisms from predation (Snelgrove *et al.*, 2000). Mangroves and salt marsh vegetated areas don't provide protection as well because here habitat complexity is higher than other vegetated habitats due to variability in salinity, temperature, exposure and oxygenation (Snelgrove *et al.*, 2000). Habitat complexity in salt marshes may have also negative effects on species for example marsh plants roots can exclude burrowers and infauna (Snelgrove *et al.*, 2000). Experiments in salt marshes with predators prove that predators here affect more the habitat modification than biodiversity itself, reducing only faunal density rather than diversity (Snelgrove *et al.*, 2000).

#### 1.5 Macrozoobenthos in soft bottom sediment

In shallow, coastal water basins, like the Lagoon of Venice (Oselladore *et al.*, 2022), the physical environment like the geomorphology, variable water dynamics and the benthic vegetation mosaics create an array of microhabitats, or micro-niches, that do impact macrofaunal communities (Sokolowski *et al.*, 2015). In soft bottoms there is a patchy variability of macrofauna, both epi- and infauna, influenced by environmental factors like grain size, organic carbon in sediments, food quality and availability; but also biological variables like food preference and habitat selection (Sokolowski *et al.*, 2015). These constraints are seen worldwide to influence macrofauna on soft bottoms in both in large scale patterns (for example seas and coastlines) and small-scale patterns (like coastal lagoons) (Sokolowski *et al.*, 2015).

In soft bottom-benthic ecosystems organisms are classified into different categories according to their body size: pico-, micro-, meio- and macrofauna (Cibic *et al.*, 2017). Macrozoobenthos includes all invertebrates larger than 0,5 mm living close to the sediment (Magni *et al.*, 2022; Oselladore *et al.*, 2022) including molluscs, Polychaetas, crustaceans and echinoderms (Herman *et al.*, 1999). Meiofauna comprises organisms especially nematodes, copepods, ostracods and foraminifera large between 32  $\mu\text{m}$  and 0,5 mm (Herman *et al.*, 1999; Magni *et al.*, 2022) and microfauna has organisms, usually bacteria and protista smaller than 32  $\mu\text{m}$  (Herman *et al.*, 1999). There is also another classification based on feeding habits, in particular suspension feeders filter plankton from the water column, while deposit feeders feed on deposition of particles in the sediments (Herman *et al.*, 1999). Macrozoobenthos organisms filter phytoplankton, oxygenate sediments, participate in nutrient cycle and

metabolize pollutants being very important for ecosystem processes (Oselladore *et al.*, 2022).

Main phyla present are: polychaetes, bivalves, gastropod molluscs and amphipods and copepods crustaceans (Oselladore *et al.*, 2022). Their distribution depends on both abiotic factors, such as salinity, depth, sediment composition, size and hydrodynamic, and biotic factors like inter- and intra-specific competition and predation. (Oselladore *et al.*, 2022; Boutoumit *et al.*, 2021). For the Water Framework Directive (WFD/2000/60/EC) they are considered biological quality elements to assess ecological quality in transitional waters since they are strongly affected by stressors and pollutants (Oselladore *et al.*, 2022; Boutoumit *et al.*, 2021).

Transitional waters, due to their fluctuation of environmental variables, present a reduced diversity of organisms with the presence of tolerant species able to adapt to changes in environmental conditions in comparison to the nearby marine environment (Tagliapietra *et al.*, 1998, Guadagnin, 2021; Oselladore *et al.*, 2022). But in general, a high number of species characterize transitional waters in good environmental status (Oselladore *et al.*, 2022).

Macrozoobenthos is also a source of food for higher trophic levels collaborating to the transport of primary production (Oselladore *et al.*, 2022; Boutoumit *et al.*, 2021). From an ecological point of view, organisms are classified into producers or autotrophs, consumers and detritivores (heterotrophs) (Cibic *et al.*, 2017). Meio and macrofaunal detritivores do not feed only on microalgae but also sediments, so grazing and detrital food webs are interlinked by processes of flow of energy and carbon (Franzo, 2012). Not only primary production but also mineralization and respiration processes should be considered (Cibic *et al.*, 2017). The process must be considered very flexible in responding to chemical, physical and biological factors either if they are natural or anthropological (Cibic *et al.*, 2017). In benthic ecosystems relationships between organisms are very variable, and can change depending on anthropogenic or natural causes, this variability is present because of a diversity in feeding strategies with non-selective organisms feeding on different sources like detritus or microalgae (Franzo, 2012), however some organisms change their feeding strategies maturing from larvae to adults (Franzo, 2012).

Macrozoobenthos living in soft-bottoms in the intertidal zone is adapted to harsh and variable conditions like wave action, substrate instability and tidal exchange, having the possibility to increase primary productivity where patches of vegetated detritus like wracks is found (Ulaski *et al.*, 2023). In the sediment of the Lagoon of Venice there are less species compared to marine bottoms, since they must be adapted to wide salinity, temperature and dissolved oxygen variations (Guadagnin, 2021).

Biodiversity is used to measure organism variability in nature either regarding differences in genetics, species, habitat and ecosystem (Snelgrove *et al.*, 2000). To measure biodiversity different indicators are used, such as the Shannon-Weiner (H) index, Hurlbert rarefaction and Whitaker index

(Snelgrove *et al.*, 2000). Whitaker indexes refer to alpha and gamma diversity (Snelgrove *et al.*, 2000). Alpha diversity refers to a small, homogeneous area, in the case of benthos could be the smallest core sampler used (Snelgrove *et al.*, 2000), while gamma is the diversity of a region obtained integrating alpha diversity (Snelgrove *et al.*, 2000). Benthic ecologists usually estimate alpha diversity for habitat comparison and sometimes gamma (Snelgrove *et al.*, 2000).

## 1.6 Sediment granulometry

In coastal bottom ecosystems, sediment granulometry is the ecological variable more studied together with organic matter composition (Rigotti, 2019) and is also studied in this work. In benthic ecosystems, there is an animal-sediment relationship, since there are strong associations between fauna and the sediments where they live (Forde *et al.*, 2012). Sediment plays an important role in providing food and substratum in bottom-dwelling organism (Jayaraj *et al.*, 2008), the energy profile of water flow above the sediment determines the particle size in the upper part of sediment since granulometry is affected by water currents and waves (Jayaraj *et al.*, 2008) affecting indirectly benthic communities (Jayaraj *et al.*, 2008). Grain size is an indicator of sediment deposition, but also sediment transport in the shoreline indicating high energy environments (Jayaraj *et al.*, 2008). Benthos is influenced mainly by sediment grains size and silt-clay content (Jayaraj *et al.*, 2008; Mancinelli *et al.*, 1998), for example, Polychaetas, molluscs and fish larvae prefer sand sediment texture (Jayaraj *et al.*, 2008), sandy and heterogeneous sediment in general host a higher species richness than clayish and homogeneous one (Mancinelli *et al.*, 1998). We can say also that fine sediment host higher densities macrobenthos than coarse that have poor organic content instead of the firsts, since they have a higher trophic enriched bottom (Mancinelli *et al.*, 1998).

There is also a different feeding type macrofauna preference regarding different grain-size sediments (Mancinelli *et al.*, 1998): filter feeders prefer silt-clay and high organic load sediment while deposit feeders prefer sandy sediments with a lower organic load (Mancinelli *et al.*, 1998). Tubicolous Polychaetas (deposit-feeders) prefer intermediate grain sizes (Mancinelli *et al.*, 1998). Except this, very few studies demonstrate a strong correlation between macrofaunal communities and sediment grain size (Forde *et al.*, 2012) because there is not a single causative factor but there are a lot of factors interacting together with granulometry in influencing macrofaunal distribution (Forde *et al.*, 2012). These factors are both biotic and abiotic like: competition, both intra- and inter-specific, pollution, microbial activity, organic matter content, bioturbation and physical disturbance like sediment transport resuspension, accumulation and hydrodynamics (Forde *et al.*, 2012; Mancinelli *et al.*, 1998). Based on sediment components size, there is a granulometric scale: the more used is the Wentworth scale (1922), that divides the sediment in five different classes (Rigotti, 2019). Based on

Wentworth scale (1922): Coarse sand is between 2000 and 500  $\mu\text{m}$ , medium sand is between 500 and 125  $\mu\text{m}$ , fine sand between 125 and 63  $\mu\text{m}$ , silt between 63 and 3,9  $\mu\text{m}$  while clay is less than 3,9  $\mu\text{m}$  (as reported on table 1) (Rigotti, 2019). Bigger classes like boulder, cobble and pebble are usually not considered in soft-bottom ecosystems studies (Rigotti, 2019), like this one.

### 1.7 Goals of the thesis

This thesis has the aim of studying the climatic micro-niches represented by the seagrass wracks and algal wracks in the salt marshes of the Venice lagoon, regarding both environmental and biological features. An important goal is to physically characterize these micro-niches, sampling also temperature, relative humidity, organic matter content and granulometry of the salt marshes algal and seagrass wracks, marsh vegetated areas (*Salicornia fruticosa*) and bare marsh soil. The study will also consider the taxonomic identification and quantification of the sampled invertebrates living in the wracks, to test whether there is any difference in terms of macrozoobenthos communities between the wracks, marsh vegetated areas and the bare soil. Outcomes are important to understand the functioning of these climatic micro-niches and if they can help to protect organisms during extreme events like summer heat waves which are foreseen to increase under future climate change (Hayhoe *et al.*, 2010).

In particular, the aims of the thesis are:

- 1) the study of environmental features, in this thesis measured as temperature, granulometry, organic matter and humidity of wracks, *Salicornia fruticosa* vegetated areas and bare salt marsh soil;
- 2) the taxonomic identification and quantification of organisms' assemblages within wracks, *Salicornia fruticosa* vegetated areas and bare soil;
- 3) to study if there is a relation between environmental feature measured of wracks and the organism community found in these micro-niches.

## 2. MATERIAL AND METHODS

We sampled three sites on a salt marsh in the southern Venice Lagoon. In each site we collected benthic biota samples and abiotic variables from areas characterized by wracks, halophyte vegetation (dominated by *Salicornia fruticosa*) and bare soil. The differences in community structure and composition in the three microhabitats were then tested and correlated to differences in abiotic variables. Sampling was repeated twice during summer 2024 (in June and July) to also have a temporal perspective on the issue. In our sites wrack formations were generally constituted by a mixture of algae and stranded seagrasses, so we were not able to compare the two main kinds of wracks and merged those samples in a unique ‘treatment’ of vegetal wracks.

### 2.1 Study site selection and sampling campaigns

#### 2.1.1 Study site selection

Three different sites in a natural salt marsh in the southern Lagoon of Venice called “Cà Manzo” (VE) (as shown in figure 2) were chosen as study sites. The marsh was chosen because of its exposure to the main wind direction (north-east) which facilitates the stranding of floating materials. The Cà Manzo salt marsh also presents high quantities of algae and seagrasses in the nearby shallow bottoms. On the marsh we selected sites where the three ‘conditions’ (wrack, vegetation and bare soil) appeared close to each other. For the ‘wrack’ condition we selected areas where the accumulation was thicker and older to minimize the chances of having them washed away by the tides during the experiment (as shown in figure 1). Another relevant feature for site selection was the position: the Cà Manzo salt marsh is subjected to a relatively small fetch which, again, reduces the chances of wracks getting lost or eroded due to the high hydrodynamical forces. The three different sites in the same salt marsh were distant around fifty meters from each other, each site presented the three micro-niches we were looking for (as shown in figure 1). At the beginning, in March 2024 we preliminarily chose to study two different salt marshes, splitting the three sites in two salt marshes, one in Fondo dei Settemorti (PD) and one in Cà Manzo (VE) since a study goal was also to see if there was any difference in terms of macrozoobenthos and environmental variables between different salt marshes. The sites were distant some kilometers away from each other, but after a month the site in Fondo dei Settemorti was conditioned by some strong storms that washed away the wracks of the study site destroying the experimental units. This event forced us to change our plans, and we decided starting from May 2024 to do all the experiment in the same salt marsh in Cà Manzo, more protected from the strong wind action than Fondo dei Settemorti.

### 2.1.2 Sampling campaigns

In March 2024 a first explorative campaign was performed to evaluate different potential salt marshes and test the sampling techniques. Different benthos samples were taken and analyzed to train and intercalibrate the operators, Joseph Da Pos and Mattia Panin, in the recognition of organisms. Once the sites were chosen, temperature sensors were positioned for the long-term continuous monitoring.

On June 4<sup>th</sup> the first sampling was performed: sediment samples for granulometry and organisms' identification of the three sites in Cà Manzo, sampling three random replicates per treatment for organisms' identification and granulometry and collecting one humidity measure per treatment (sampling close to the logger). GPS data and elevation of temperature loggers were also taken. On July 18<sup>th</sup> organisms were sampled for identification, collecting three random replicates per treatment, sediment was also used for organic carbon analysis. Humidity data were collected, collecting one measure per treatment (sampling close to the logger). In the same campaign temperature data were also downloaded from the loggers. Samples were taken approximately at the same elevation and distance from the water.

For each sampling day, we sampled only the morning, we noted the date, tide, starting time and finishing time, weather and sea conditions. To plan the sampling days we checked the weather, sea conditions and especially the predicted tide level, sampling only during the low tide to be able to have the entire study site empty from the water coverage.

### 2.1.3 GPS location

Sampling sites were named using a number from 1 to 3 for site specification, and adding letters B, S, W for treatment specification. B means bare soil, S means *Salicornia fruticosa* vegetated area, W means wracks (as shown in figure 2).

For GPS data detection ZENITH16 GNSS (GEOMAX) (<https://geomax-positioning.com/it-it/products/gnss/zenith16-series>) was used, and data were later downloaded in a .txt file. Elevation was measured placing the GNSS device as close as possible to the temperature logger stick.

Elevation data were later corrected subtracting 43.256 meters. This value explains the combination of the ellipsoidal height measured with GNSS in Chioggia Punta San Felice and general effect of subsidy and eustatism on the Venice Lagoon (<https://www.unavco.org/software/geodetic-utilities/geoid-height-calculator/geoid-height-calculator.html>). Later 8.5 cm were added to corrected data, that represents the tip length.

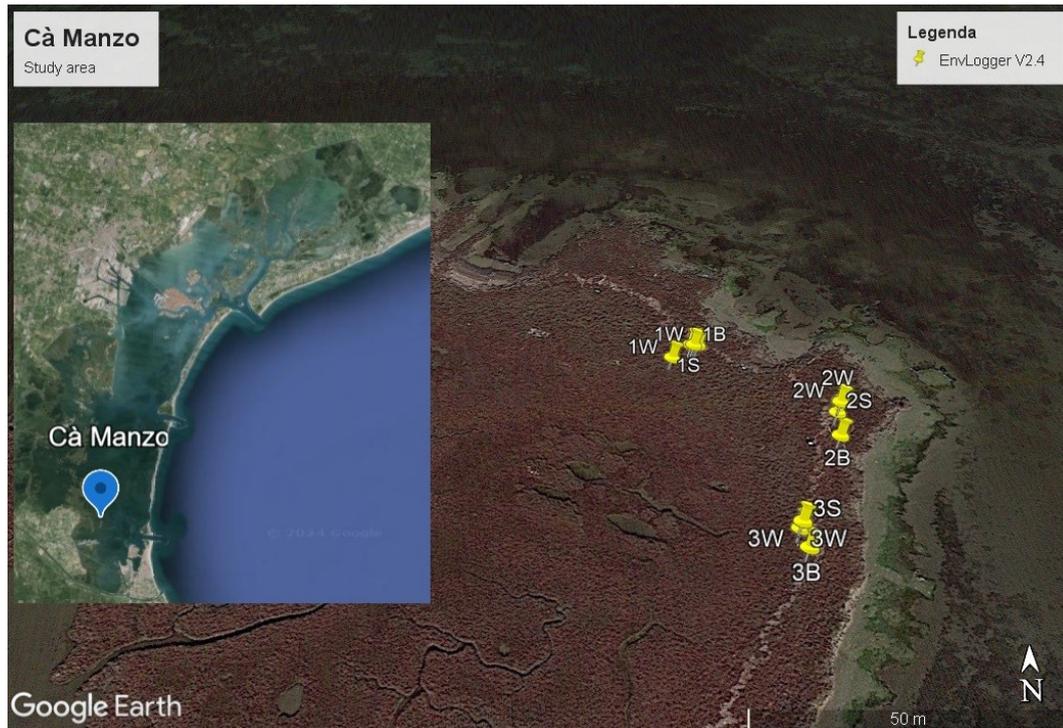


Figure 2. Google Earth picture showing the study area in Cà Manzo placed in the southern Lagoon of Venice and the experimental design splitted in three different study sites in the same salt marsh in Cà Manzo. 1= site 1; 2= site 2; 3=site 3. B= bare soil; S= *Salicornia fruticosa* vegetation; W = vegetal wracks.

## 2.2 Experimental design

For the experiment three sites were chosen in the same salt marsh. For each site three treatments were fixed: wracks, *Salicornia fruticosa* (marsh plant) vegetated area and bare soil. For each treatment a temperature logger was fixed at the edge of the soil, temperature was sampled continuously each 30 minutes and data were later downloaded on June July 18<sup>th</sup>. For each treatment three replicates of sediment for macrozoobenthos identification were sampled in each campaign on June 4<sup>th</sup> and July 18<sup>th</sup> (the closest possible to the loggers). Humidity was sampled in each campaign on June 4<sup>th</sup> and July 18<sup>th</sup> collecting one data per treatment the closest possible to temperature loggers. GPS location and elevation of each treatment was taken only during the campaign of June 4<sup>th</sup>, the closest possible to the loggers. TOC and granulometry were sampled collecting one sediment sample per treatment. Granulometry was sampled only during the campaign of June 4<sup>th</sup>, TOC only during the campaign of July 18<sup>th</sup>.

## 2.3 Temperature variability measure

### 2.3.1 Temperature loggers

To measure the temperature variability of the different micro-niches EnvLoggers V2.4 (ElectricBlue) (<https://electricblue.eu/>) were used. This logger allowed us to perform precise (0.1°C precision) long term monitoring, data were downloaded on July 18<sup>th</sup>. Loggers were fixed to wooden sticks and placed as close as possible to the sediment (but without pushing them into the mud) underneath the wrack or the plants when present (as shown in figure 3 and 4). The sensors were set to measure temperature every 30 minutes to be able to have the best trade-off between resolution and battery lifespan and data were downloaded on each sampling day.

A total of 12 Electric blue EnvLogger V2.4 27 mm were used for our study, for each site, four loggers were deployed.



Figure 3. Wrack treatment with the temperature ElectricBlue EnvLogger V2.4 inside and the stick to fix it on site 3 in Cà Manzo.

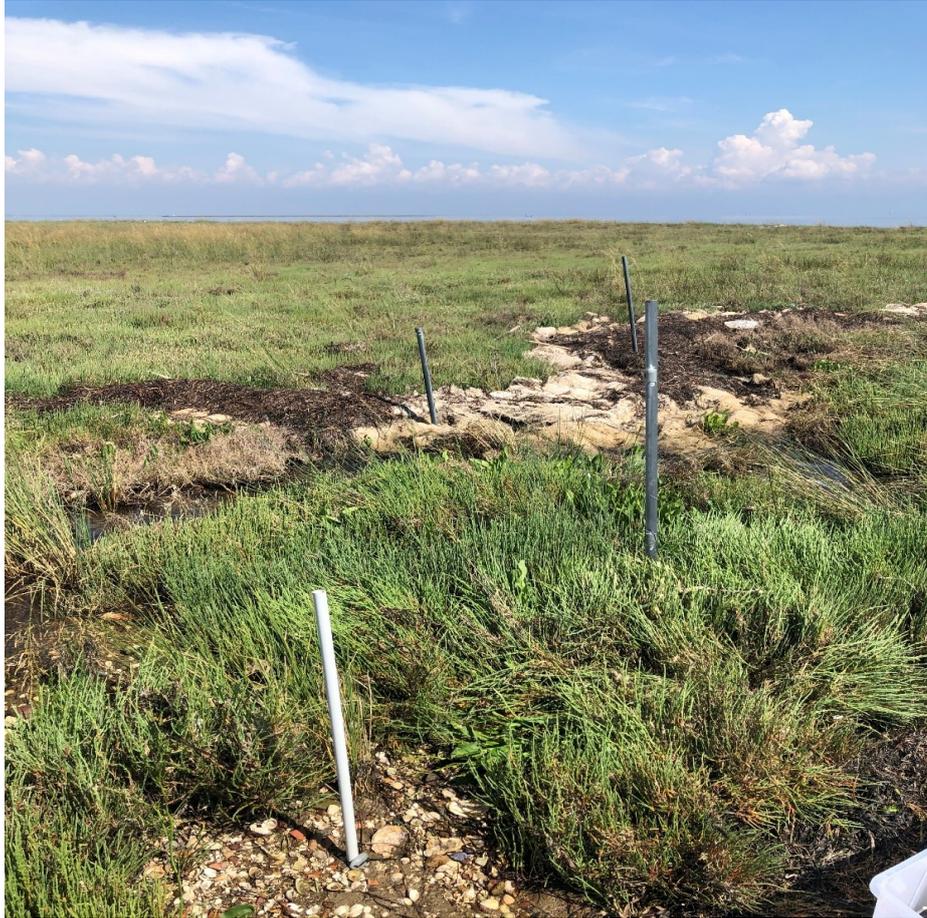


Figure 4. Three different treatments on the site 3 in Cà Manzo, from the bottom: bare soil, *Salicornia fruticosa* area and wracks.

### 2.3.2 Temperature calculations

Once temperature data were downloaded, it was calculated: daily average temperature, maximum daily temperature, minimum daily temperature, temperature range between daily maximum and minimum, and temperature daily difference, either between maximum and average and minimum and average for each treatment and site.

Daily calculations were done with temperature measures taken within a range of 24 hours to have a daily pattern.

## 2.4 Humidity measure

### 2.4.1 Relative humidity

Air is a mixture of gases and the pressure of air is calculated by the sum of partial pressures of its components following Dalton's law (Ramis *et al.*, 2012), partial pressure of water present in the air is the measure of water in the atmosphere (Ramis *et al.*, 2012) and saturation vapour pressure is defined as: "the maximum vapour pressure value at a determined temperature and this value cannot be surpassed unless sublimation or condensation occurs" (Ramis *et al.*, 2012).

Air water vapour has a temporal and spatial variability, relative humidity is expressed in percentage and is a quotient between vapour pressure and saturated vapour pressure at a determined temperature (Ramis *et al.*, 2012).

$$RH \% = 100 * e / e_s(t)$$

Where:

RH % is the relative humidity in percentage (from 0 to 100 %)

e is the vapour pressure

$e_s(t)$  is the saturation vapour pressure

(Ramis *et al.*, 2012)

### 2.4.2 Hygrometer

To characterize the physical profile of wracks is also important to measure humidity. To measure humidity an hygrometer Humidity and Temperature Meter with Dew Point and Wet Bulb Temperature M86 (Mengshen) was used (<https://imengshen.com/products/mengshen-digital-temperature-and-humidity-meter-with-dew-point-and-wet-bulb-temperature-battery-included-m86>). This instrument measures both temperature and relative humidity (RH), dew point and wet bulb temperature. Humidity range is between 0 and 100 %, temperature between -20 and 80 C°, dewpoint temperature between -20 and -80 C° and wet bulb temperature between 0 and -100 C°. Accuracy is +/- 3 RH, +/- 5 C° and resolution is 0,01 C°. Humidity value was taken when hygrometer measure was stabilized.

Humidity was sampled on every sampling day putting Hygrometer humidity Meter m86 inside wracks, bare soil and *Salicornia fruticosa* vegetated area in contact with the EnvLoggers V2.4 that we used for temperature sampling.

## 2.5 Sediment granulometry analysis

For granulometry analysis one random replicate per treatment was analyzed. To check similarity of replicates collected within a treatment also a random triplicate from a random treatment was analyzed. Samples of sediment for granulometry analysis were taken during the sampling of June 4th from the sediment samples of macrozoobenthos. 20 gr of sediment were weighed from each sample, also from sediment samples that were not analyzed, to minimize standard error in taxonomic identification.

### 2.5.1 Grain size protocol

20 gr of sediment were weighed using a balance and a spoon, previously mixed in the 500 mL phytoplankton bottle (Laswell *et al.*, 2010). Later weighed sediment was put in a beaker, then:

- Add 100 ml of H<sub>2</sub>O<sub>2</sub> 15% and mix the sample 2-3 times per day, to help peroxide work, repeat till bubbles are not formed anymore, H<sub>2</sub>O<sub>2</sub> degrades the organic component of the sample.
- Add 10 ml of 6.2 g/L dispersant agent sodium hexametaphosphate (NaNHP), to each beaker, stir for 15 minutes and let the sample rest for 4/5 hours.
- Dry the sample in the oven at 62 C° overnight (62 C° are enough, but with 100 C° there is the 100 % probability that the sample is dried). (see Buchanan, 1984)

### 2.5.2 Granulometry size analyzer

To measure granulometry a LS 13 320 XR Laser Diffraction Particle Size Analyzer, 2022 (Beckman Coulter) was used. (<https://www.beckman.com/particle-characterization/ls-13-320-xr/features>). This instrument uses the principle of light scattering to measure diameter of particles in a liquid or dry powder. This technology measures granulometry by measuring scattering patterns of particles, and each pattern is characteristic of the size of particles. Electric light scattering (ELS) is the main method for particle size characterization since the intensity of scattered light is a function of particles' optical properties and dimension. From the scattering intensity it is possible to resolve size distribution of particles, knowing the relationship between particle size, scattering angle, scattering intensity and particle shape. In this analysis, all particles, sediment in our case, are considered as a sphere, with diameter as the only variable measured.

As light primary source the particle size analyzer uses a 5-mW laser diode of 750 nm. Light from diode is monochromatic. The sample is collected in a sample cell, in which beam light passes through and then through Fourier optic light is scattered into three sets of detectors.

The secondary source is a tungsten-halogen light that has a set of filters that select different wavelengths through two orthogonally oriented polarizers and is detected by six groups of detectors.

(LS 13 320 XR Laser Diffraction Particle Size Analyzer Instructions for Use, Beckman Coulter, 2022; <https://www.beckman.com/particle-characterization/ls-13-320-xr/features>).

Data are exported in micrometers and in Phi, following Krumbein granulometric scale, modified from Wentworth (as shown in table 1).

$$\text{Phi} = -\log_2 D/D_0$$

Where:

D= diameter of the particle in the sample

D<sub>0</sub>= standard diameter 1 mm

( LS 13 320 XR Laser Diffraction Particle Size Analyzer Instructions for Use, Beckman Coulter, 2022; <https://www.beckman.com/particle-characterization/ls-13-320-xr/features> ; Krumbein, 1938)

Dimensional range	Phi	Wentworth
2–4 mm	from -1 to -2	Granule
1–2 mm	from 0 to -1	Very Coarse sand
½–1 mm	from 1 to 0	Coarse sand
¼–½ mm	from 2 to 1	Medium sand
125-250 µm	from 3 to 2	Fine sand grain
62,5–125 µm	from 4 to 3	Very fine sand grain
3,90625–62,5 µm	from 8 to 4	Silt
< 3,90625 µm	> 8	Clay particle
< 1 µm	>10	Colloid

Table 1. Dimensionale range of particles with correspondent Krumbein and Wentworth scale.

(Rigotti, 2019; Krumbein, 1938; Blair and McPherson, 1999)

Data were later exported in Excel and for each treatment relative % of sand, silt and clay from Wentworth scale were calculated using Krumbein Phi scale (Laswell *et al.*, 2010; Krumbein, 1938). For each treatment, only overlapping laser run patterns were considered for calculation, having three run per sample at maximum. Using these data, through a textural triangle of Agricultural Technology Center (<https://agritechcenter.com.np/soil->

[calculator.html](#)), each granulometric class was calculated considering relative percentages of silt, clay and sand. Later data were exported, and a total textural triangle was calculated (Shailesh Kumar *et al.*, 2023).

## 2.6 Total organic carbon

As said in the introduction, another important environmental variable to analyze in macrozoobenthic communities' identification works is the organic matter in soil (Rigotti, 2019). Organic matter can strongly affect macrozoobenthos communities (Sokolowski *et al.*, 2015) and here is measured as total organic carbon (TOC). There are different methods to measure total organic carbon, but the one that has been used here is the one by Gazzetta Ufficiale: method 248 (1999).

As for granulometry, one random replicate per treatment was analyzed. Also, as for granulometry, one random triplicate from a random treatment was analyzed to check similarity of replicates within a treatment. To do the analysis a CHNS analyzer was used. Samples of sediment for organic carbon analysis were taken during the sampling of July 18th from sediment samples of macrozoobenthos. 20 gr of sediment were weighed from each sample, also from sediment samples that were not analyzed, to minimize standard error in taxonomic identification.

### 2.6.1 Sample preparation

Circa 20 gr of sediment were weighed from sediment samples (Gazzetta Ufficiale: method 248, 1999).

Then:

- Put the sediment in a crucible and dry it at 100 C° till reach a constant weight.
- Grind it using a mortar and a 500 µm mesh-size sieve.
- Weight between 8 and 9 mg of sediment per sample in a silver capsule using an analytical balance.
- Add 40 µl of HCl 10 % per sample then let sample rest overnight
- Dry the sample in oven at 65 C° for 4 hours.
- Seal silver capsule, then transfer it into a tin capsule and transfer it in the autosampler.

(Gazzetta ufficiale: method 248, 1999)

### 2.6.2 CHNS analyzer

For the analysis of organic carbon, a Flash smart elemental analyzer (Thermo Scientific) was used (<https://www.thermofisher.com/order/catalog/product/11206100>). It is a gas chromatograph that burns the sample at 1800 C° and detects the difference in electrical conductivity between the sample part passing through channel

only with reference (only He) and the one passing through channel with combustion gases and He (carrier).

The outcome is reported as a percentage of the total organic carbon (TOC) per sample.

As parameters for the analysis were used:

- He flux “reference” 140 ml/min
- He flux “reference” 100 ml/min
- O<sub>2</sub> flux 250 ml/min
- Run time 400 s (per sample)

## 2.7 Benthic community sampling and characterization

### 2.7.1. Macrozoobenthos sampling

A plastic quadrat 20 X 20 cm was used to sample the invertebrates. For each treatment three random replicates were sampled. For wrack treatment, the quadrat was put over the wrack and through a knife the wrack was opened and organisms together with the wrack were collected by hand and put in a 10 L plastic bag. Below the wrack, the first centimeter of soil was sampled using a trowel and later was collected in a 500 mL phytoplankton bottle with the help of a funnel. Both plastic bag and phytoplankton bottle were previously marked with the name of the replicate for the cleaning and sorting process (Ince et al., 2007).

The same procedure was followed for *Salicornia fruticosa* vegetated area and bare soil, but only collecting the first centimeter of soil since these treatments were free from stranded vegetal wrack.

### 2.7.2 Sample cleaning

#### 2.7.2.1 Soil samples cleaning

From the 500 ml phytoplankton bottle, after taking 20 gr of sediment from each sample for sediment analysis, we followed this procedure:

- Wash all the sediment in the bottle pipetting with water using a 2 mm mesh-size sieve above and a 0,5 mm mesh-size sieve below. Sieve everything, washing carefully with water.
- Once sieved, use a spoon to take out all the organism from the 0,5 mm mesh-size sieve and put them in a falcon previously marked with the name of the replicate helping with a funnel. Add ethanol 70 % exceeding the first centimeter of the sample in height.
- collect all the organisms and detritus from the 2 mm mesh-size sieve using a spoon, put them again in the 500 mL phytoplankton bottle and add ethanol 70 % exceeding the first centimeter of the sample in height.

### 2.7.2.2 Wracks samples cleaning

10 L plastic bag with macrozoobenthos and wrack was opened:

- Wash carefully with water 50 % of the wracks sample twice for 30 seconds each using a 2 mm mesh-size sieve. After each wash, sieve the water at the bottom collector using a 0.5 mm mesh-size sieve.
- After the second time collect the organisms left in the 2 mm mesh-size sieve, taking away all the detritus and taking a fixed time of 5 minutes for organisms' collection. Collect them with a tweezer searching them in the sieve and leaves and put them in a pre-marked falcon.
- Collect all the organisms left in the 0,5 mm mesh-size sieve, sieve carefully and put them in the same falcon and fix them in ethanol 70%.
- Use water to collect organisms at the edge of the sieve.
- Repeat the same protocol for the other 50 % of detritus.
- Collect all the sample in the same Falcon previously marked and fix it in ethanol 70% exceeding the first centimeter in height.

It was important to not leave sieves without any bottom collector to be able to filter again.

### 2.7.3 Organism sorting

To sort the organisms each sample was opened and briefly washed to remove alcohol. Then the material was put on a white plate with water to help the sorting. Organisms were divided into different Eppendorf tubes and ethanol 70 % was added, one centimeter thick over the organism, to preserve them. The excess detritus was washed with water to collect the organisms attached to leaves and later was put apart from the sample. See also: Oselladore *et al.*, 2022; Tagliapietra *et al.*, 1998; Tagliapietra *et al.*, 2016; Sfriso *et al.*, 2001.

### 2.7.4 Taxonomic identification and quantification

Organisms were identified using some taxonomic keys present in scientific papers and taxonomic identification books presents in the library of the Hydrobiological Station (see Sconfetti, 2004; D'Angelo and Gargiullo, 2010; Riedl, 1986; Ruffo, 1998; Sansoni, 2001). For taxonomic identification organisms were put in a Petri dish. To search for the features of the smaller organisms a stereomicroscope was also used. Accuracy was till the lowest possible taxonomic level to avoid errors. Taxon and species name were checked throughout the database WoRMS (World Register of Marine Species) (<https://www.marinespecies.org/aphia.php?p=search>). (see also Oselladore *et al.*, 2022)

The organisms, once identified, were counted to set a presence number for each taxon.

Later the features of the organism community present in this study area in Cà Manzo were assessed. Main features assessed were abundance, but also locomotory behavior, feeding strategy, habitat, size and phylum. These functional traits were selected to ecologically characterize the community.

## 2.8 Data analysis

For data analysis PRIMER-e v6 software was used (Clarke *et al.*, 2014). Principal component analysis (PCA), permutational multivariate analysis of variance (PERMANOVA), either main test and pair-wise and Similarity percentage (SIMPER) analysis were done using environmental data.

Non-metric multidimensional scaling (nMDS), permutational multivariate analysis of variance (PERMANOVA), both Main test and pair-wise and Similarity percentage (SIMPER) analysis were done using taxonomic identification data (Oselladore *et al.*, 2022).

nMDS and PCA are two data ordination methods that show patterns of ordinated samples on two dimensions. PERMANOVA, either main test and pair-wise, is a statistical test that shows whether the observed differences are statistically significant between treatments, sites and month (main test) and between pairs of levels of them (pair-wise). The SIMPER analysis shows which variables (either environmental or biological) contribute the most to dissimilarities between levels of factors (Clarke *et al.*, 2014).

Either for biological data or environmental data were prepared two different PRIMER Datasets, using Excel.

### 2.8.1 Environmental data

For environmental data, a dataset with RH in percentage (%) and textural class expressed in number was prepared. Number were assigned based on textural class, that depends on the percentage of sand, silt and clay in the sediment: 1 was assigned for silt loam, 2 was assigned for loam, 3 was assigned for sandy loam.

For temperature, the average temperature of the first 10 days before the sampling of June and July were calculated. Regarding site 3, since loggers were fixed on the campaign of June, the mean of sites 1 and 2 were used, since loggers were relatively close each other and site 1 and 2 showed a similar average temperature. Elevation was analyzed in centimeters and total organic carbon (TOC) in percentage (%).

Environmental data were first normalized, and a resemblance matrix was performed using Euclidean distance. For environmental data principal component analysis (PCA) was done with, as factors, site, treatment and month. The PERMANOVA Main test was done with site as random factors, treatment and month as fixed factors, design was tested with Monte Carlo test. From the main test results a pair-wise test was done between more

significant factors. As last test SIMPER analysis was done to test which were the variables more strongly contributing to dissimilarities between factors (Clarke *et al.*, 2014).

### 2.8.2 Biological data

In the dataset the identified organisms were identified to the lower taxonomic level possible with their relative abundances.

Biological data were first pretreated: they were first transformed using the function ' $\log(X+1)$ ', a resemblance matrix was performed using Bray-Curtis similarity. This matrix was used to perform nMDS with factors site, treatment and month.

The PERMANOVA main test was done using site as random factor and both treatment and month as fixed factors, design was tested using Monte Carlo test.

To better explore the data also a pair-wise test was done between more significant factors. As last test SIMPER analysis was done to test which were the taxa more strongly contributing to the dissimilarities between factors (Clarke *et al.*, 2014).

### 3. RESULTS

#### 3.1 Daily temperature fluctuations

##### 3.1.1 Temperature in Fondo dei Settemorti

The first sensors installed in the experimental sites were six EnvLoggers V2.4 in Fondo dei Settemorti splitted in two different sites, installed on March 18<sup>th</sup>, 2024, and removed on May 2<sup>nd</sup>, after the site wracks disruption by strong storm surges as demonstrated by visual inspection.

This data represents the first pilot monitoring used to explore differences in temperature between the treatments and test the instruments and protocol. Temperature data were plotted on Microsoft Excel (as shown in fig. 5 and 6).

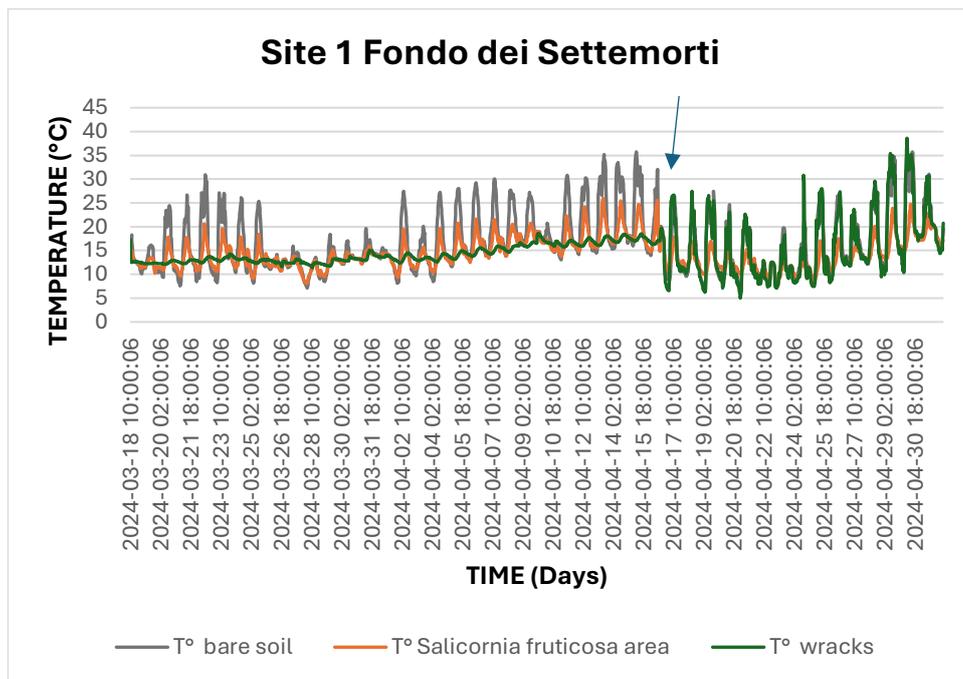


Figure 5. Temperature fluctuations of the site 1 in Fondo dei Settemorti. Green line: wracks; orange: *Salicornia fruticosa* vegetated area; grey: bare soil. Arrow indicates when wracks were presumably washed away by storms.

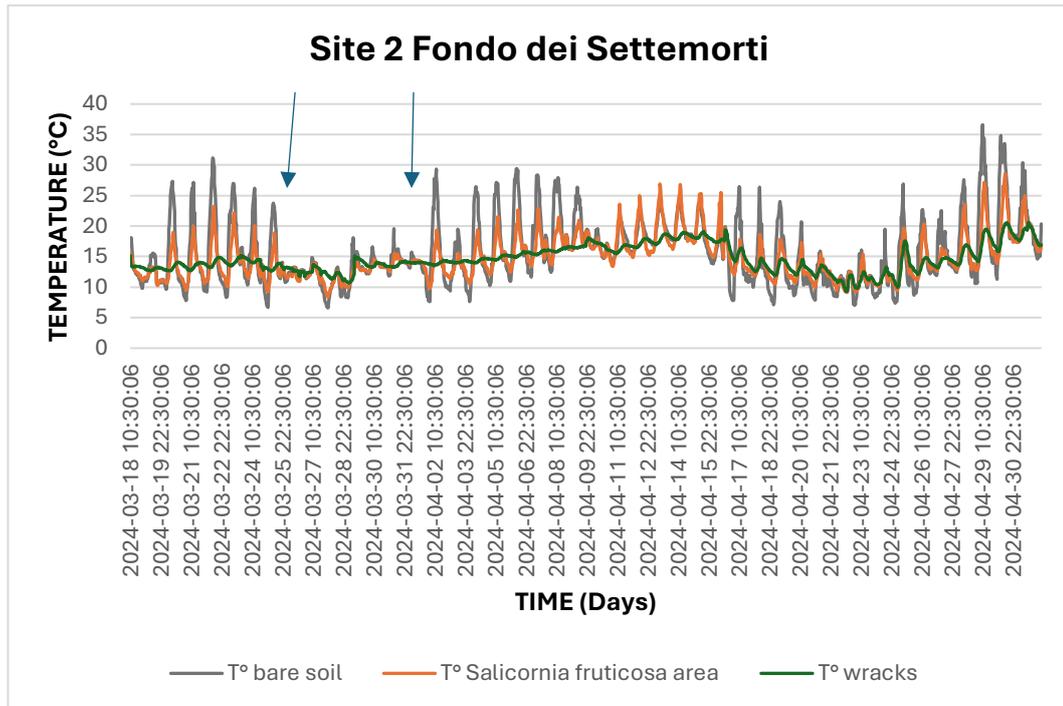


Figure 6. Temperature fluctuations of the site 2 in Fondo dei Settemorti. Green line: wracks; orange: *Salicornia fruticosa* area; grey: bare soil. The couple of arrows indicate the period when bare soil loggers and *Salicornia fruticosa* were buried.

The three different treatments have different temperature daily fluctuations: wracks show always an almost about constant temperature, that range in maximum 1-2 °C daily and does not show high or low temperature peaks. Bare soil, since it is spoiled from any vegetal cover, shows daily temperature fluctuations of about 15- 20 °C. *Salicornia fruticosa* vegetated area fluctuates around 10 °C daily. On site 1 (fig. 5), it is possible to see the overlapping of wracks and bare soil temperature fluctuations since after mid-April (presumably) all the wracks were washed away, and the logger was sampling bare soil temperature. On site 2 (fig. 6), this overlapping is not seen while it looks like all the temperature loggers were buried by the sand transported during the storm surges. In both graphs, tide-related fluctuations are not seen, probably due to a high elevation of the salt marsh study sites, so loggers were not flooded by water.

### 3.1.2 Temperature in Cà Manzo

Temperature sensors EnvLoggers V2.4 on site 1 and 2 in Cà Manzo were installed on May 2<sup>nd</sup> while on site 3 were installed on June 4<sup>th</sup>. As in Fondo dei Settemorti, also in Cà Manzo some wracks were characterized by the wash-off by wind and storms.

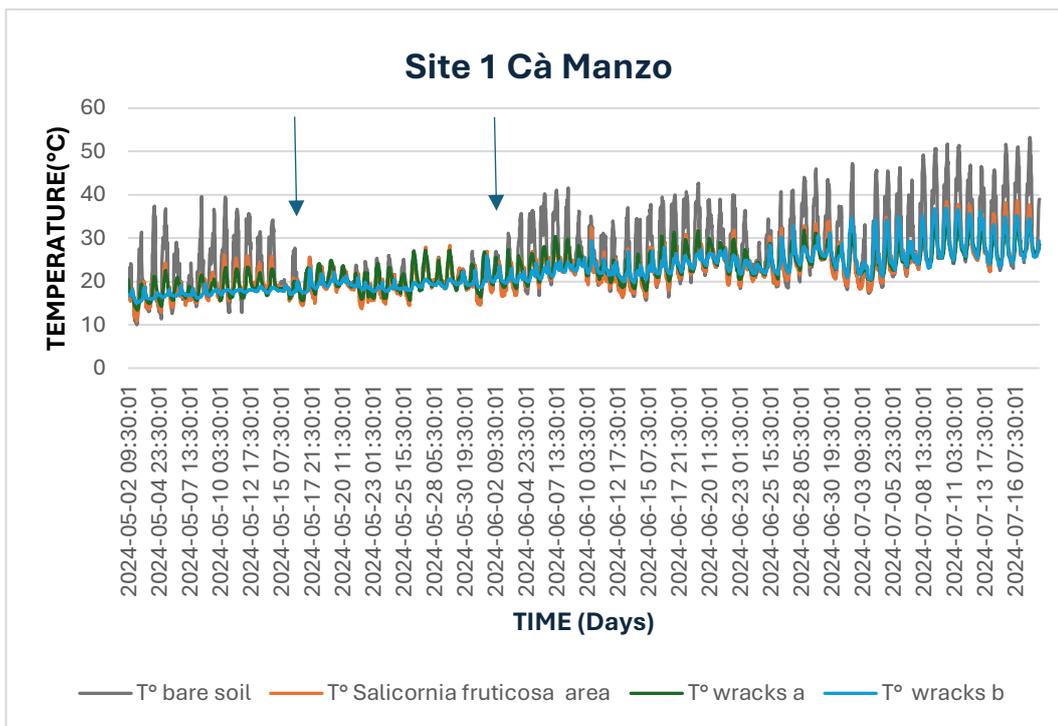


Figure 7. Temperature fluctuations of the site 1 in Cà manzo. Green/blu line: wracks; orange: *Salicornia fruticosa* vegetated area; grey: bare soil. The couple of arrows indicate the period when bare soil loggers were buried.

On site 1, temperature under wracks b daily fluctuates around 5 °C but then after the storms of the beginning of June it overlaps *Salicornia fruticosa* fluctuating around 10 °C daily. Temperature under wracks a fluctuates around 8 °C daily while on bare soil fluctuations are around 25 °C daily.

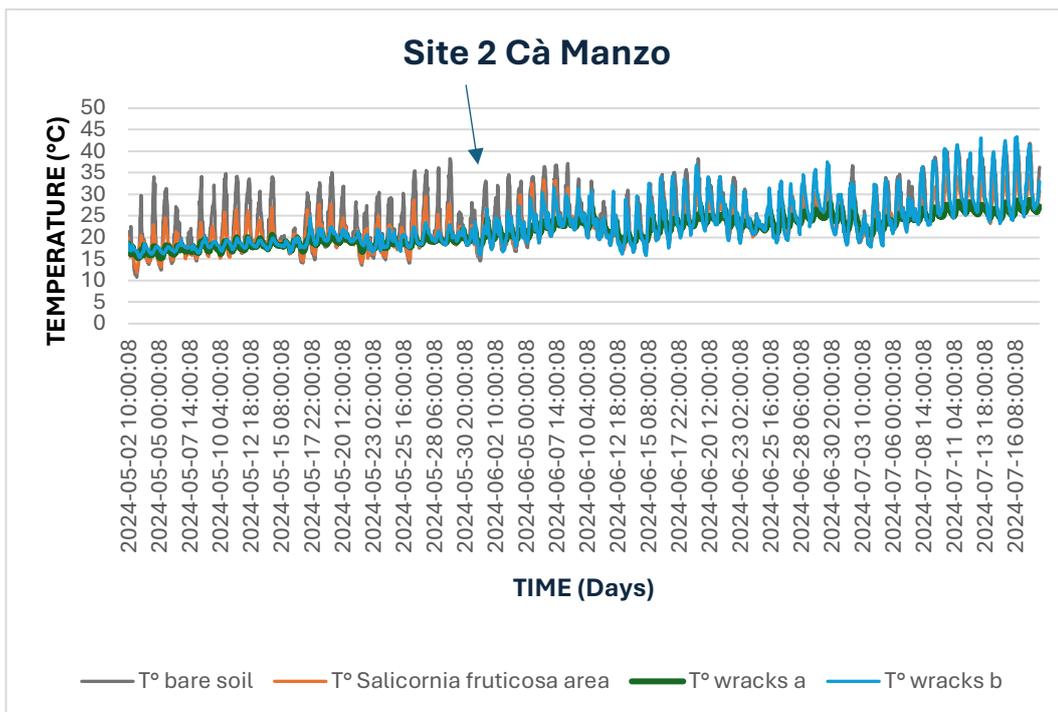


Figure 8. Temperature fluctuations of the site 2 in Cà manzo. Green/blu line: wracks; orange: *Salicornia fruticosa* area; grey: bare soil. The arrow indicates when wracks have presumably been washed away by storms of the end of May and the beginning of June.

On site 2, as in site 1, wracks b temperature fluctuates around 5 °C daily but then after the storms of the beginning of June it overlaps bare soil fluctuating 20 °C daily from June 2<sup>nd</sup>. Here wracks temperature fluctuates about constantly 5 °C daily. *Salicornia fruticosa* fluctuate around 10 °C daily.

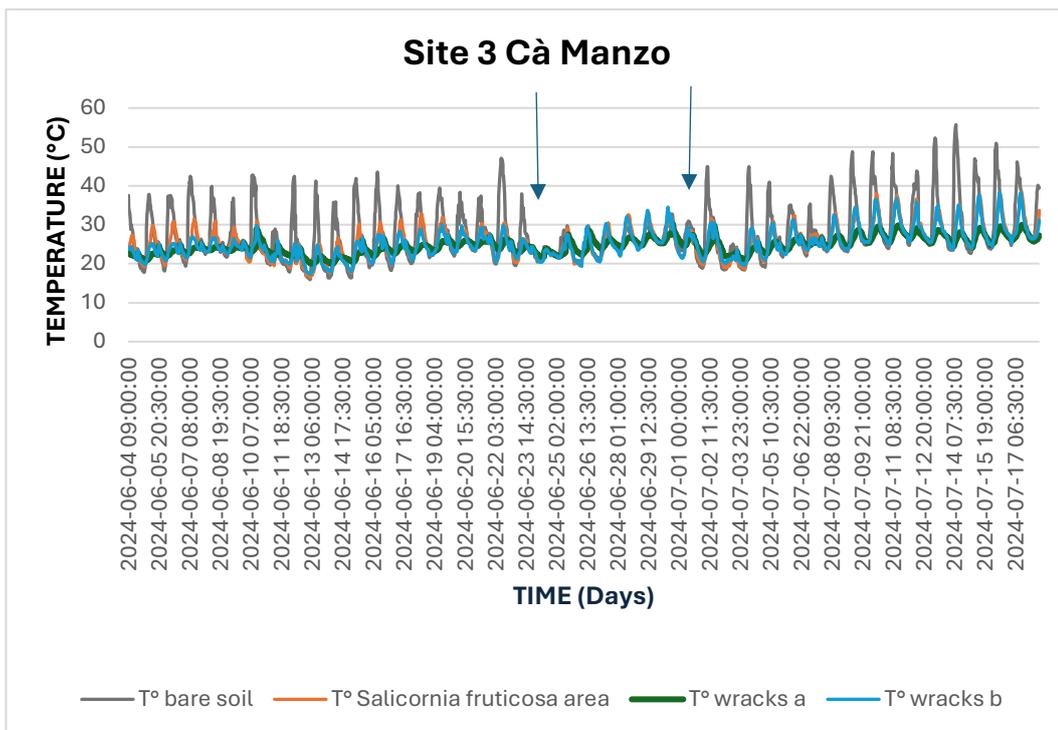


Figure 9. Temperature fluctuations of the site 3 in Cà manzo. Green/blu line: wracks; orange: *Salicornia fruticosa* area; grey: bare soil. The couple of arrows indicate the period when bare soil loggers were buried.

On site 3, as the other two sites, wracks b fluctuate 5 °C daily but after the storms of June 23<sup>rd</sup> overlaps *Salicornia fruticosa* that shows fluctuations of 10 °C daily, wracks a maintain a about constant temperature fluctuating only around 2 °C daily. Bare soil here fluctuates around 25 °C daily.

As seen in Fondo dei Settemorti, either wracks a and b keep a nearly about constant temperature over the day: as in Fondo dei Settemorti, *Salicornia fruticosa* area daily fluctuate less than bare soil, in between bare soil and wracks. Different fluctuation patterns in the three treatments may be set by the covering or re-covering of temperature loggers by wracks or sediment.

### 3.1.3 Average daily temperature

Using Microsoft Excel, daily average temperature was calculated using a moving average with a range of 24 hours.

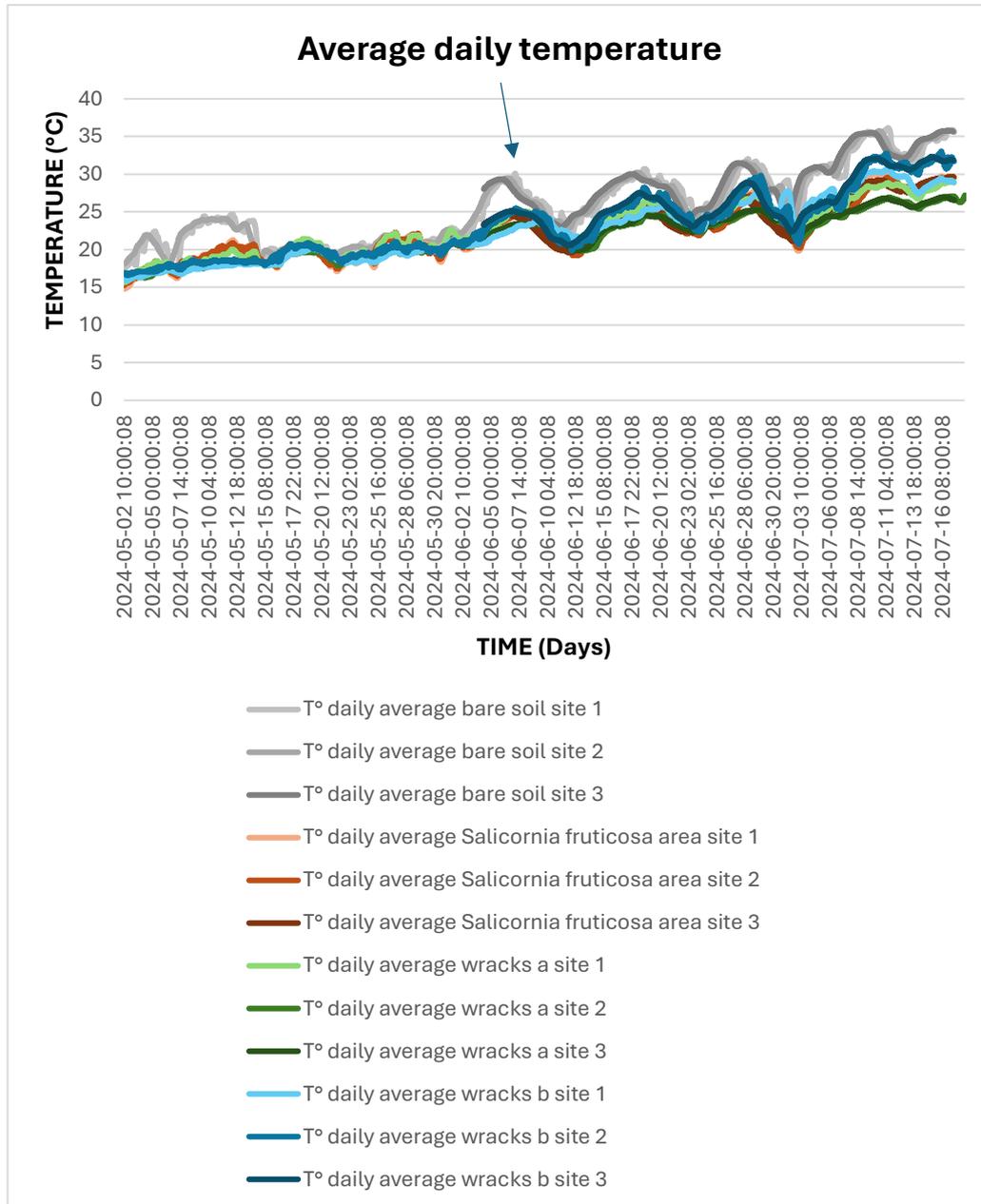


Figure 10. Daily average temperature of the three sites and treatments. Green/blu line: wracks; orange: *Salicornia fruticosa* vegetated area; grey: bare soil. The arrow indicates when wracks were washed away by storms at the beginning of June.

Daily average temperature of wracks a and b and *Salicornia fruticosa* vegetated area is about constant till June 2<sup>nd</sup> (arrow), when wracks were washed away in June. At the beginning daily average bare soil temperature was

5 °C higher than wracks and *Salicornia fruticosa* vegetated area average daily temperature, then temperature overlapped between May 14<sup>th</sup> and June 2<sup>nd</sup>. Starting from June 2<sup>nd</sup> the temperature of all the treatments presents a similar pattern, with daily fluctuations approximately of 10 °C. The highest daily average temperature was showed by bare soil on site 1 with 36,125 °C, while the lowest by *Salicornia fruticosa* area on site 1 with 11,758 °C.

At the beginning of May average bare soil daily temperature is 17,9 °C (site 2), while at the end of July is 36,125 °C (site1). Wracks a average temperature at the beginning of May is 15,65 °C (site 1), while at the end of July is 29,06 °C (site 1), wracks b and a at the beginning of May shows 15,87 °C (site 1) of temperature while at the end of July wracks a shows 29,06 °C (site 1), overlapping with wracks b (30,65 °C, site 1) and *Salicornia fruticosa* (29,63 °C, site 3).

### 3.1.4 Maximum daily temperature

Using Excel also the maximum daily temperature was calculated, calculating the highest temperature value over a moving window with a range of 24 hours.

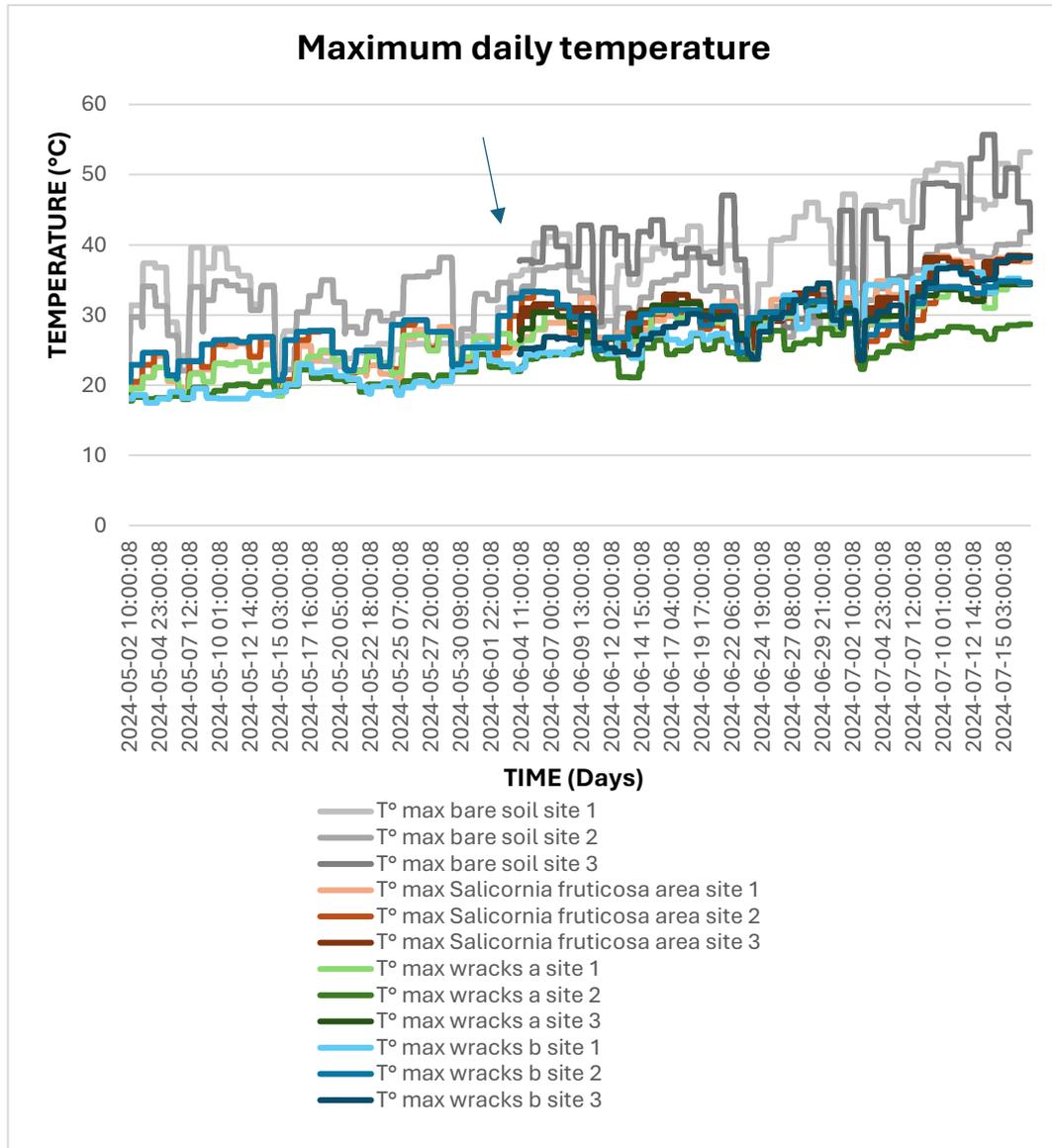


Figure 11. Maximum daily temperature of the three sites and treatments. Green/blu line: wracks; orange: *Salicornia fruticosa* vegetated area; grey: bare soil. The arrow indicates when wracks were washed away by storms at the beginning of June.

Figure 11 shows that the maximal daily temperature of bare soil has peaks of 55,7 °C (bare soil site 3) in mid-July and on average shows daily fluctuations of 20 °C. *Salicornia fruticosa* maximum daily temperature fluctuates around 4 °C daily while wracks a and b fluctuate 1 °C daily. Wracks a maximum daily temperature in May is around 17,8 °C (site 2), till the beginning of June, when it rises till 34,4 °C (site 1 and 3). Wracks b maximum daily temperature in May is around 17,5 °C (site 1) till the beginning of June, when it rises till 38,3 °C (site

3), as all the other micro-niches. *Salicornia fruticosa* vegetated area has about constant pattern between wracks and the other micro-niches with a maximum daily temperature of 18,1 °C (site 1) at the beginning and of 38,6 °C (site 1) at the end. The highest value of maximum daily temperature is shown by bare soil on site 3 with 55,7 °C, while the lowest maximum daily temperature is shown by wracks b on site 1 with 17,5 °C.

### 3.1.5 Minimum daily temperature

Using Excel the minimum daily temperature was also calculated.

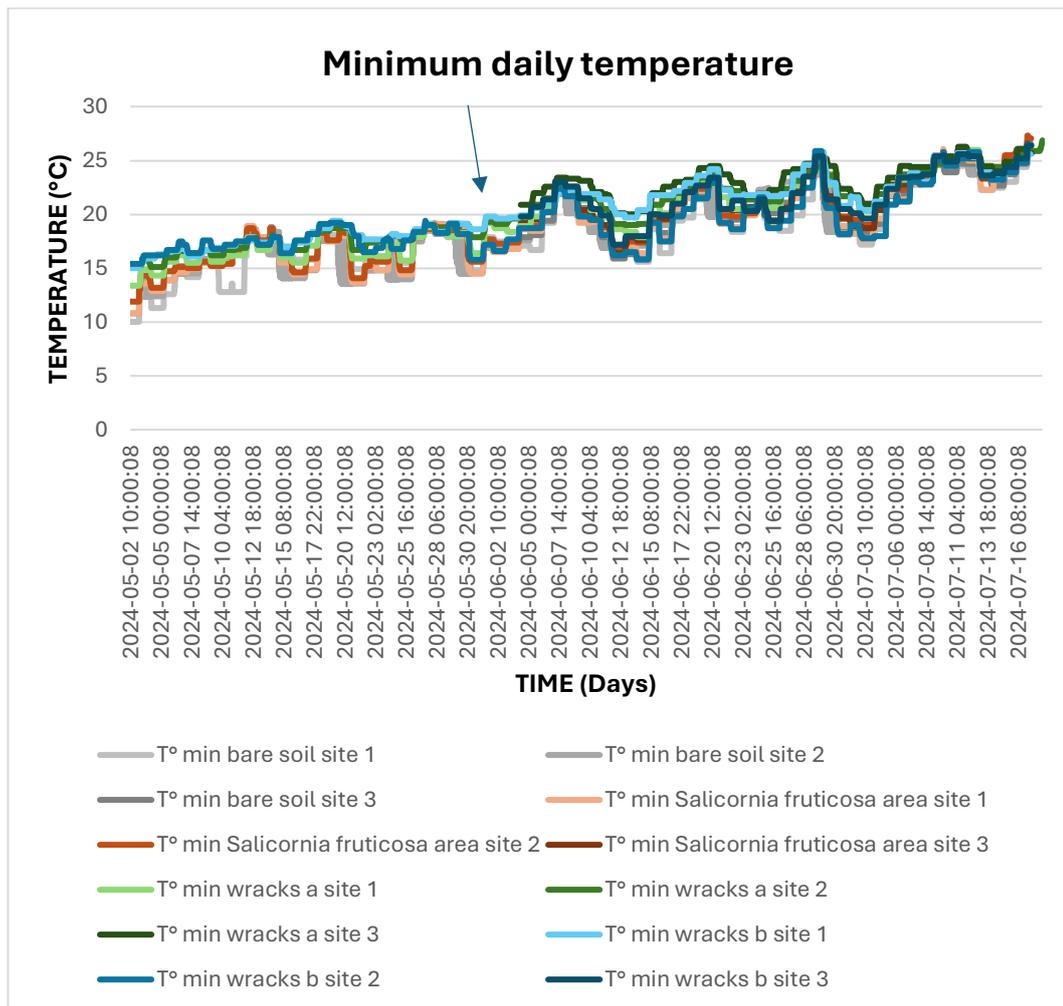


Figure 12. Minimum daily temperature of the three sites and treatments. Green/blu line: wracks; orange: *Salicornia fruticosa* vegetated area; grey: bare soil. The arrow indicates when wracks were washed away by storms at the beginning of June.

Figure 12 shows that minimum daily temperature has a similar pattern between treatments, with bare soil showing the lower daily minimum (10 °C, site 1). Bare soil has a 2 °C lower daily temperature than *Salicornia fruticosa* (11,9 °C, site 1), that has a 1 °C lower daily temperature than wracks a (13,4 °C, site 1) that have a 1 °C lower daily temperature than wracks b (15 °C, site

1). Highest value is shown by *Salicornia fruticosa* area on site 2 with 27,3 °C, while the lowest is shown by bare soil on site 1 with 10 °C. Highest daily minimum temperature range is shown by bare soil that fluctuates around 4 °C daily, followed by *Salicornia fruticosa* (2 °C daily) and wracks (1 °C daily).

### 3.1.6 Temperature daily range

Using Excel the temperature daily range between the maximum and minimum was also calculated.

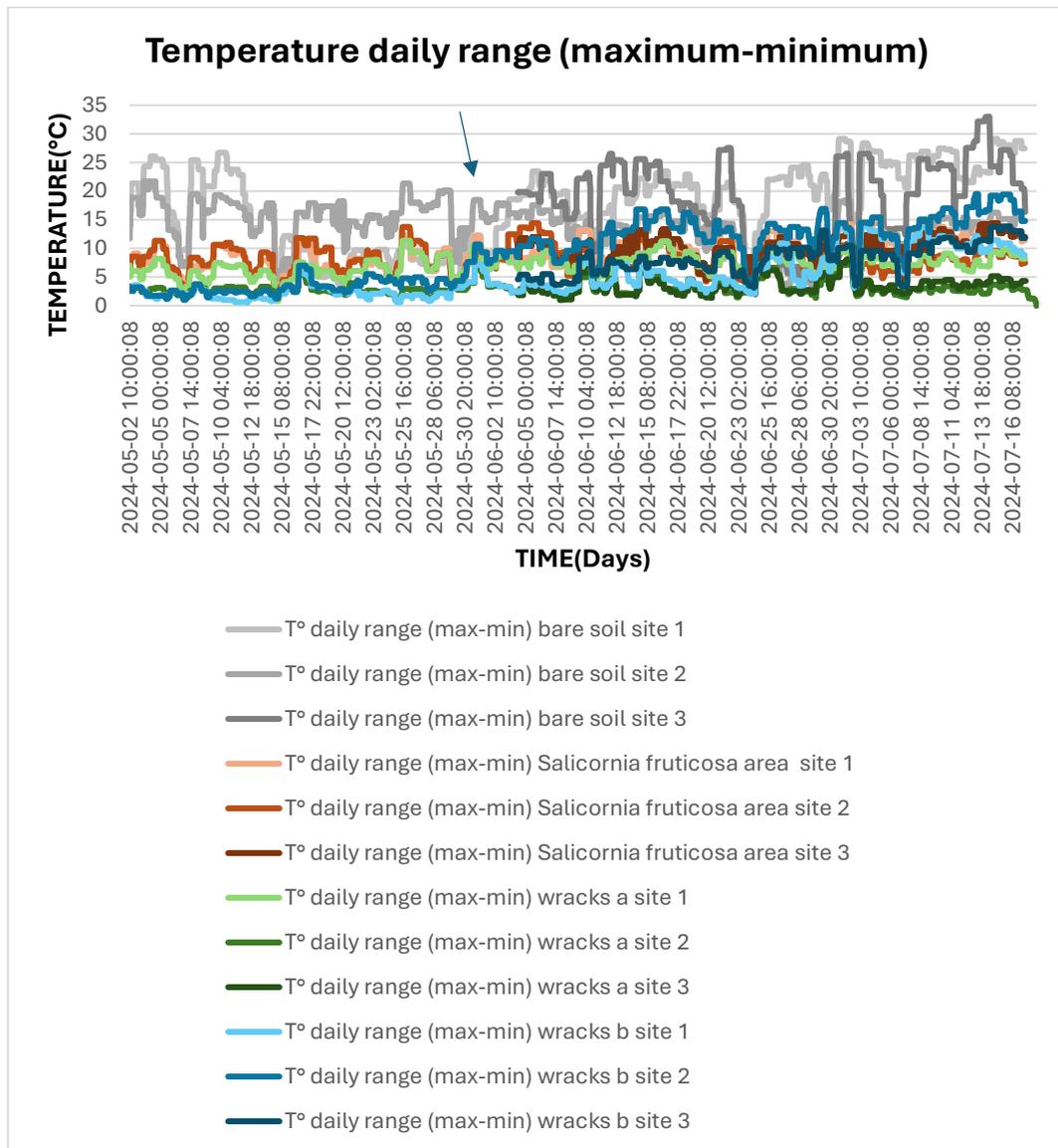


Figure 13. Temperature daily range of the three sites and treatments. Green/blu line: wracks; orange: *Salicornia fruticosa* vegetated area; grey: bare soil. The arrow indicates when wracks were washed away by storms at the beginning of June.

Figure 13 shows that bare soil temperature daily range is 20 °C, daily range of wracks b, till the beginning of June, is 1 °C daily, while later rises till 15 °C daily in mid-July. *Salicornia fruticosa* has a constant daily temperature range between 5 and 10 °C daily.

Wracks in general have about constant temperature range too, around 5 °C daily. Highest range is shown by bare soil on site 3, with 33 °C, while lowest by wracks a on site 2 with 0 °C daily.

### 3.1.7 Daily temperature difference maximum-average

Using Excel temperature daily difference between the maximum and the average was also calculated. This value helps to understand the daily variation of temperature between highest values compared to the average and explains thermal stability.

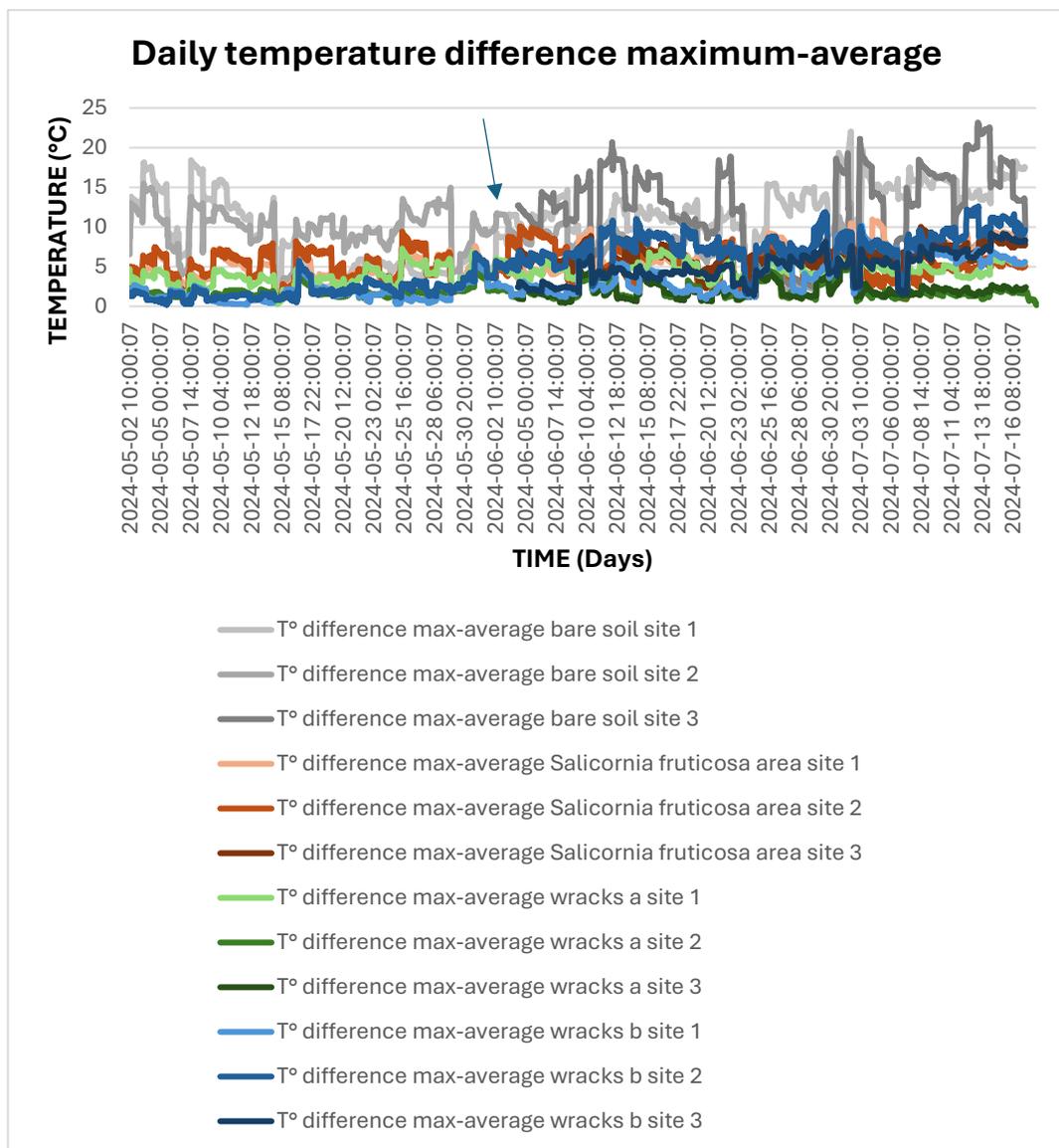


Figure 14. Difference between maximum temperature daily value and the daily average temperature. Green/blu line: wracks; orange: *Salicornia fruticosa* vegetated area; grey: bare soil. The arrow indicates when wracks were washed away by storms at the beginning of June.

Figure 14 shows that bare soil present a about constant and high temperature difference, shows daily fluctuations between 10 and 15 °C, and rise till daily fluctuations of 20 °C. Wracks b till the end of may present the lower temperature difference, with daily fluctuations of 1 or 2 °C, and from the beginning of June site 2 and 3 fluctuate around 10°C daily, while site 1 remain about constant fluctuating 4 °C daily. Wracks a on site 1 and 2 fluctuate around 5 °C daily, while on site 3 remain about constant fluctuating around 2 °C daily. *Salicornia fruticosa* vegetated area fluctuate around 5 and 10 °C daily. The highest difference is shown by bare soil on site 3, with 23,2 °C, while the lowest is shown by wracks a of site 2(0,15 °C).

### 3.1.8 Daily temperature difference minimum-average

Using Excel the temperature daily difference between minimum daily temperature and temperature daily average was calculated. This value helps to understand the daily variation of temperature between lowest values compared to the average and explain thermal stability.

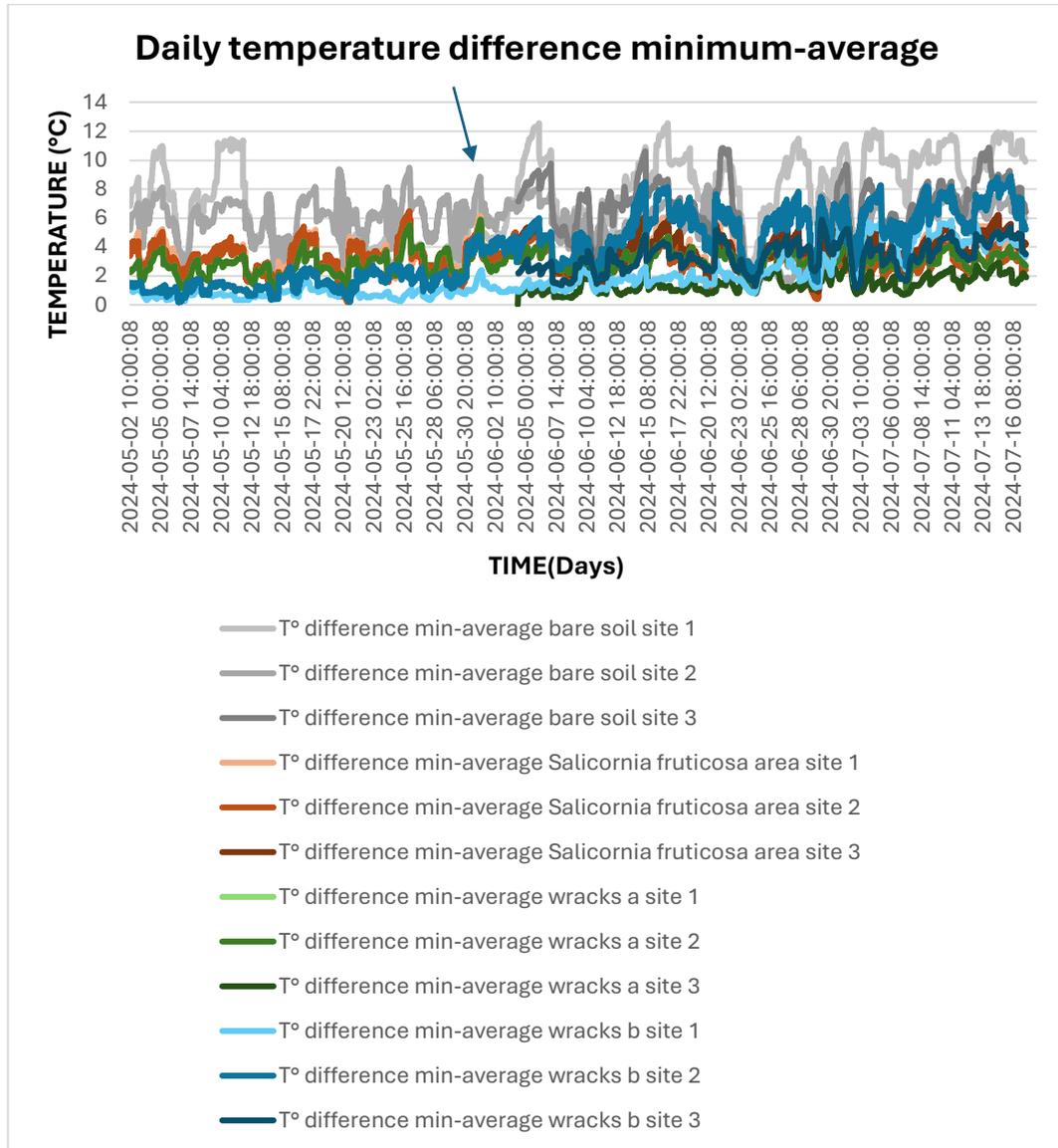


Figure 15. Daily temperature difference min-average of the three sites and treatments. Green/blu line: wracks; orange: *Salicornia fruticosa* vegetated area; grey: bare soil. The arrow indicates when wracks were washed away by storms at the beginning of June.

Figure 15 shows that daily temperature difference is about constant for wracks b on site 1, that shows daily fluctuations of 1 °C, till the end of June, when temperature fluctuations increase till 4 °C daily. Wracks b on site 2 and 3, fluctuate 8 °C daily. Bare soil has a higher temperature difference, showing

about constant daily fluctuations between 4 and 12 °C. *Salicornia fruticosa* vegetated area is in between, showing daily fluctuations of 3 °C, while wracks a on site 1 and 2 daily fluctuate between 1 °C and 2 °C, while on site 3 are about constant and fluctuate around 2 °C daily. Highest value is shown by bare soil on site 1 (12,57 °C), while the lowest value is shown by wracks b on site 1 and 2 (0,24 and 0,17 °C).

### 3.1.9 Average temperature

For subsequent data analysis, we also calculated the average temperature of the previous ten days before each invertebrate sampling with the relative standard deviation calculated using Excel. For site 3, since the loggers were not installed in May, the mean between the temperature of site 1 and 2 was used.

treatment	temperature June °C	temperature July °C	Difference July- June °C
1B	21,47+/-3,15	34,22 +/- 9,05	12,75+/-9,38
1S	20,43+/-2,84	28,94 +/- 3,96	8,51+/-4,87
1Wa	21,07+/-2,71	28,11 +/- 2,75	7,04+/-3,86
1Wb	19,83+/-1,22	29,24 +/- 3,88	9,41+/-4,06
2B	22,89+/-5,56	31,33+/-5,34	8,44+/-7,71
2S	20,58+/-2,76	28,31+/-2,59	7,73+/-3,79
2Wa	19,76+/-1,10	26,2+/-1,07	6,44+/-1,53
2Wb	20,27+/-1,20	31,19+/-5,46	10,92+/-5,59
3B	22,1+/-7,00	32,03+/-7,63	9,93+/-10,35
3S	21+/-4,43	29,17+/-3,74	8,67+/-5,80
3Wa	20+/-3,71	27,06+/-1,42	7,06+/-3,97
3Wb	20,05+/- 5,03	28,87+/-3,55	8,82+/-6,16

Table 2. Average temperature of the ten days before each sampling. B: bare soil; S: *Salicornia fruticosa* area; W: wracks. 1: site 1; 2: site 2; 3: site 3.

Table 2 shows the average temperature of the first 10 days before each sampling and relative difference. Bare soil shows the higher differences, and site 1 presents the highest difference with 12,75 +/- 9,38 °C. Bare soil on site 1 shows also the highest temperature of June with 21,47 +/-3,15 °C, and the highest temperature of July with 34,22 +/-9,05 °C. Temperature mean is always higher in July than in June.

The lowest temperature difference is shown by wracks a on site 2 with 6, 44 +/- 1,53 °C, that shows also the lowest temperature of June with 19,76 +/- 1,10 °C and the lowest of July with 26,2 +/- 1,07 °C.

In general, bare soil shows the higher temperature average, followed by *Salicornia fruticosa* vegetated area, then wracks.

### 3.3 Relative humidity

From the values of relative humidity sampled by the humidity meter from each monthly sampling, relative humidity was reported in a table with the relative humidity difference between months.

treatment	RH % June	RH % July	RH % difference
1B	77	63	-14
1S	88	66	-22
1Wa	82	75	-7
1Wb	88	78	-10
2B	81	63	-18
2S	83	62	-21
2Wa	89	72	-17
2Wb	91	72	-19
3B	75	66	-9
3S	83	71	-12
3Wa	84	71	-13
3Wb	83	76	-7

Table 3. Relative humidity % for each treatment in June and July with the relative difference. N: bare soil; S: *Salicornia fruticosa* area; W: wracks. 1: site 1; 2: site 2; 3: site 3.

Table 3 shows that the highest humidity values were sampled in June, with wracks b showing the highest humidity values, followed by wracks a, then *Salicornia fruticosa* vegetated area and then bare soil. July shows the same pattern, with wracks showing a higher humidity, followed by *Salicornia fruticosa* vegetated area and then bare soil. The highest relative humidity value is shown by wracks b on site 2 in June (91 RH %), while the lowest is shown by *Salicornia fruticosa* vegetated area in July (62 RH %). The lowest relative humidity value of June is shown by bare soil on site 1 (77 RH %), while the highest relative humidity value of July is shown by wracks b on site 1 (78 RH

%). The treatment that shows the higher differences in terms of relative humidity between June and July is *Salicornia fruticosa* vegetated area, followed by bare soil, then wracks. The highest difference in term of relative humidity is shown by *Salicornia fruticosa* vegetated area of site 1 (-22 RH %), while the lowest is shown by wracks b and a of site 1 and 3 (-7%).

In general, relative humidity gap measured in June between treatments (91 RH % of wracks b on site 2 against 75 RH % of bare soil on site 1) is like gap measured in July (78 RH % of wracks b on site 1 against 62 RH % of *Salicornia fruticosa* on site 2).

### 3.3 Sediment granulometry

Using Excel and a textural class calculator (<https://agritechcenter.com.np/soil-calculator.html>) the textural class of each treatment was calculated based on percentages of sand, silt and clay.

treatment	sand %	silt %	clay %	textural class
1B	28,88%	57,46%	13,66%	silt loam
1S	31,63%	56,10%	12,27%	silt loam
1Wa	27,12%	58,58%	14,30%	silt loam
1Wb	54,73%	36,68%	8,58%	sandy loam
2B	24,54%	60,33%	15,12%	silt loam
2S	24,38%	60,95%	14,66%	silt loam
2Wa	30,83%	55,63%	13,52%	silt loam
2Wb	21,50%	62,51%	15,78%	silt loam
3B	49,88%	38,22%	11,87%	loam
3S	73,89%	21,61%	4,49%	sandy loam
3Wa	32,26%	53,93%	13,81%	silt loam
3Wb	31,21%	54,95%	13,84%	silt loam
3Wbi	25,12%	60,69%	14,17%	Silt loam
3Wbii	28,75%	55,90%	15,36%	Silt loam
3Wbiii	40,99%	47,77%	11,23%	loam

Table 4: percentage of sand, silt and clay and the textural class of each treatment. B: bare soil; S: *Salicornia fruticosa* area; W: wracks. 1: site 1; 2: site 2; 3: site 3. i: replicate 1; ii: replicate 2; iii: replicate 3.

## Soil Textural Triangle

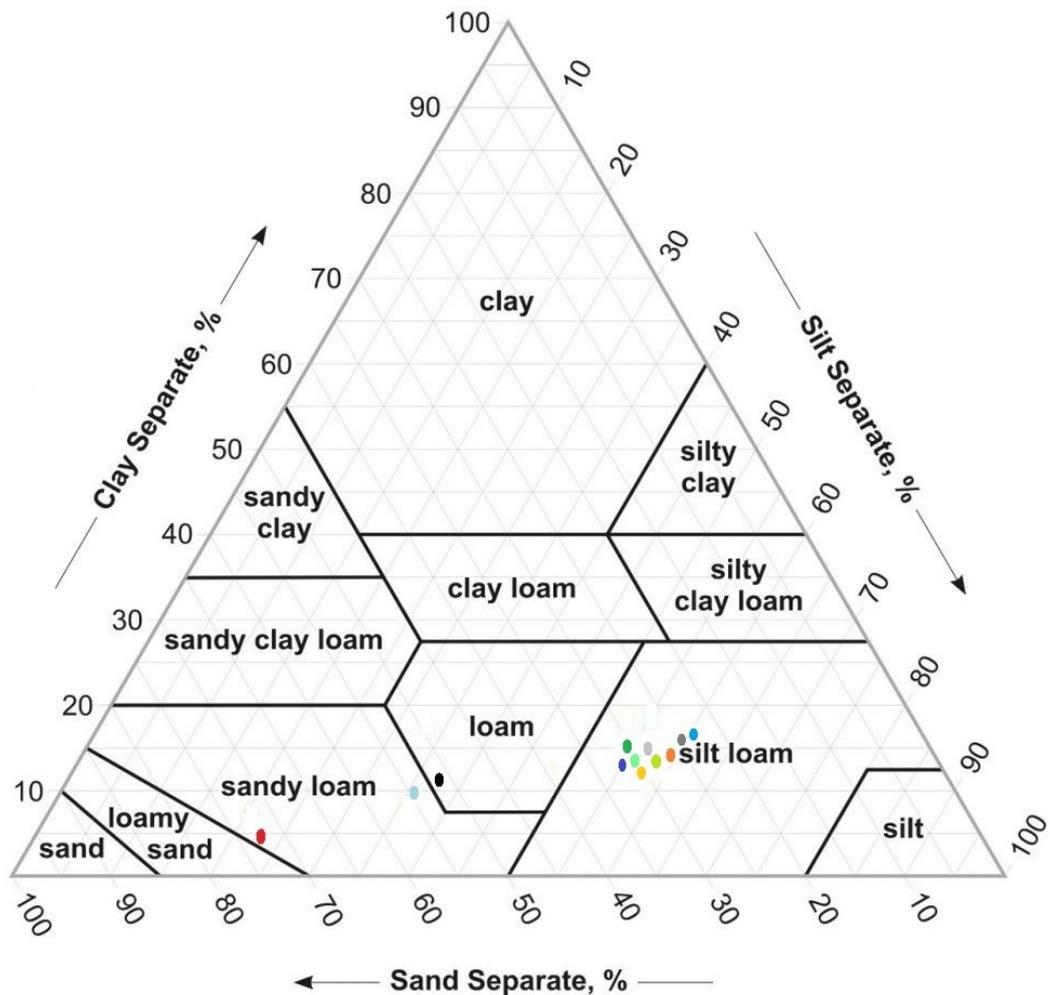


Figure 16. Textural triangle with the treatment plotted together. Each dot indicates a treatment. Grey: bare soil; red: *Salicornia fruticosa*; blue and green: wracks. Light colour: site 1; medium colour: site 2; dark colour: site 3.

Textural triangle was downloaded from <https://mavink.com/explore/Soil-Texture-Classification-Chart>.

Table 4 and figure 16 show that nine treatments out of twelve have silt loam textural class, and all have loam sediment in general. Treatment 3 B is loam and 3 S and 1 A are sandy loam. In general, granulometry was pretty consistent between treatments and sites.

### 3.4 Marsh elevation

For each treatment elevation was calculated in centimeter.

Elevation data taken with ZENITH16 GNSS (GEOMAX) (<https://geomax-positioning.com/it-it/products/gnss/zenith16-series>) were corrected subtracting 43,256 meters. Finally, measures were converted in centimeter.

treatment	elevation(cm)
1B	23,9
1S	24,6
1Wa	21,0
1Wb	27,3
2B	34,3
2S	33,6
2Wa	31,0
2Wb	33,6
3B	30,2
3S	31,2
3Wa	28,1
3Wb	22,9

Table 5. Elevation data corrected for each treatment.

B: bare soil; S: *Salicornia fruticosa* area; W: wracks. 1: site 1; 2: site 2; 3: site 3.

In general, most of all treatments shown in table 5 are elevated around 25-30 cm, treatment 1 Wa has the lowest elevation with 21 cm, while 2 B the highest with 34,3 cm.

### 3.5 Total organic carbon

treatment	TOC %
1B	1,458
1S	0,948
1Wa	7,336
1Wb	5,692
2B	1,371
2S	1,016
2Wa	7,716
2Wb	5,379
3B	0,266
3S	1,721
3Wa	6,372
3Wb	6,687
3Wbi	5,473
3Wbii	1,988
3Wbiii	7,902

Table 6. Total organic carbon per treatment in % weight / weight. B: bare soil; S: *Salicornia fruticosa* area; W: wracks. 1: site 1; 2: site 2; 3: site 3. i: replicate 1; ii: replicate 2; iii: replicate 3.

TOC data shows that bare soil has the lowest content of organic carbon, followed by *Salicornia fruticosa*, then wracks. The lowest value of TOC is shown by bare soil on site 3, with 0,266 %, while the highest is shown by wracks b on site 3 (replicate iii) with 7,902 %.

### 3.6 Taxonomic identification

#### 3.6.1 Total individual number of organisms

During the two sampling campaigns, the total number of organisms were quite similar, with 5950 organisms counted and recognized in total in June against 5735 recognized in July.

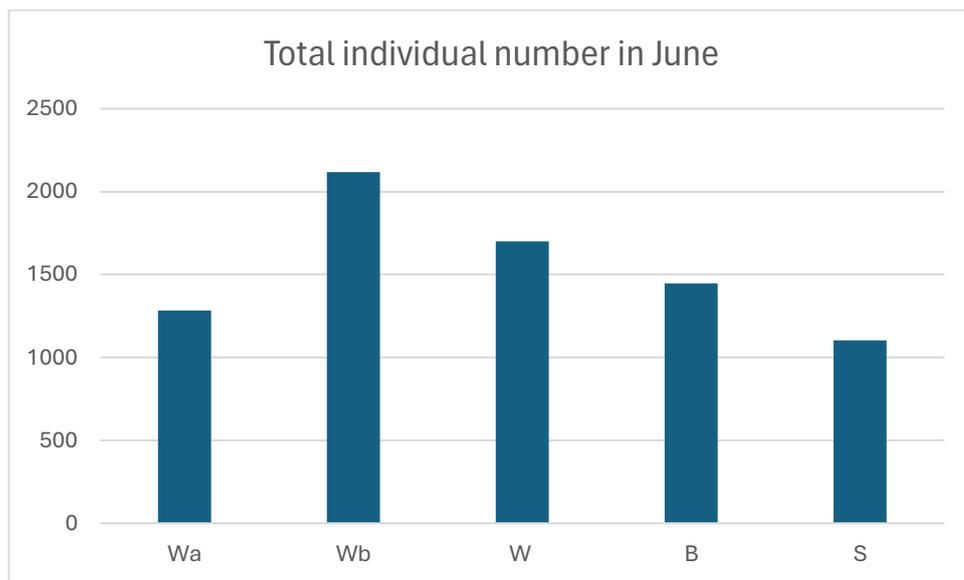


Figure 17. Total number of individuals quantified after sampling of June 4<sup>th</sup>. Wa: wracks a; Wb: wracks b; W: wracks mean; B: bare soil; S: *Salicornia fruticosa* area.

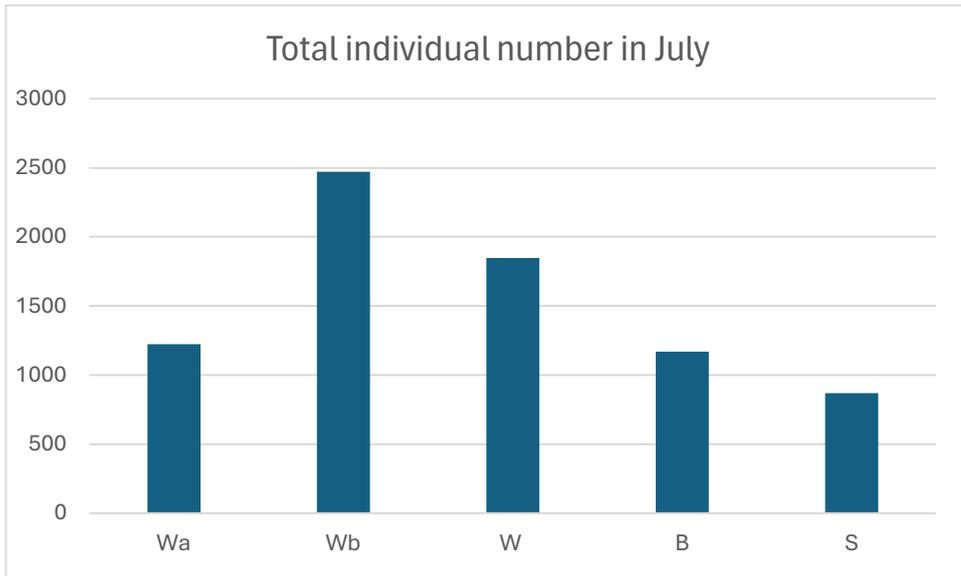


Figure 18. Total number of individuals quantified after sampling of July 18<sup>th</sup>. Wa: Wracks a; Wb: wracks b; W: wracks mean; B: bare soil; S: *Salicornia fruticosa* area. W: wracks.

month	Wa	Wb	W	B	S	tot
June	1283	2117	1700	1447	1103	5950
July	1222	2472	1847	1171	870	5735

Table 7. Number of organisms found per treatment and month.

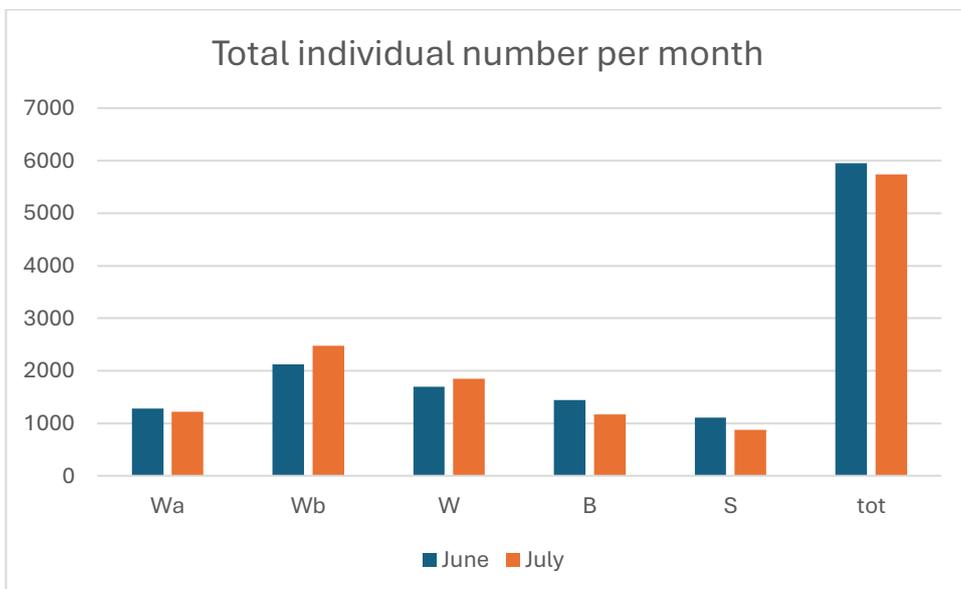


Figure 19. Total number of individuals of the sampling of June 4<sup>th</sup> and July 18<sup>th</sup> compared. Wa: wracks a; Wb: wracks b; W: wracks mean; B: bare soil; S: *Salicornia fruticosa* vegetated area; tot: total.

Either in June and July, the treatment that shows the highest number of individuals is the wracks b treatment with 2117 organisms in June and 2472 organisms in July, while the lowest is the *Salicornia fruticosa* vegetated area treatment with 1103 organisms in June and 870 in July. Also, the mean between wracks shows a slightly higher number of organisms in July.

### 3.6.2 Benthic community structure

Taxonomic community present in the salt marsh in Cà Manzo was assessed during the two sampling campaigns, either in June or July. During the two samplings 35 taxa of organisms were recognized down to the lowest taxonomic level possible: 21 till species level, 8 till genus, 4 till family and 2 till phylum level. Organisms were later assigned to four different functional feeding groups: detritivores, grazers, filter feeders and predators. Together with the feeding behavior locomotory behavior was assigned: crawler, sessile, walker, jumper, burrower organisms. Another assigned group was the habitat: marine, brackish water and terrestrial.

Phylum	Taxonomic Identification	size	Locomoto ry behavio ur	feeding strategy	habitat
Gastropoda	<i>Myosotella myosotis</i>	>1 mm	crawler	grazer	brackish
Gastropoda	<i>Cyclope</i> spp.	>2 mm	crawler	grazer	marine
Gastropoda	<i>Gibbula</i> spp.	>2 mm	crawler	grazer	marine
Gastropoda	<i>Truncatella subcylindrica</i>	>0,5 mm	crawler	grazer	brackish
Gastropoda	<i>Peringia ulvae</i>	>0,5 mm	crawler	grazer	brackish
Gastropoda	<i>Paludinella sicana</i>	>0,5 mm	crawler	grazer	brackish
Gastropoda	<i>Ovatella firminii</i>	>2 mm	crawler	grazer	brackish
Gastropoda	<i>Raphitoma purpurea</i>	>2 mm	crawler	detritivore	marine
Gastropoda	<i>Hinia reticulata</i>	>2 mm	crawler	detritivore	marine

Gastropoda	<i>Tritia corrugata</i>	>2 mm	crawler	detritivore	marine
Gastropoda	<i>Akera bullata</i>	>2 mm	crawler	detritivore	marine
Gastropoda	<i>Acteon tornatilis</i>	>2 mm	crawler	detritivore	marine
Gastropoda	<i>Haminoea hidatis</i>	>2 mm	crawler	detritivore	marine
Gastropoda	<i>Bittium reticulatum</i>	>0,5 mm	crawler	detritivore	marine
Gastropoda	<i>Tricolia pullus</i>	>2 mm	crawler	detritivore	marine
Gastropoda	<i>Leufroyia leufroyi</i>	>2 mm	crawler	detritivore	marine
Gastropoda	<i>Dermomurex</i> spp.	>2 mm	crawler	predator	marine
Bivalvia	<i>Cerastoderm a glaucum</i>	>2 mm	sessile	filter feeder	marine
Bivalvia	<i>Ostrea edulis</i>	>2 mm	sessile	filter feeder	marine
Bivalvia	<i>Mactra corallina</i>	>0,5 mm	sessile	filter feeder	marine
Bivalvia	<i>Diplodonta rotundata</i>	>0,5 mm	sessile	filter feeder	marine
Bivalvia	<i>Abra</i> spp.	>0,5 mm	sessile	filter feeder	brackish
Bivalvia	<i>Macomopsis cumana</i>	>2 mm	sessile	filter feeder	marine
Bivalvia	<i>Scrobicularia plana</i>	>2 mm	sessile	filter feeder	marine
Bivalvia	<i>Lucinella divaricata</i>	>2 mm	sessile	filter feeder	marine
Amphipoda	<i>Gammarus</i> spp.	>0,5 mm	jumper	grazer	brackish
Amphipoda	<i>Stenothoe</i> spp.	>1 mm	jumper	grazer	brackish
Isopoda	<i>Armadillidiida e</i>	>0,5 mm	walker	grazer	terrestrial

Polychaeta	<i>Nephtys</i> spp.	>0,5 mm	burrower	detritivore	brackish
Polychaeta	<i>Serpulidae</i>	>0,5 mm	sessile	detritivore	brackish
Polychaeta	<i>Spirorbidae</i>	>0,5 mm	sessile	detritivore	brackish
Polychaeta	<i>Aphelocheata</i> spp.	>0,5 mm	burrower	detritivore	brackish
Coleoptera	Coleoptera	>1 mm	flyer	grazer	terrestrial
Diptera	<i>Stratiomyidae</i>	>1 mm	flyer	grazer	terrestrial
Arachnida	Arachnida	>1 mm	walker	predator	terrestrial

Table 8. Community in Cà manzo identified in June and July. Phylum, taxonomic identification down to the lowest taxonomic level possible, size, locomotory behaviour, feeding strategy and habitat are shown.

Phylum	Taxonomic Identification	abundance June	abundance July
Gastropoda	<i>Myosotella myosotis</i>	206	437
Gastropoda	<i>Cyclope</i> spp.	84	24
Gastropoda	<i>Gibbula</i> spp.	549	453
Gastropoda	<i>Truncatella subcylindrica</i>	1082	869
Gastropoda	<i>Peringia ulvae</i>	1030	1025
Gastropoda	<i>Paludinella sicana</i>	451	190
Gastropoda	<i>Ovatella firminii</i>	1	-
Gastropoda	<i>Raphitoma purpurea</i>	17	-

Gastropoda	<i>Hinia reticulata</i>	-	3
Gastropoda	<i>Tritia corrugata</i>	2	-
Gastropoda	<i>Akera bullata</i>	1	-
Gastropoda	<i>Acteon tornatilis</i>	5	-
Gastropoda	<i>Haminoea hidatis</i>	4	-
Gastropoda	<i>Bittium reticulatum</i>	137	89
Gastropoda	<i>Tricolia pullus</i>	112	169
Gastropoda	<i>Leufroyia leufroyi</i>	1	-
Gastropoda	<i>Dermomurex</i> spp.	1	1
Bivalvia	<i>Cerastoderma glaucum</i>	121	112
Bivalvia	<i>Ostrea edulis</i>	1	-
Bivalvia	<i>Mactra corallina</i>	-	3
Bivalvia	<i>Diplodonta rotundata</i>	2	-
Bivalvia	<i>Abra</i> spp.	36	23
Bivalvia	<i>Macomopsis cumana</i>	43	48
Bivalvia	<i>Scrobicularia plana</i>	9	2
Bivalvia	<i>Lucinella divaricata</i>	22	4
Amphipoda	<i>Gammarus</i> spp.	87	-
Amphipoda	<i>Stenothoe</i> spp.	43	26
Isopoda	<i>Armadillidiidae</i>	314	316
Polychaeta	<i>Nephtys</i> spp.	445	141
Polychaeta	<i>Serpulidae</i>	43	383

Polychaeta	<i>Spirorbidae</i>	903	1074
Polychaeta	<i>Aphelochaeta</i> spp.	131	171
Coleoptera	Coleoptera	10	6
Diptera	<i>Stratiomyidae</i>	41	136
Arachnida	Arachnida	2	2

Table 9. Organisms identified in Cà Manzo with their relative abundance between June and July.

During the sampling of June, gastropods of the specie *Truncatella subcylindrica* were the organisms more present with 1082 individuals, while *Hinia reticulata* and *Maetra corallina* were absent. During the two taxonomic identifications of June and July, 35 taxa of organisms were identified down to the lowest taxonomic level possible. Gastropods were the most present taxa (17), followed by bivalves (8), then Polychaetas (4), amphipods (2), isopods (1), Dipterans (1), Coleopterans (1) and arachnids (1). In June 33 different taxa were classified, while in July 25.

During the sampling of July, *Spirorbidae* were the most abundant organisms with 1074 individuals, while on the other hand a lot of species were absent: *Ovatella firminii*, *Raphitoma purpurea*, *Tritia corrugata*, *Akera bullata*, *Acteon tornatilis*, *Haminoea hidatis*, *Leufroyia leufroyi*, *Ostrea edulis*, *Diplodonta rotundata* and *Gammarus* spp.

Regarding locomotory behavior of taxa, more crawlers were found (16), followed by sessile (10) and then burrowers (2), flyer (2) and walkers (2) and jumpers (2). Regarding feeding strategy, the most abundant taxa turned out to be detritivores (13), followed by grazers (12), then filter feeders (8), and predators (2). Regarding the size, organisms with size above 2 mm were the most present (17), followed by organisms with size above 0,5 mm (13), then five taxa with size in between (>1mm).

In general, both marine, brackish water and terrestrial taxa were found. Marine taxa were mostly present (18), followed by brackish water taxa (12) and then terrestrial ones (5).

Organisms' community of different treatments is reported in table 26, 27 and 28 of the appendix. Regarding bare soil, 25 taxa of organisms were identified in June, while 17 in July.

Regarding *Salicornia fruticosa* vegetated area, 17 taxa of organisms were identified in June, while 19 in July.

Regarding wracks, 28 taxa of organisms were identified in June, while 23 in July.

### 3.7 Environmental data analysis

#### 3.7.1 Principal component analysis

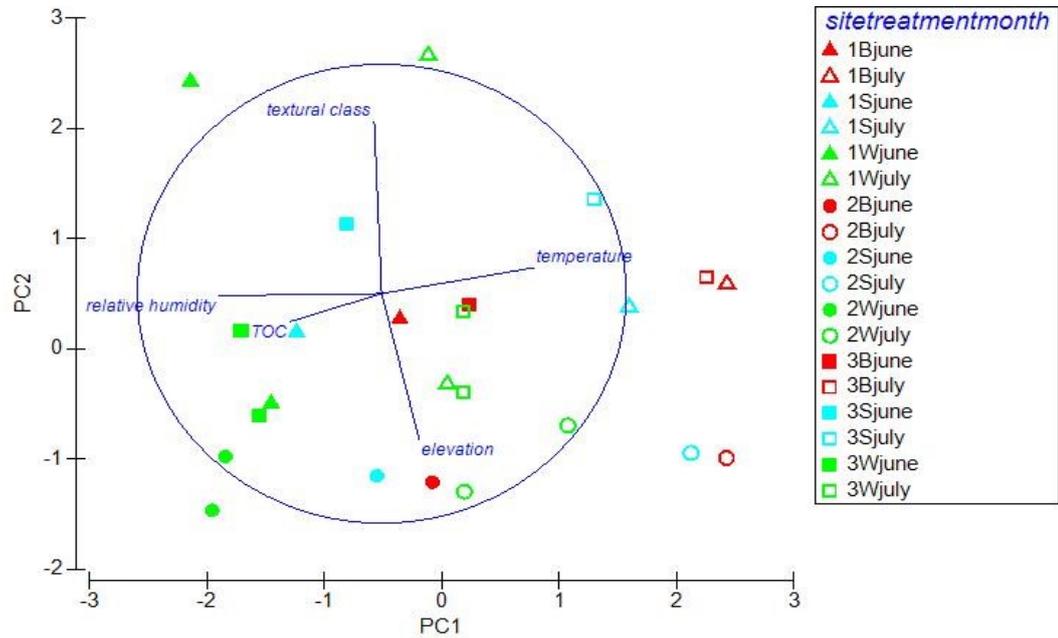


Figure 21. PCA with environmental data. B: bare soil; S: *Salicornia fruticosa* vegetated area; W: wracks. 1: site 1; 2: site 2; 3: site 3. Full figures: June; empty figures: July.

PC	Eigenvalues	%Variation	Cum. %Variation
1	2,06	41,2	41,2
2	1,19	23,8	65
3	1,05	21,1	86
4	0,605	12,1	98,1
5	9,32E-02	1,9	100

Table 10. PCA eigenvalues.

PCA on figure 21 shows interaction between environmental variables sampled in this work: temperature, relative humidity, TOC, elevation and textural class. Red symbols show bare soil, light blue *Salicornia fruticosa* vegetated area, while green shows wracks. Triangles represent site 1, dots site 2, quadrats site 3, full figures represent June samples, while empty ones July samples. Table 10 shows on PCA that PC1 and PC2 explain 65 % of variance.

PC1 explains 41,2 % of variation and is dominated by temperature and relative humidity while PC2 explains 23,8% of variance and is dominated by granulometry and elevation. Time is tendentially separated along PC1 while PC2 mostly accounts for differences between sites.

### 3.7.2 PERMANOVA main test

Source	df	Pseudo-F	P(perm)	perms	P(MC)
si	2	46,573	0,001	999	0,001
tr	2	4,3341	0,029	982	0,027
mo	1	73,93	0,116	38	0,001
sixtr	4	15,005	0,001	999	0,001
sixmo	2	2,0091	0,11	998	0,114
trxmo	2	2,8323	0,111	999	0,094
sixtrxmo	4	0,56938	0,768	998	0,793

Table 11. PERMANOVA main test of environmental variable data. Si: site; mo: month; tr: treatment.

Table 11 PERMANOVA shows results of statistical interactions within factors. This table shows presence of statistically significant interactions between site, month and site x treatment ( $p < 0,05$ ).

### 3.7.3 PERMANOVA pair-wise test

Site x treatment for pairs of levels of factor treatment

site	Groups	t	P(perm)	perms	P(MC)
1	B, S	Denominator is 0			
1	B, W	3,6707	0,001	632	0,001
1	S, W	3,372	0,001	620	0,001
2	B, S	Denominator is 0			
2	B, W	7,5289	0,001	642	0,001
2	S, W	7,4163	0,001	626	0,001
3	B, S	Denominator is 0			
3	B, W	10,11	0,001	633	0,001
3	S, W	11,387	0,001	642	0,001

Table 12. PERMANOVA pair-wise test between levels 1,2,3 of factor site. B: bare soil; S: *Salicornia fruticosa* area; W: wracks. 1: site 1; 2: site 2; 3: site 3. Full figures: June; empty figures: July. Some of the tests could not be computed correctly because, part of the measures were repeated between months and replicates.

In all three levels of factor sites, there is a statistically significant interaction, within pairs of levels of factor treatment ( $p < 0,05$ ).

### 3.7.4 SIMPER analysis

Groups	Variable	Contrib %	Cum.%
B, S	temperature	27,71	27,71
B, S	relative humidity	26,72	54,44
B, S	textural class	24,7	79,13
B, S	elevation	20,19	99,32
B, W	TOC	32,19	32,19
B, W	temperature	20	52,2
B, W	relative humidity	19,44	71,64
B, W	elevation	17,58	89,22
B, W	textural class	10,78	100
S, W	TOC	30,33	30,33
S, W	textural class	21,92	52,25
S, W	relative humidity	17,68	69,93
S, W	elevation	16,91	86,84
S, W	temperature	13,16	100
June, July	temperature	28,57	28,57
June, July	relative humidity	25,72	54,29
June, July	TOC	15,24	69,53
June, July	elevation	15,24	84,76
June, July	textural class	15,24	100

Table 13. SIMPER analysis for environmental data.

Table 13 shows SIMPER analysis for environmental data. Between groups bare soil and wracks, TOC is the variable that explain more dissimilarity, with 32,19 % of contribution, followed by temperature, with 20 % and then relative humidity (19,44%).

Between bare soil and *Salicornia fruticosa*, temperature explain the highest difference, with 27,71 % of contribution, followed by relative humidity with 26,72 % and then textural class (24,70%).

Between *Salicornia fruticosa* and wracks, TOC is the variable that explains the highest dissimilarity, with 30,33 % of contribution, followed by textural class with 21,9 % and then by relative humidity (17,68 %). Regarding SIMPER between months June and July, temperature explain the highest dissimilarity with 28,57 % of contribution, followed by relative humidity with 25,72 % and then TOC with 15,24 %.

### 3.8 Biological data analysis

#### 3.8.1 Non-metric multidimensional scaling

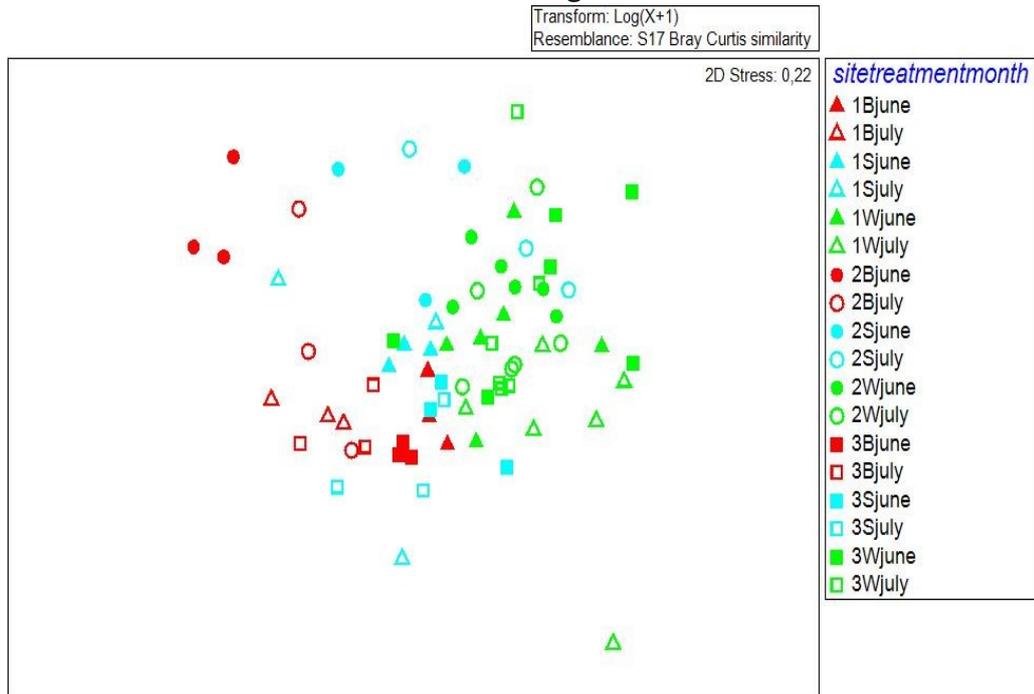


Figure 20. MDS with biological data. B: bare soil; S: *Salicornia fruticosa* area; W: wracks. 1: site 1; 2: site 2; 3: site 3. Full symbols: June; empty symbols: July.

The nMDS (Fig. 20) shows distribution in 2 dimensions of biological data. Red figures show bare soil, light blue *Salicornia fruticosa* vegetated area, while green shows wracks. nMDS shows a different distribution pattern of samples, with samples taken from *Salicornia fruticosa* vegetated area in the middle between bare soil and wracks.

#### 3.8.2 PERMANOVA main test

Source	df	Pseudo-F	P(perm)	perms	P(MC)
si	2	4,9643	0,001	999	0,001
tr	2	2,9478	0,053	984	0,018
mo	1	0,9979	0,409	38	0,487
sixtr	4	3,8202	0,001	998	0,001
sixmo	2	2,4612	0,003	999	0,003
trxmo	2	1,3257	0,272	999	0,249
sixtrxmo	4	1,608	0,026	999	0,042

Table 14. PERMANOVA results of biological data. Si: site; mo: month; tr: treatment.

Table 14 shows PERMANOVA results of biological data. Looking at the table results, there are statistically significant interactions within sites, treatments, sites x treatments, site x months and site x treatment x month ( $p < 0,05$ ).

### 3.8.3 PERMANOVA pair-wise test

#### 3.8.3.1. Site x treatment x month for pairs of levels of factor treatment

Site: month	Groups	t	P(perm)	perms	P(MC)
1 July	B, W	2,2714	0,008	84	0,012
2 June	B, W	3,3742	0,014	84	0,002
2 June	S, W	2,5066	0,009	84	0,003
2 June	B, S	2,4472	0,118	10	0,023
2 July	B, W	2,1229	0,017	84	0,012
3 June	B, W	2,3904	0,015	84	0,005
3 June	S, W	1,9906	0,025	84	0,026
3 July	B, W	2,5167	0,013	84	0,003
3 July	S, W	2,1083	0,009	84	0,015

Table 15. PERMANOVA pair-wise test between site x treatment x month for pairs of levels of factor site. B: bare soil; S: *Salicornia fruticosa* area; W: wracks

Table 15 shows statistical interactions between site x treatment x month for pairs of levels of factor treatment. The most common statistically significant difference is shown by bare soil and wracks, shown in five combinations of levels out of six, with only pair '1 June' not showing a statistical significance between bare soil and wracks. While *Salicornia fruticosa* and wracks shows statistically significant differences in three combinations of levels out of six, and bare soil and *Salicornia fruticosa* in one out of six ( $p < 0,05$ ).

#### 3.8.3.2 Site x treatment x month for pairs of levels of factor month

site: treatment	Groups	t	P(perm)	perms	P(MC)
1 B	June, July	1,9691	0,118	10	0,044

Table 16. PERMANOVA pair-wise test between site x treatment x month for pairs of levels of factor month.

Table 16 shows that only for the combination of level '1' of factor site and level 'bare' of factor treatment there is a statistically significant interaction between June and July ( $p < 0,05$ ).

### 3.8.4 SIMPER analysis

site	month	group	species	Contrib%	Cum.%
1	June	B, W	<i>Armadillidiidae</i>	9,52	9,52
1	June	B, W	<i>Peringia ulvae</i>	8,18	17,7
1	June	B, W	<i>Tricolia pullus</i>	7,49	25,18
1	June	B, W	<i>Myosotella myosotis</i>	6,48	31,66
1	June	B, W	<i>Cerastoderma glaucum</i>	5,28	36,94
1	June	B, W	<i>Macomopsis cumana</i>	4,87	41,81
1	June	B, W	<i>Spirorbidae</i>	4,73	46,53
1	June	B, W	<i>Paludinella sicana</i>	4,5	51,04
1	July	B, W	<i>Peringia ulvae</i>	12,44	12,44
1	July	B, W	<i>Stratiomyidae</i>	10,42	22,86
1	July	B, W	<i>Serpulidae</i>	7,58	30,44
1	July	B, W	<i>Gibbula</i> spp.	7,24	37,68
1	July	B, W	<i>Spirorbidae</i>	6,08	43,76
1	July	B, W	<i>Truncatella subcylindrica</i>	5,72	49,48
1	July	B, W	<i>Aphelochaeta</i> spp.	5,45	54,93

Table 17. SIMPER analysis between bare soil and wracks on site 1 in June and July.

site	month	group	Species	Contrib%	Cum.%
1	June	B, S	<i>Peringia ulvae</i>	11,14	11,14
1	June	B, S	<i>Tricolia pullus</i>	8,91	20,04
1	June	B, S	<i>Myosotella myosotis</i>	8,29	28,33
1	June	B, S	<i>Paludinella sicana</i>	5,83	34,17
1	June	B, S	<i>Nephtys</i> spp.	5,8	39,96
1	June	B, S	<i>Cyclope</i> spp.	5,44	45,4
1	June	B, S	<i>Cerastoderma glaucum</i>	5,23	50,64
1	July	B, S	<i>Paludinella sicana</i>	9,52	9,52
1	July	B, S	<i>Peringia ulvae</i>	7,91	17,43
1	July	B, S	<i>Truncatella subcylindrica</i>	7,64	25,07
1	July	B, S	<i>Armadillidiidae</i>	7,46	32,53
1	July	B, S	<i>Abra</i> spp.	6,79	39,32
1	July	B, S	<i>Tricolia pullus</i>	6,76	46,08
1	July	B, S	<i>Bittium reticulatum</i>	6,07	52,16

Table 18. SIMPER analysis between bare soil and *Salicornia fruticosa* on site 1 in June and July.

site	month	group	Species	Contrib%	Cum.%
1	June	S, W	<i>Armadillidiidae</i>	10,76	10,76
1	June	S, W	<i>Peringia ulvae</i>	7,35	18,11
1	June	S, W	<i>Macomopsis cumana</i>	7,32	25,43
1	June	S, W	<i>Spirorbidae</i>	6,13	31,56
1	June	S, W	<i>Myosotella myosotis</i>	5,7	37,26
1	June	S, W	<i>Aphelochaeta</i> spp.	5,51	42,78
1	June	S, W	<i>Nephtys</i> spp.	5,37	48,14
1	June	S, W	<i>Gibbula</i> spp.	4,76	52,9
1	July	S, W	<i>Serpulidae</i>	9,72	9,72
1	July	S, W	<i>Peringia ulvae</i>	9,01	18,73
1	July	S, W	<i>Spirorbidae</i>	8,17	26,9
1	July	S, W	<i>Gibbula</i> spp.	8,16	35,06
1	July	S, W	<i>Paludinella sicana</i>	6,54	41,61
1	July	S, W	<i>Aphelochaeta</i> spp.	6,46	48,06
1	July	S, W	<i>Stratiomyidae</i>	6,3	54,36

Table 19. SIMPER analysis between wracks and *Salicornia fruticosa* on site 1 in June and July.

Tables 17,18 and 19 shows SIMPER results between treatments and months on site 1.

SIMPER results of sites 2 and 3 can be found on appendix (table 20-25).

Between bare soil and wracks in the three sites in June, *Armadillidiidae* (isopoda), *Peringia ulvae* (Gastropoda), *Tricolia pullus* (gastropod), *Macomopsis cumana* (Bivalvia), *Spirorbidae* (Polychaeta), *Aphelochaeta* (Polychaeta), *Nephtys* spp. (Polychaeta), *Truncatella subcylindrica* (Gastropoda) and *Gibbula* spp. (Gastropoda) explain 50 % of dissimilarity between wracks and bare soil.

In July *Peringia ulvae*, *Stratiomyidae* (Diptera), *Serpulidae*, *Gibbula* spp., *Spirorbidae*, *Truncatella subcylindrica*, *Aphelochaeta*, *Armadillidiidae* and *Nephtys* spp. explain 50 % of dissimilarity between wracks and bare soil.

In June, *Peringia ulvae*, *Paludinella sicana*, *Tricolia pullus*, *Truncatella subcylindrica*, *Gibbula* spp., *Cyclope* spp., *Bittium reticulatum* (gastropod), *Myosotella myosotis* (Gastropoda) and some bivalvs (*Abra* spp. and *Cerastoderma glaucum*), *Stratiomyidae* and *Nephtys* spp. explain 50 % of dissimilarity between *Salicornia fruticosa* and bare soil.

In July between *Salicornia fruticosa* and bare soil, *Paludinella sicana*, *Peringia ulvae*, *Truncatella subcylindrica* (Gastropoda), followed by *Armadillidiidae*, *Abra* spp., *Tricolia pullus*, *Bittium reticulatum*, *Cerastoderma glaucum* and *Stratiomyidae* explain 50 % of dissimilarity.

Between *Salicornia fruticosa* and wracks in June, *Armadilidiidae* explain the highest dissimilarity in site 1 and 2. Followed later by *Paludinella sicana*, *Nephtys* spp., *Spirorbidae*, *Stratiomyidae*, *Aphelochaeta*, *Macomopsis cumana*, *Myosotella myosotis*, *Bittium reticulatum*, *Gammarus* spp., *Gibbula* spp. and *Peringia ulvae*, that together with *Armadilidiidae* explain 50 % of dissimilarity.

In July there are less *Armadilidiidae* and more *Serpulidae* and *Truncatella subcylindrica*, followed by: *Peringia ulvae*, *Spirorbidae*, *Gibbula* spp., *Paludinella sicana*, that with *Aphelochaeta*, *Stratiomyidae*, *Nephtys* spp. and *Cerastoderma glaucum* all together explain 50 % of dissimilarity.

## 4. DISCUSSION

### 4.1 Temperature and relative humidity

Temperature is, as expected, the most important abiotic factor in determining the differences between environmental conditions in June and July, but also, together with organic carbon content, between the different treatments.

At the beginning of the work, on the site in Fondo dei Settemorti, diel temperature fluctuations were assessed, with different patterns based on the treatment. From this outcome the experiment on the site in Cà Manzo was planned, and here this pattern was confirmed. In Cà Manzo temperature fluctuations were wider because temperature was sampled in the warmer months of the year (June and July) as explained also by Lindsey and Dahlam (2024). Looking at the data it is possible to say that temperature pattern in Cà Manzo is similar to that in Fondo dei Settemorti. In general, in Cà Manzo, on site 1, 2 and 3, temperature fluctuations graphs on figure 7, 8 and 9 shows that, under wracks, temperature patterns are more constant than under *Salicornia fruticosa* and in bare soil areas. Regarding average daily temperature, results shows that wracks and *Salicornia fruticosa* keep a lower and a more constant daily average temperature than bare soil. Maximum daily temperature on bare soil also shows that in July there were temperature peaks over 50 °C (55,7 °C) with fluctuations up to 20 °C.

The analysis of minimum, maximum temperatures and daily oscillations all confirm the intense buffering effect of wracks on environmental conditions: those microhabitats, probably through shading and thermal insulation, are very efficient at providing stability and mitigate temperature extremes. Live salt marsh vegetation (*Salicornia fruticosa*) also provides a similar effect but at a lower rate, realistically due to the lower density and shading ability that also make the buffering effect of live vegetation more efficient and lower temperatures. Yet, importantly, on the other hand live vegetation is not subjected to being easily washed away by tides and wave energy representing a spatially stabler microhabitat than wracks (as shown in figures 5 to 9).

Looking at relative humidity results, wracks maintain a higher and more constant humidity (also explained by Ruiz-Delgado *et al.*, 2015).

These results confirm that wracks, during heat waves of July, act as climatic micro-niches keeping a constant temperature and a higher and constant relative humidity compared to bare soil (Strachan *et al.*, 2014). Wracks keep local climatic conditions decoupled from regional climate variations (Lenoir *et al.*, 2017). Regional climate variations can be considered to be mirrored by the variations of humidity and temperature seen in *Salicornia fruticosa* vegetated area and bare soil that together constitute the main habitat of salt marshes in the Venice Lagoon (Guadagnin, 2021). Wracks keep also a higher moisture content, reducing soil and air variability of temperature (Lenoir *et al.*, 2017).

## 4.2 Textural class

As already said, textural class, like elevation and TOC, was considered a fixed element over time, so just one sampling was done.

Results show that textural class does not explain important differences between treatments, which was expected since nine treatments out of twelve have the same textural class, and the three treatments that show a different textural class can be considered outliers: despite the fact that the presence of wracks and vegetation can influence some sediment properties differences in granulometry (Zhang *et al.*, 2011), in our sites variations are very small and can mostly be attributed to natural spatial variability.

## 4.3 Marsh elevation

Elevation of treatments is typical of a Venice Lagoon salt marsh, following Bonometto (2014) that says that margins in the Venice Lagoon are high between 25 and 45 cm; only a couple of treatments are lower, but not that low to induce any bias in the work, with treatment 1 Wa with 21 cm and 3 Wb with 22,9 cm of elevation.

Looking at SIMPER analysis on table 13, we can say that elevation is not statistically significant as temperature, relative humidity and TOC.

## 4.4 Total organic carbon

Following SIMPER results on table 13, it is possible to say that total organic carbon is the most important variable to explain abiotic differences between *Salicornia fruticosa* and wracks and bare soil and wracks, while between *Salicornia fruticosa* and bare soil TOC is not as important.

Hence, we can confirm that wracks enrich the sediment in organic carbon, as explained also by Olabarria *et al.* (2007) and this organic matter can affect macrozoobenthos community (Sokolowski *et al.*, 2015), especially detritivore organisms, like polychaetes, that feed on organic matter in sediments (Tagliapietra *et al.*, 1998).

Results of TOC in sediments also confirm that wracks are an example of spatial subsidy event, since they transfer energy (of the wrack itself) from a donor habitat to a recipient habitat (Ince *et al.*, 2007).

## 4.5 Macroinvertebrate community in Cà Manzo

During the two sampling campaigns, macrozoobenthic community in Cà Manzo was assessed. In general, differences between the communities in the two months were mostly determined by the presence or absence of a few rare species, especially gastropods and bivalves, while the most abundant ones did not change much.

Just four taxa differed from this: *Gammarus* spp. on wracks; *Stratiomyidae* on bare soil; *Paludinella sicana* on bare soil; *Armadillidiidae* on *Salicornia*

*fruticosa* area. These taxa showed some very abundant organisms' presence in one sampling while were completely absent in the other one, and further on the reasons why will be described.

In general, between June and July the same amount of isopods was found, while amphipods decreased (*Gammarus* spp., *Stenothoe* spp.), and in July overall taxa richness was lower (25 instead of 33). This can be explained as a consequence of the successional pattern that follows the drying-out process of wracks (Ruiz-Delgado *et al.*, 2014; Ince *et al.*, 2007), and also because amphipods are very sensible to environmental conditions change, especially chemical-physical parameters (Oselladore *et al.*, 2022).

The organisms found in wracks and *Salicornia fruticosa* were mostly detritivores, which makes sense since they feed on sediment with a higher TOC content (see also Tagliapietra *et al.* (1998)). Then they were followed by grazers found more in wracks, especially amphipods and isopods crustaceans and gastropods (as explained also by Costa *et al.*, 2022; Mascart *et al.*, 2015). Filter feeders, on the other hand, were mostly found in the bare soil. Few taxa of predators (mostly gastropods and spiders) were found evenly distributed between the treatments. Benthic communities in our sites were mostly composed by marine and brackish water organisms, with few terrestrials' taxa found especially in wracks, similarly to what was observed by Ruiz-Delgado *et al.* (2014) and Beltran *et al.* (2020).

This community composition is typical of the Venice lagoon (see Oselladore *et al.*, 2022; Sfriso *et al.*, 2001; Tagliapietra *et al.*, 1998), having either marine, brackish water and terrestrial organisms, since the Lagoon is an ecotone: a transitional environment between land and sea (Guadagnin, 2021) that hosts organisms from different habitats (Guadagnin, 2021). The same pattern is also typical of wracks stranded on the shore, that host either terrestrial and marine organisms (Ruiz-Delgado *et al.*, 2014). Therefore, we can conclude that, while wracks maintain a higher average humidity than bare soil they also provide terrestrial species with shelter and protection from inundation.

Polychaetes, bivalves, gastropods molluscs, amphipods and isopods crustaceans were the most abundant taxa, confirming the findings by Oselladore *et al.* (2022) in a study of the effect of seagrass restoration on salt marsh macrozoobenthos in the northern Venice Lagoon.

In bare soil and *Salicornia fruticosa* vegetated area more bivalves and Dipterans (*Stratiomyidae*) were found than in wracks, while gastropods, polychaetes, amphipods, and isopods were found more in wracks. This could be mainly due to the feeding behavior of the taxa, since bare soil has less TOC and is spoiled from any vegetal cover. Bivalves, found more in bare soil, are mainly filter feeders and can adapt to live in bare soil patches since they do not need to feed on organic matter of sediment, also because wracks are difficult to reach since bivalves can't move fast. On the other hand, on wracks less bivalves but more detritivores organisms like polychaetes, as explained above, and grazers were found (amphipods, isopods, gastropods). Wracks

offer either fresh organic matter on wracks for grazers that crawl (gastropods) or walk (isopods) or jump (amphipods) and organic matter in sediments for detritivores that burrow sediment (polychaetes) (Olabarria *et al.*, 2007; Tagliapietra *et al.*, 1998).

*Salicornia fruticosa* vegetated areas do not act as climatic micro-niche, although the relative humidity content is higher than bare soil and is the second environmental variable after temperature to explain differences between bare soil and *Salicornia fruticosa*. Average temperature between wracks and *Salicornia fruticosa* is also comparable, and looking at SIMPER analysis on table 13 explain the lowest dissimilarity between these two treatments. Temperature is slightly less fluctuating than bare soil, and less constant than wracks, colder than bare soil. On the opposite side the TOC content is like bare soil, and it seems that *Salicornia fruticosa* acts as burrower and infauna excluder (as explained also by Snelgrove *et al.*, 2000). Marsh plant habitat complexity is also higher than other vegetated habitats due to variability in salinity, temperature, exposure and oxygenation (Snelgrove *et al.*, 2000), as explained in the introduction. Looking at PERMANOVA pair-wise (table 15) and table 26 and 27 of the appendix, organisms' assemblages are comparable to bare soil, and *Salicornia fruticosa* vegetated area shows the less organisms present either in June and July, also taxa number is lower than wracks. Due to these last features and the low TOC content, is possible to say that *Salicornia fruticosa* vegetated area do not provide all the features of wracks climatic micro-niches. Despite this, temperature shading and good relative humidity content could explain the presence of 43 *Armadillidiidae* individuals found in July in this micro-habitat, while in June were absent, and in general a similar organism's presence between June and July.

Bare soil is neither a climatic micro-niche, showing high and extreme temperature fluctuations, and the lowest relative humidity and TOC content between all treatments and the highest temperature mean, and a different organisms assemblage compared to wracks with lower organisms' abundance and taxa present either in June and July. Bare soil does not present a lot of mobile organisms (crawler, jumper and walker) compared to wracks, except some crawlers' gastropods, because they avoid to live in this kind of microhabitat that is unfavorable during extreme temperature conditions. These statement above can explain the absence of crawler gastropod *Paludinella sicana* on bare soil in July, although 110 organisms were found in June in the same treatment, but also in general can explain the decrease of crawler organisms in bare soil in July.

#### 4.6 Wracks climatic micro-niches features

Wracks showed a more constant temperature, both in June and July, a higher relative humidity, both in June and July and a higher TOC content compared to *Salicornia fruticosa* and bare soil. These differences between the treatments are also reflected in benthic assemblages: wracks host a higher species richness and organisms' quantity compared to bare soil, also in accordance with Mascart *et al.* (2015), Ruiz-Delgado *et al.* (2014) and Ulaski *et al.* (2023). Although PERMANOVA pair-wise test is not statistically significant between month (table 16), slight differences in species presence were observed between June and July. Wracks presented more oniscoid isopods (*Armadillidiidae* in this case) and amphipods (*Stenothoe* spp., *Gammarus* spp.) in June, while Dipterans (*Stratiomyidae*) were more abundant in July when the wracks dried out, as expected by the change of microhabitat conditions (Ruiz-Delgado *et al.*, 2014; Olabarria *et al.*, 2007).

Amphipods and isopods show a distribution pattern that depends on the relative humidity and temperature of the air and colonize wracks less frequently during drying-out period of July (Olabarria *et al.*, 2007). This can explain the absence of *Gammarus* spp. in July (against 43,5 organisms found in June). *Gammarus* spp. are very sensible to environmental conditions change and changes in chemical-physical parameters can affect the presence of these organisms that are indicators of disturbed environments (Oselladore *et al.*, 2022). Amphipods are in general more susceptible to desiccation while insects prefer dried wracks (Ince *et al.*, 2007).

Higher presence of terrestrial invertebrates like polychaetes, Dipterans, Coleopterans and spiders in July can be explained also because they migrate to land-sea ecotones only in summer searching for food on wracks because in this period land ecosystems do not provide much food (Ruiz-Delgado *et al.*, 2014; Beltran *et al.*, 2020). This feature of terrestrial organisms colonizing transitional environments can also explain the high presence of *Stratiomyidae* on bare soil in July (101), while in June they were absent.

This link between different micro habitats is in accordance with previous literature: there is an higher abundance and species richness of invertebrates macrofauna in wracks patches compared to bare soil sediment (Ruiz-Delgado *et al.*, 2014; Mascart *et al.*, 2015) where assemblages reduce their resilience and resistance to environmental threats, due to worsening of environmental conditions (Magni and Gravina, 2023), especially because salt marshes habitat have an high intrinsic variability of temperature and salinity (Snelgrove *et al.*, 2000). Moreover, wracks can also protect organisms from predation compared to bare soil (Olabarria *et al.*, 2010), and, despite we did not directly test for this specific effect it can weight into the complexity of these differences. Another important feature of wracks is that they release a higher amount of total organic carbon in the sediment underneath following grazing and decomposition by shredders that act as a link between wracks subsidy

and nutrient cycling (Lowman *et al.*, 2019). Shredder organisms break down detritus enhancing availability of organic matter, due to this sediment underneath wracks have a higher TOC content compared to *Salicornia fruticosa* vegetated area and bare soil, that present low amount of organic matter, and organic carbon can serve as food for detritivores and burrower organisms (Sokolowski *et al.*, 2015). Organic matter content, together with the constant temperature and higher relative humidity content, do affect macrozoobenthic communities, keeping both a higher number of individuals and a higher number of taxa from different habitats and with different feeding strategies, size and locomotory behavior (Sokolowski *et al.*, 2015).

In the sediment underneath wracks more detritivores were found than in bare soil and *Salicornia fruticosa*, especially polychaetes (*Nephtys* spp., *Aphelocheata* spp.), probably due to a higher TOC content than bare soil and *Salicornia fruticosa*. These organisms have the possibility to cope with emersion and high temperatures since they can burrow, so they can cope against extreme temperature and low humidity of bare soil and *Salicornia fruticosa*, but the higher TOC content can affect their behavior, since detritivores are indicators of environments with a high organic carbon content (Tagliapietra *et al.*, 1998). This result was found also by Beltran *et al.*, (2020). The community found in this study slightly differs from the communities found by Ruiz-Delgado *et al.*, (2014), Beltran *et al.*, (2020) and Olabarria *et al.*, (2007;2010), in different studies on wracks stranded in the Mediterranean sandy beaches. These studies found more insects and amphipods and isopods, rather than gastropods grazing wracks maybe because there are more gastropods living in Lagoon salt marshes (Costa *et al.*, 2021; Oselladore *et al.*, 2022).

The variability in spatial and temporal distribution of wrack on the salt marsh surface is probably not an obstacle to the buffering effect of those microhabitats because, as shown by Olabarria and colleagues (2007) more than 80% of mobile organisms recolonize newly strands wracks in less than 3 days. This explain also locomotory behavior of taxa found on wracks: more crawlers, walkers and jumpers were found on wracks than sessile organisms, that were found more on bare soil and *Salicornia fruticosa* area.

Venice lagoon salt marshes wracks act as climatic micro-niches, thus providing refugia and shelter for macrozoobenthos, buffering temperature variations and retaining a higher relative humidity compared to bare soil and *Salicornia fruticosa* vegetated areas. Wracks also releases a higher TOC content and needs to be protected from human removal, especially on sandy beaches, to enhance the survival of organisms under events of summer heat waves, as said also by Morelli *et al.* (2016) and Hylander *et al.* (2015). Organisms can adapt their behavior to use these micro-niches to avoid heat waves or adverse climatic conditions also for a short amount of time during the peak unfavorable period and then they can go back to live in the previous habitat (Hylander *et al.*, 2015; Morelli *et al.*, 2016).

In general, we can say, from our results, that unvegetated soil, vegetated soil and wracks represent three different micro habitats with specific abiotic characteristics and different benthic communities. How the two components interact in determining those differences should be addressed with further analyses (Forde *et al.*, 2012; Macinelli *et al.*, 1998).

#### 4.7 Future studies in the Venice Lagoon

This study also confirms that wracks stranded on the shore (salt marshes in this case) act as a marine subsidy influencing salt marsh communities (Ince *et al.*, 2007; Olabarria *et al.*, 2007). On the other hand, large scale algae strandings can cause anoxic events on soil with negative impacts on macrozoobenthic communities (Harris *et al.*, 2020) and further studies regarding this topic should be conducted in the Lagoon of Venice.

Different studies demonstrate the preference of algal wracks instead of seagrasses from grazers due to lower phenols concentrations and more mucus secretion in algae (Ulaski *et al.*, 2023). Macroalgae have also a higher nutritional value of secondary metabolites, more water content, and a lower tissue toughness compared to seagrasses and salt marsh plants (Poore and Gallagher, 2013). In this regard Ince *et al.* (2007) states that amphipods in general prefer macroalgae compared to seagrass wracks. On the other hand, there are different studies reporting grazers preferences of seagrass and marsh plant wracks over algal wracks (Parker *et al.*, 2008) or preferences between different species of macroalgae dependent on grazers species (Duarte *et al.*, 2010). Since here wracks were sampled as a uniform detritus, it was not possible to assess a grazer preference between seagrass and algal wracks in this study, but further studies in the Lagoon of Venice should consider this topic.

Wracks stranded on salt marshes can negatively affect the growth of marsh plants through reduction of light under algal mats and releasing harmful compounds or nutrients throughout decomposition (Wasson *et al.*, 2017). The impact of algal wrack can decrease resilience of marshes against erosion threats and can negatively affect carbon sequestration of marsh plants (Wasson *et al.*, 2017; Bonometto, 2014). Due to these findings, further studies in the Lagoon of Venice regarding this topic should be conducted to fully understand the ecological role of these microhabitats.

## 5. CONCLUSIONS

This work has assessed the macrozoobenthic community present in a salt marsh in Cà Manzo, in the central lagoon of Venice focusing on three different microhabitats and corresponding niches: algae and seagrasses wracks, *Salicornia fruticosa* vegetated areas, and bare salt marsh soil. Together with taxonomic identification and quantification, environmental variables were sampled: temperature, relative humidity, total organic carbon, textural class and elevation. This was the first-ever study that focused on wracks as climatic micro-niches in the Lagoon of Venice. Results regarding temperature, relative humidity and total organic carbon, together with the organisms' assemblages found in wracks, help us to state that wracks stranded in the salt marsh of the Venice Lagoon act as climatic micro-niches.

These micro-niches offer to organisms a stable temperature condition over time and hold a higher relative humidity content compared to bare salt marsh soil or salt marsh plant vegetated area (*Salicornia fruticosa*), which can be quite extreme habitats with high temperature peaks, extreme variations and lower humidity when not submerged. Another important point is set by the content of organic carbon (TOC) from the sediment underneath wracks, this organic carbon is another important characteristic of wracks, since degrading vegetal detritus release a high amount of carbon that can be used as food by detritivores organisms, that already can find shelter through wracks. Granulometry was similar between treatments, with class silt loam being the mostly found, with just three treatments being outliers, and elevation was expected, and together with textural class did not explain large differences between treatments.

Connected to their specific environmental features, Venice lagoon wracks climatic micro-niches host a higher species richness and abundance of mobile organisms, especially gastropods, amphipods, Dipterans, isopods and polychaetes, that also graze or burrow the substrate searching for food. These organisms can find shelter and protection from local climatic conditions, compared to bare soil and *Salicornia fruticosa* areas.

These wracks climatic micro-niches can also offer shelter to mobile organisms for a small amount of time to contrast extreme summer heat waves or other unfavorable periods and can help organisms' communities in the future against extreme climatic events.

Wrack climatic micro-niches host a different assemblage of organisms, with more grazers and detritivores organisms, while bare soil hosts more filter feeders and grazers and *Salicornia fruticosa* is in between, with more grazers, detritivores and filter feeders. Marine, brackish and terrestrial organisms were found, as expected, with almost all terrestrials found in wracks, together with brackish water organisms, also found in *Salicornia fruticosa* vegetated area, while on bare soil were found more marine and brackish water organisms. Wracks host also more mobile organisms compared to bare soil.

Although is not statistically significant, a slightly different pattern of organisms that colonize wracks was assessed, with more amphipods and isopods in

June when wracks were fresh, and more Dipterans grazing wracks when they dried out, in July, this is found in different other studies in the Mediterranean (Ruiz-Delgado *et al.*, 2014; Olabarria *et al.*, 2007).

In conclusion, there are different other monitoring studies that can integrate this first analysis, regarding wracks stranded on salt marshes in the Lagoon of Venice, to increase our understanding of their ecological role. These studies either regard anoxia effect of degrading wracks, wracks effect on marsh plant canopies growth, and grazer preference between algae and seagrass wracks.

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## APPENDIX

site	month	group	Species	Contrib%	Cum.%
2	June	B, W	<i>Truncatella subcylindrica</i>	17,15	17,15
2	June	B, W	<i>Armadillidiidae</i>	13,73	30,87
2	June	B, W	<i>Spirorbidae</i>	9,7	40,57
2	June	B, W	<i>Paludinella sicana</i>	8,86	49,43
2	June	B, W	<i>Myosotella myosotis</i>	7,98	57,41
2	July	B, W	<i>Armadillidiidae</i>	11,87	11,87
2	July	B, W	<i>Spirorbidae</i>	10,92	22,8
2	July	B, W	<i>Myosotella myosotis</i>	10,73	33,53
2	July	B, W	<i>Serpulidae</i>	8,38	41,9
2	July	B, W	<i>Paludinella sicana</i>	8,07	49,97
2	July	B, W	<i>Truncatella subcylindrica</i>	6,64	56,61

Table 20. SIMPER analysis between bare soil and wracks on site 2 in June and July compared.

site	month	group	Species	Contrib%	Cum.%
3	June	B, W	<i>Nephtys</i> spp.	7,9	7,9
3	June	B, W	<i>Cerastoderma glaucum</i>	7,76	15,66
3	June	B, W	<i>Cyclope</i> spp.	7,62	23,28
3	June	B, W	<i>Armadillidiidae</i>	6,46	29,74
3	June	B, W	<i>Tricolia pullus</i>	6,27	36,01
3	June	B, W	<i>Bittium reticulatum</i>	5,7	41,7
3	June	B, W	<i>Peringia ulvae</i>	5,31	47,01
3	June	B, W	<i>Paludinella sicana</i>	5,28	52,29
3	July	B, W	<i>Nephtys</i> spp.	10,38	10,38
3	July	B, W	<i>Armadillidiidae</i>	8,83	19,21
3	July	B, W	<i>Myosotella myosotis</i>	8,41	27,62
3	July	B, W	<i>Truncatella subcylindrica</i>	8,26	35,88
3	July	B, W	<i>Serpulidae</i>	7,57	43,44
3	July	B, W	<i>Cerastoderma glaucum</i>	6,9	50,35

Table 21. SIMPER analysis between bare soil and wracks on site 3 in June and July compared.

site	month	group	Species	Contrib%	Cum.%
2	June	B, S	<i>Truncatella subcylindrica</i>	23,54	23,54
2	June	B, S	<i>Peringia ulvae</i>	11,64	35,18
2	June	B, S	<i>Myosotella myosotis</i>	11,21	46,39
2	June	B, S	<i>Stratiomyidae</i>	11,04	57,43
2	July	B, S	<i>Stratiomyidae</i>	11,43	11,43
2	July	B, S	<i>Myosotella myosotis</i>	10,13	21,55
2	July	B, S	<i>Spirorbidae</i>	9,75	31,31

2	July	B, S	<i>Cerastoderma glaucum</i>	9,38	40,69
2	July	B, S	<i>Peringia ulvae</i>	9,34	50,04

Table 22. SIMPER analysis between bare soil and *Salicornia fruticosa* on site 2 in June and July compared.

site	month	group	Species	Contrib%	Cum.%
3	June	B, S	<i>Cerastoderma glaucum</i>	14,01	14,01
3	June	B, S	<i>Cyclope</i> spp.	9,16	23,17
3	June	B, S	<i>Abra</i> spp.	6,94	30,12
3	June	B, S	<i>Truncatella subcylindrica</i>	6,5	36,62
3	June	B, S	<i>Bittium reticulatum</i>	5,54	42,16
3	June	B, S	<i>Tricolia pullus</i>	5,27	47,44
3	June	B, S	<i>Gibbula</i> spp.	5,21	52,64
3	July	B, S	<i>Paludinella sicana</i>	9,52	9,52
3	July	B, S	<i>Peringia ulvae</i>	7,91	17,43
3	July	B, S	<i>Truncatella subcylindrica</i>	7,64	25,07
3	July	B, S	<i>Armadillidiidae</i>	7,46	32,53
3	July	B, S	<i>Abra</i> spp.	6,79	39,32
3	July	B, S	<i>Tricolia pullus</i>	6,76	46,08
3	July	B, S	<i>Bittium reticulatum</i>	6,07	52,16

Table 23. SIMPER analysis between bare soil and *Salicornia fruticosa* on site 3 in June and July compared.

site	month	group	Species	Contrib%	Cum.%
2	June	S, W	<i>Armadillidiidae</i>	13,18	13,18
2	June	S, W	<i>Paludinella sicana</i>	12,81	25,99
2	June	S, W	<i>Spirorbidae</i>	11,46	37,45
2	June	S, W	<i>Stratiomyidae</i>	9,69	47,14
2	June	S, W	<i>Gibbula</i> spp.	8,17	55,31
2	July	S, W	<i>Truncatella subcylindrica</i>	11,58	11,58
2	July	S, W	<i>Serpulidae</i>	11,28	22,86
2	July	S, W	<i>Armadillidiidae</i>	11,13	33,99
2	July	S, W	<i>Gibbula</i> spp.	10	43,99
2	July	S, W	<i>Spirorbidae</i>	9,72	53,71

Table 24. SIMPER analysis between *Salicornia fruticosa* and wracks on site 2 in June and July compared.

site	month	group	Species	Contrib%	Cum.%
3	June	S, W	<i>Nephtys</i> spp.	10,62	10,62
3	June	S, W	<i>Paludinella sicana</i>	8,88	19,5
3	June	S, W	<i>Armadillidiidae</i>	8,46	27,95
3	June	S, W	<i>Aphelocheata</i> spp.	7,3	35,25

3	June	S, W	<i>Peringia ulvae</i>	7,11	42,36
3	June	S, W	<i>Myosotella myosotis</i>	6,45	48,82
3	June	S, W	<i>Gammarus</i> spp.	5,45	54,27
3	July	S, W	<i>Truncatella subcylindrica</i>	9,52	9,52
3	July	S, W	<i>Myosotella myosotis</i>	9,49	19,01
3	July	S, W	<i>Nephtys</i> spp.	8,03	27,04
3	July	S, W	<i>Serpulidae</i>	6,77	33,81
3	July	S, W	<i>Cerastoderma glaucum</i>	6,65	40,46
3	July	S, W	<i>Armadillidiidae</i>	5,2	45,66
3	July	S, W	<i>Gibbula</i> spp.	4,88	50,54

Table 25. SIMPER analysis between *Salicornia fruticosa* and wracks on site 3 in June and July compared.

phylum	Taxonomic Identification	size	Locomoto ry behavio r	feedin g strateg y	habitat	abun danc e June	abun danc e July
Gastropod a	<i>Myosotella myosotis</i>	>1 mm	crawler	grazer	brackish	52	6
Gastropod a	<i>Cyclope</i> spp.	>2 mm	crawler	grazer	marine	54	10
Gastropod a	<i>Gibbula</i> spp.	>2 mm	crawler	grazer	marine	155	121
Gastropod a	<i>Truncatella subcylindrica</i>	>0,5 mm	crawler	grazer	brackish	165	109
Gastropod a	<i>Peringia ulvae</i>	>0,5 mm	crawler	grazer	brackish	349	493
Gastropod a	<i>Paludinella sicana</i>	>0,5 mm	crawler	grazer	brackish	110	-
Gastropod a	<i>Ovatella firminii</i>	>2 mm	crawler	grazer	brackish	1	-
Gastropod a	<i>Raphitoma purpurea</i>	>2 mm	crawler	detritiv ore	marine	1	-
Gastropod a	<i>Hinia reticulata</i>	>2 mm	crawler	detritiv ore	marine	-	2

Gastropoda	<i>Tritia corrugata</i>	>2 mm	crawler	detritivore	marine	-	-
Gastropoda	<i>Akera bullata</i>	>2 mm	crawler	detritivore	marine	-	-
Gastropoda	<i>Acteon tornatilis</i>	>2 mm	crawler	detritivore	marine	1	-
Gastropoda	<i>Haminoea hidatis</i>	>2 mm	crawler	detritivore	marine	4	-
Gastropoda	<i>Bittium reticulatum</i>	>0,5 mm	crawler	detritivore	marine	61	29
Gastropoda	<i>Tricolia pullus</i>	>2 mm	crawler	detritivore	marine	71	51
Gastropoda	<i>Leufroyia leufroyi</i>	>2 mm	crawler	detritivore	marine	1	-
Gastropoda	<i>Dermomurex</i> spp.	>2 mm	crawler	predator	marine	-	-
Bivalvia	<i>Cerastoderma glaucum</i>	>2 mm	sessile	filter feeder	marine	90	55
Bivalvia	<i>Ostrea edulis</i>	>2 mm	sessile	filter feeder	marine	1	-
Bivalvia	<i>Mactra corallina</i>	>0,5 mm	sessile	filter feeder	marine	-	2
Bivalvia	<i>Diplodonta rotundata</i>	>0,5 mm	sessile	filter feeder	marine	1	-
Bivalvia	<i>Abra</i> spp.	>0,5 mm	sessile	filter feeder	brackish	26	15
Bivalvia	<i>Macomopsis cumana</i>	>2 mm	sessile	filter feeder	marine	12	20
Bivalvia	<i>Scrobicularia plana</i>	>2 mm	sessile	filter feeder	marine	-	-
Bivalvia	<i>Lucinella divaricata</i>	>2 mm	sessile	filter feeder	marine	10	2

Amphipoda	<i>Gammarus</i> spp.	>0,5 mm	jumper	grazer	brackish	-	-
Amphipoda	<i>Stenothoe</i> spp.	>1 mm	jumper	grazer	brackish	1	-
Isopoda	<i>Armadillidiidae</i>	>0,5 mm	walker	grazer	terrestrial	-	-
Polychaeta	<i>Nephtys</i> spp.	>0,5 mm	burrower	detritivore	brackish	9	4
Polychaeta	<i>Serpulidae</i>	>0,5 mm	sessile	detritivore	brackish	18	-
Polychaeta	<i>Spirorbidae</i>	>0,5 mm	sessile	detritivore	brackish	222	132
Polychaeta	<i>Aphelocheata</i> spp.	>0,5 mm	burrower	detritivore	brackish	15	7
Coleoptera	Coleoptera	>1 mm	flyer	grazer	terrestrial	-	-
Diptera	<i>Stratiomyidae</i>	>1 mm	flyer	grazer	terrestrial	-	101
Arachnida	Arachnida	>1 mm	walker	predator	terrestrial	1	-

Table 26. Bare soil organisms community in Cà Manzo.

Phylum	Taxonomic Identification	size	Locomotor behavior	feeding strategy	habitat	abundance June	abundance July
Gastropoda	<i>Myosotella myosotis</i>	>1 mm	crawler	grazer	brackish	49	63
Gastropoda	<i>Cyclope</i> spp.	>2 mm	crawler	grazer	marine	48	10
Gastropoda	<i>Gibbula</i> spp.	>2 mm	crawler	grazer	marine	78	100
Gastropoda	<i>Truncatella subcylindrica</i>	>0,5 mm	crawler	grazer	brackish	273	273
Gastropoda	<i>Peringia ulvae</i>	>0,5 mm	crawler	grazer	brackish	165	115

Gastropoda	<i>Paludinella sicana</i>	>0,5 mm	crawler	grazer	brackish	98	36
Gastropoda	<i>Ovatella firminii</i>	>2 mm	crawler	grazer	brackish	-	-
Gastropoda	<i>Raphitoma purpurea</i>	>2 mm	crawler	detritivore	marine	-	-
Gastropoda	<i>Hinia reticulata</i>	>2 mm	crawler	detritivore	marine	-	-
Gastropoda	<i>Tritia corrugata</i>	>2 mm	crawler	detritivore	marine	-	-
Gastropoda	<i>Akera bullata</i>	>2 mm	crawler	detritivore	marine	-	-
Gastropoda	<i>Acteon tornatilis</i>	>2 mm	crawler	detritivore	marine	-	-
Gastropoda	<i>Haminoea hidatis</i>	>2 mm	crawler	detritivore	marine	-	-
Gastropoda	<i>Bittium reticulatum</i>	>0,5 mm	crawler	detritivore	marine	34	35
Gastropoda	<i>Tricolia pullus</i>	>2 mm	crawler	detritivore	marine	24	29
Gastropoda	<i>Leufroyia leufroyi</i>	>2 mm	crawler	detritivore	marine	-	-
Gastropoda	<i>Dermomurex</i> spp.	>2 mm	crawler	predator	marine	-	-
Bivalvia	<i>Cerastoderma glaucum</i>	>2 mm	sessile	filter feeder	marine	8	35
Bivalvia	<i>Ostrea edulis</i>	>2 mm	sessile	filter feeder	marine	-	-
Bivalvia	<i>Mactra corallina</i>	>0,5 mm	sessile	filter feeder	marine	-	1
Bivalvia	<i>Diplodonta rotundata</i>	>0,5 mm	sessile	filter feeder	marine	-	-

Bivalvia	<i>Abra spp.</i>	>0,5 mm	sessile	filter feeder	brackish	-	8
Bivalvia	<i>Macomopsis cumana</i>	>2 mm	sessile	filter feeder	marine	19	19
Bivalvia	<i>Scrobicularia plana</i>	>2 mm	sessile	filter feeder	marine	-	-
Bivalvia	<i>Lucinella divaricata</i>	>2 mm	sessile	filter feeder	marine	4	-
Amphipoda	<i>Gammarus spp.</i>	>0,5 mm	jumper	grazer	brackish	-	-
Amphipoda	<i>Stenothoe spp.</i>	>1 mm	jumper	grazer	brackish	5	14
Isopoda	<i>Armadillidiidae</i>	>0,5 mm	walker	grazer	terrestrial	-	43
Polychaeta	<i>Nephtys spp.</i>	>0,5 mm	burrower	detritivore	brackish	18	8
Polychaeta	<i>Serpulidae</i>	>0,5 mm	sessile	detritivore	brackish	8	9
Polychaeta	<i>Spirorbidae</i>	>0,5 mm	sessile	detritivore	brackish	266	217
Polychaeta	<i>Aphelochaeta spp.</i>	>0,5 mm	burrower	detritivore	brackish	16	19
Coleoptera	Coleoptera	>1 mm	flyer	grazer	terrestrial	-	-
Diptera	<i>Stratiomyidae</i>	>1 mm	flyer	grazer	terrestrial	26	29
Arachnida	Arachnida	>1 mm	walker	predator	terrestrial	-	-

Table 27. *Salicornia fruticosa* area organisms community in Cà manzo.

Phylum	Taxonomic Identification	size	Locomotor behavior	feeding strategy	habitat	abundance June	abundance July
Gastropoda	<i>Myosotella myosotis</i>	>1 mm	crawler	grazer	brackish	97,5	52,5

Gastropod a	<i>Cyclope</i> spp.	>2 mm	crawler	grazer	marine	13	13
Gastropod a	<i>Gibbula</i> spp.	>2 mm	crawler	grazer	marine	158	158
Gastropod a	<i>Truncatella subcylindrica</i>	>0,5 mm	crawler	grazer	brackish	322	340
Gastropod a	<i>Peringia ulvae</i>	>0,5 mm	crawler	grazer	brackish	252	208,5
Gastropod a	<i>Paludinella sicana</i>	>0,5 mm	crawler	grazer	brackish	121,5	77
Gastropod a	<i>Ovatella firminii</i>	>2 mm	crawler	grazer	brackish	-	-
Gastropod a	<i>Raphitoma purpurea</i>	>2 mm	crawler	detritiv ore	marine	4	-
Gastropod a	<i>Hinia reticulata</i>	>2 mm	crawler	detritiv ore	marine	-	1
Gastropod a	<i>Tritia corrugata</i>	>2 mm	crawler	detritiv ore	marine	1	-
Gastropod a	<i>Akera bullata</i>	>2 mm	crawler	detritiv ore	marine	0,5	-
Gastropod a	<i>Acteon tornatilis</i>	>2 mm	crawler	detritiv ore	marine	2	-
Gastropod a	<i>Haminoea hidatis</i>	>2 mm	crawler	detritiv ore	marine	-	-
Gastropod a	<i>Bittium reticulatum</i>	>0,5 mm	crawler	detritiv ore	marine	21	25
Gastropod a	<i>Tricolia pullus</i>	>2 mm	crawler	detritiv ore	marine	8,5	44,5
Gastropod a	<i>Leufroyia leufroyi</i>	>2 mm	crawler	detritiv ore	marine	-	-
Gastropod a	<i>Dermomurex spp.</i>	>2 mm	crawler	predat or	marine	0,5	1

Bivalvia	<i>Cerastoderma glaucum</i>	>2 mm	sessile	filter feeder	marine	11,5	17
Bivalvia	<i>Ostrea edulis</i>	>2 mm	sessile	filter feeder	marine	-	-
Bivalvia	<i>Mactra corallina</i>	>0,5 mm	sessile	filter feeder	marine	-	-
Bivalvia	<i>Diplodonta rotundata</i>	>0,5 mm	sessile	filter feeder	marine	-	-
Bivalvia	<i>Abra</i> spp.	>0,5 mm	sessile	filter feeder	brackish	5	-
Bivalvia	<i>Macomopsis cumana</i>	>2 mm	sessile	filter feeder	marine	6	4,5
Bivalvia	<i>Scrobicularia plana</i>	>2 mm	sessile	filter feeder	marine	4,5	1
Bivalvia	<i>Lucinella divaricata</i>	>2 mm	sessile	filter feeder	marine	4	1
Amphipoda	<i>Gammarus</i> spp.	>0,5 mm	jumper	grazer	brackish	43,5	-
Amphipoda	<i>Stenothoe</i> spp.	>1 mm	jumper	grazer	brackish	18,5	4
Isopoda	<i>Armadillidiidae</i>	>0,5 mm	walker	grazer	terrestrial	155,5	130
Polychaeta	<i>Nephtys</i> spp.	>0,5 mm	burrower	detritivore	brackish	209	64,5
Polychaeta	<i>Serpulidae</i>	>0,5 mm	sessile	detritivore	brackish	8,5	187
Polychaeta	<i>Spirorbidae</i>	>0,5 mm	sessile	detritivore	brackish	193,5	362,5
Polychaeta	<i>Aphelochaeta</i> spp.	>0,5 mm	burrower	detritivore	brackish	50	72,5
Coleoptera	Coleoptera	>1 mm	flyer	grazer	terrestrial	5	3
Diptera	<i>Stratiomyidae</i>	>1 mm	flyer	grazer	terrestrial	4,5	5
Arachnida	Arachnida	>1 mm	walker	predator	terrestrial	1	1

Table 28. Wracks organisms community in Cà manzo.

