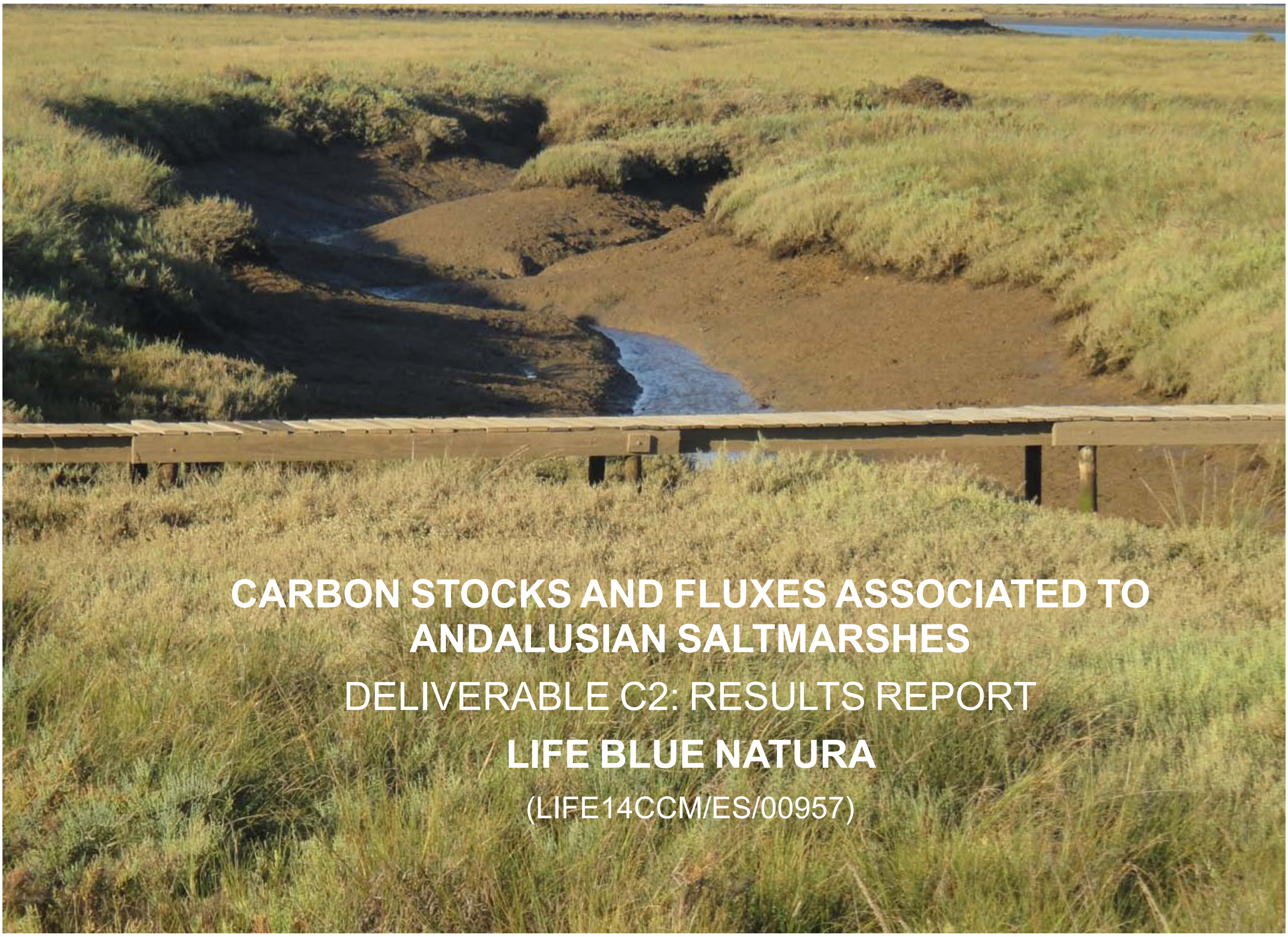

CARBON STOCKS AND FLUXES ASSOCIATED TO ANDALUSIAN SALTMARSHES

DELIVERABLE C2: RESULTS REPORT

LIFE BLUE NATURA

(LIFE14CCM/ES/00957)

Group of Aquatic Macrophyte Ecology
Centre for Advanced Studies of Blanes
Spanish Council for Scientific Research

Puerto Rico
28 February 2019

Photo: Los Toruños, Parque Natural de la Bahía de Cádiz
Source: Group of Aquatic Macrophyte Ecology, GAME

CARBON STOCKS AND FLUXES ASSOCIATED TO ANDALUSIAN SALTMARSHES

DELIVERABLE C2: RESULTS REPORT

STOCKS Y FLUJOS DE CARBONO ASOCIADOS AL SUMIDERO DE MARISMAS EN ANDALUCÍA

ENTREGABLE C2: INFORME DE RESULTADOS

LIFE BLUE NATURA

LIFE14CCM/ES/000957

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Blanes 28 February 2019
Group of Aquatic Macrophyte Ecology
CEAB-CSIC

JUNTA DE ANDALUCIA
CONSEJERÍA DE MEDIO AMBIENTE Y ORDENACIÓN DEL TERRITORIO

Socios beneficiarios:

JUNTA DE ANDALUCIA
CONSEJERÍA DE MEDIO AMBIENTE
Y ORDENACIÓN DEL TERRITORIO
Agencia de Medio Ambiente y Agua

CSIC
CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS

UICN

HyT

Cofinanciador:

CEPSA

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Abbreviations

LIFE BN	Life Blue Natura
AMAYA	Agencia de Medio Ambiente y Agua de Andalucía
CMAOT	Consejería de Medio Ambiente y Ordenación del territorio
GAME	Group of Aquatic Macrophyte Ecology (CEAB-CSIC)
CEAB-CSIC	Centro de Estudios Avanzados de Blanes - Consejo Superior de Investigaciones Científicas
IUCN	International Union for the Conservation of Nature
HyT	Hombre y Territorio
UNEP	United Nations Environment Program
UNFCCC	United Nations Framework Convention on Climate Change
IPCC	Intergovernmental Panel for Climate Change
COP	Conference of the Parties
ICAO	International Civil Aviation Organization
IMO	International Maritime Organization
ITMOs	Internationally Transferable Mitigation Outcomes
SMEs	Small and Medium Enterprises
CORSIA	Carbon Offsetting and Reduction Scheme for International Aviation
VCS	Verified Carbon Standard
BC	Blue Carbon
BCE	Blue Carbon Ecosystem
POM	Particulate Organic Matter
POC	Particulate Organic Carbon
TOM	Total Organic Matter
TOC	Total Organic Carbon
SOM	Sediment Organic Matter
PIC	Particulate Inorganic Carbon
TIC	Total Inorganic Carbon
GHG	Greenhouse Gasses
tCO_2	Ton of Carbon Dioxide
$tCO_{2\text{-}e}$	Ton of Carbon Dioxide equivalents
R/V	Research Vessel
ROV	Remotely Opperated Vehicle

Units

kt	Kiloton, 1000 tons, 10^9 grams.
Mt	Megaton, 1 million tons, 10^{12} grams.
Pg = Gt	Petagram = Gigaton, 10^{15}. Common unit for the global carbon cycle.
C to CO_2	1 g of Carbon equals 3.67 grams of CO_2.
Yr	Years
Km, ha, m^2	Square kilometers, hectares and square meters. Common units to express carbon stocks per unit surface.

Glossary of terms and definitions

LIFE Programme: "LIFE is the EU's financial instrument supporting environmental, nature conservation and climate action projects throughout the EU. Since 1992, LIFE has co-financed more than 4500 projects. For the 2014-2020 funding period, LIFE will contribute approximately €3.4 billion to the protection of the environment and climate." (LIFE)

LIFE Blue Natura: Project funded within the EU LIFE Programme entitled "Andalusian Blue Carbon for Climate Change Mitigation Quantification and Valorisation Mechanisms" (LIFE14CCM/ES/000957). It aims at providing the scientific knowledge on the distribution and size of the blue carbon carbon sinks associated to seagrass meadows and saltmarshes in the region of Andalusia, as well as providing the instruments to make possible its inclusion in the inventories of the national emission compensation systems as well and its monetization in the voluntary carbon markets.

Blue Carbon: Term coined in 2009 by Nellemann et al., (2009) that typically refers to the organic carbon captured by coastal vegetated ecosystems, mainly mangrove forests, tidal saltmarshes, and seagrass meadows. Both the organic carbon in the living tissues and buried in the sediments are considered BC. Whether the carbon contained in the form of carbonates is to be considered Blue Carbon, is still a matter of debate within the scientific community. The organic carbon accumulated in other areas of the ocean, in a chemical form or in the sediments, would also be a part of the BC but not typically included in the global inventories.

Biospheric carbon sink: A carbon sink is any compartment of the biosphere that captures a net amount of carbon and locks it for a long period of time, relevant to global change. Oceans, forest and soils are the main biospheric carbon sinks. When a sink stops adding net carbon, it no longer is a sink but turns into a in steady state stock, in stationary stock, or in a slow source .

Carbon stock: Mass of organic or inorganic carbon accumulated by seagrass ecosystems. The organic forms can be living or dead debris of the seagrass, both from above or belowground. The inorganic fraction is basically represented by carbonates, largely calcium carbonate.

Carbon sequestration rate = carbon flux = carbon long-term burial rate: is the pace at which the fraction of organic or inorganic carbon is buried in the sediments of seagrass meadows to stay for long periods of time. Not to be confused with photosynthetic carbon fixation by primary producers. Only a small fraction of the photosynthetically fixed carbon will be derived by some types of macrophytes to the long-term compartment in the sediments (namely, saltmarshes, mangrove forests, and seagrass meadows).

Saltmarsh, tidal (or salt marsh): is a coastal ecosystem in the upper coastal intertidal zone between land and open saltwater or brackish water that is regularly flooded by tides. It is dominated by dense stands of salt-tolerant plants such as herbs, grasses, or low shrubs. These plants are terrestrial in origin and are essential to the stability of the saltmarsh in trapping and binding sediments. Saltmarshes play a large role in the aquatic food web and the delivery of nutrients to coastal waters. They also support terrestrial animals and provide coastal protection.

Cap and trade system: consists in measurably reducing national GHG emissions below certain levels (cap) in strategic economic activities. Flexibility mechanisms allow entities to compensate their GHG emissions excess from these caps, by purchasing carbon credits, which consist in certified carbon emission reductions (carbon offsets), or un-used carbon emission permissions from other countries.

Carbon credit: a carbon credit is a generic term for any tradable certificate or permit representing the right to emit one tone of carbon dioxide or the mass of another greenhouse gas with a greenhouse effect equivalent to that of one ton of carbon dioxide.

Carbon market: Markets where carbon credits/carbon offsets are traded, directly or indirectly between entities seeking to compensate for their carbon emissions and enterprises that have reduced their carbon emissions below a certain quantity assigned (under the Kyoto protocol) and have the permission to sell their carbon offsets (cap and trade scheme), or entities implementing projects to produce a net reduction in global GHG emissions. The carbon markets can be regular, where clients are enterprises obliged to maintain their GHG emissions under certain thresholds, and where the carbon credits/offsets that can be traded are regulated, both things under the Kyoto Protocol. There are also voluntary carbon markets, for enterprises and projects producing carbon credits are not regulated by the Kyoto Protocol.

Carbon offset: a carbon offset is a reduction in emissions of carbon dioxide or greenhouse gases made in order to compensate for or to offset an emission made elsewhere. Carbon offsets are produced by projects that carry out on-the-ground emissions reduction activities, and are typically measured in metric tonnes of carbon dioxide equivalents, or tCO_{2e}.

Verified Carbon Standard (VCS): Standard for Certifying Carbon Emissions Reductions. “The VCS Program is the world’s most widely used voluntary GHG program. More than 1300 certified VCS projects have collectively reduced or removed more than 200 million tonnes of carbon and other GHG emissions from the atmosphere”. (Verra)

Conference of the Parties: Is the supreme decision-making body of the UNFCCC. Its main task is to review the implementation progress made in reducing GHG emissions by the nations having joined the Conference (Parties).

Paris Agreement: was an initiative of the UNFCCC that aimed at bringing for the first time “all nations into a common cause to undertake ambitious efforts to combat climate change and adapt to its effects, with enhanced support to assist developing countries to do so”. (UNFCCC).

^{14}C age = radiocarbon age: time since and organic material stopped being biomass and started to be necromass, estimated through its remaining content in the radioactive ^{14}C isotope. This method is is used for determining the age of an object containing organic material by using the properties of radiocarbon, a radioactive isotope of carbon, that decays regularly with time. Given that the half life of ^{14}C is 5730 years (± 40), this technique allows us to date organic materials usually between 100 and 50.000 years of age.

^{210}Pb age: age of a sediment layer estimated from its excess content in the radioactive isotope ^{210}Pb. its half-life of 22.3 years, allows to date sediments from present to 150 years ago.

Chronological model: is a statistical model to interpolate several ages assigned with one or different dating methods to several sediment layers, in order to assign a date to any sediment layer along a core.

Corer, core, coring: A corer is a cylinder that can be made of various materials, have different diameters and be driven into de soils or sediments manually or using different percussion and rotation devices. The core is the soil/sediment sample within the corer which, a priori, conserves its chronological sequence of sedimentation. Coring is the action of sampling cores using corers.

Manual coring: Were mechanical coring techniques cannot be used, typically in shallow waters, manual coring is the choice. It consists on slowly hammering PVC corers down in the sediments while rotating them to minimize core compression. Depending on the grain size of the sediments being cored, the pipe will require to be fitted with a core catcher to retain lose sediments. Core lengths of up to 3 m can be obtained using this technique. Both the penetration and removal of the manual cores can be a very arduous work, especially when it has to be performed underwater in SCUBA. Retrieval usually requires the participation of several divers and a lift air balloon.

Grain size analysis: measurement of the abundance of different sediment grain-size classes. It is performed by successive sieving through decreasing size-mesh, or analyzing laser diffraction patterns.

1. Preface

Within Actions A1, A3, and C2 of this project (mapping, sampling design and field sampling), it was evidenced that the diversity of types of saltmarshes in Andalusia was much larger than previoiusly thought. The first results revealed that some particular of the types investigated presented higher stocks and fluxes than the rest and seemed to be those located at medium elevation and away from the main channels and from the mouth of the rivers. The stocks and fluxes in those types were roughly 600 $tCO_2\ h^{-1}$ and 1.5 $tCO_2\ h^{-1}\ yr^{-1}$ respectively, about twice as much as for the rest of types on average.

It was also found that an important conversion action for saltmarshes in Los Toruños (Cádiz) and in Marismas del Odiel (Huelva), was turning them into salt mines. Up to 10% of all Andalusian saltmarshes have been turned into artisanal or industrial saltmarshes over the last 50 years (Vasquez 2017).

Finally, during the works in the area, a contact was established with Dr. Jesús Castillo, from the University of Sevilla, who had worked in a reforestation project of *Spartina maritima* in Odiel between 2006 and 2009 (in Punta el Sebo, the confluence of the rivers Odiel and Tinto). The relevance of visiting this site after 12 years and knowing the impact of the reforestation action in the blue carbon stock was highest.

In view of all above, it became ovbious that a complementary field mission for the action C2 in order to cover all those new types would be of special interest for carbon offset projects. To this end, an extension of the action C2 was proposed and approved, and the additional mission was performed in november/december 2018. Nine new types of marshes were sampled, both in Toruños and Odiel, including high, medium, restored marshes, and salt mines (Table 1.1.)

Table 1.1. New saltmarsh typologies sampled in the additional Life Blue Natura mission of November/December 2019.

Site	Date	Tipology
Cadiz Bay	27/11/2018	Tidal saltmarsh
		Abundant artisanal salina
	28/11/2018	Salina artisanal
		Salina abundant with tide influence
Odiel	29/11/2018	High salt marshes
		Restored salt marshes
	30/11/2018	High salt marshes
		Medium salt marshes
		Control station (unvegetated sediment)

This report covers only the results of the original Action C2, that is, the resutls obtained from the mission counducted in Spetember/October 2016, which is due 28th February 2019. A comprehensive report, inlcuding all types of marshes sampled, will be issued in the second quarter of 2019, as scheduled in the project timeline of deliverables.

2. Materials and methods

2.1. Field sampling strategy

The vast geographic extension of the Andalusian coast, as well as the large variability of environmental conditions makes a full factorial sampling design totally out of reach and of scope of this project. We therefore sought to capture as much as possible of the variability in the 2 tidal saltmarshes contemplated in the project, which are those of Cadiz Bay and Odiel Natural Parks.

Odiel saltmarsh is a bar built estuary (Borrego, 1997) in the confluence of the Odiel and Tinto rivers mouths, which is growing eastwards, parallel to the coastline, by the combined effects of the sediments transported by these rivers and the main coastal current sediment transport in this area (Pendón 1997). Most of its surface is non-transformed saltmarsh (Thematic cartography of Odiel saltmarsh, A1.1 deliverable).

Cadiz Bay saltmarsh is mainly formed by the landward net sediment transport in that area, which coastline is perpendicular to the main eastward current, although there are also inputs from some small rivers (Gracia et al, 2017). More than half of the Cadiz Bay saltmarsh surface has been traditionnaly exploited as artisanal salinas. Today, only one third of that surface is still being exploited for salt. Roughly another third has been transformed for aquaculture, and the rest have been abandoned, with varying degrees of restoration of the tidal influence (Thematic cartography of Cadiz Bay saltmarsh, A1.2 deliverable). Only 26% of the Cadiz Bay space consists in un-transformed tidal saltmarsh. Half of it is located towards the north, in the area called Los Toruños.

Following the design of action A3, we studied *saltmarsh* stocks and fluxes variability depending on the tidal immersion gradient (dependent on saltmarsh and tide height), identified by changes in vegetation and flora. Odiel (OD) and Toruños (TOR), were sampled at vegetated mid saltmarshes (stations ODE.M, in El Manto islet, and TOR.M, respectively) and high saltmarshes (stations ODE.H, in El Saltés islet, and TOR.H). At the low marsh we sampled in vegetated (ODM.L, in El Manto islet, and TOR.L) and un-vegetated (ODM.L-C, TOR.L-C) sediments. In addition to the natural gradient, we also explored at Odiel changes in carbon stocks and fluxes in a station of continentalized saltmarsh in the northern part of the site, with low influence of tidal regime. Within this area, we distinguished one part conserving typical high saltmarsh vegetation (ODN.D-V), and another of bare sediment (ODN.D-C), which would represent a degraded saltmarsh area, which is typically called “sterile saltmarsh” (Borrego, 1997). We also sampled an area called Llanos de Bacuta (ODB.Z), which had been dry and before 1956, and which has been rewetted by reconnection to the tidal regime since 2005. Finally, we sampled in an area close to the delta tip, which was planted with vegetation typical of mid marsh in 2012, after sediment movements to install a pipe (Sealine, ODL.R; Fig. 2.1).

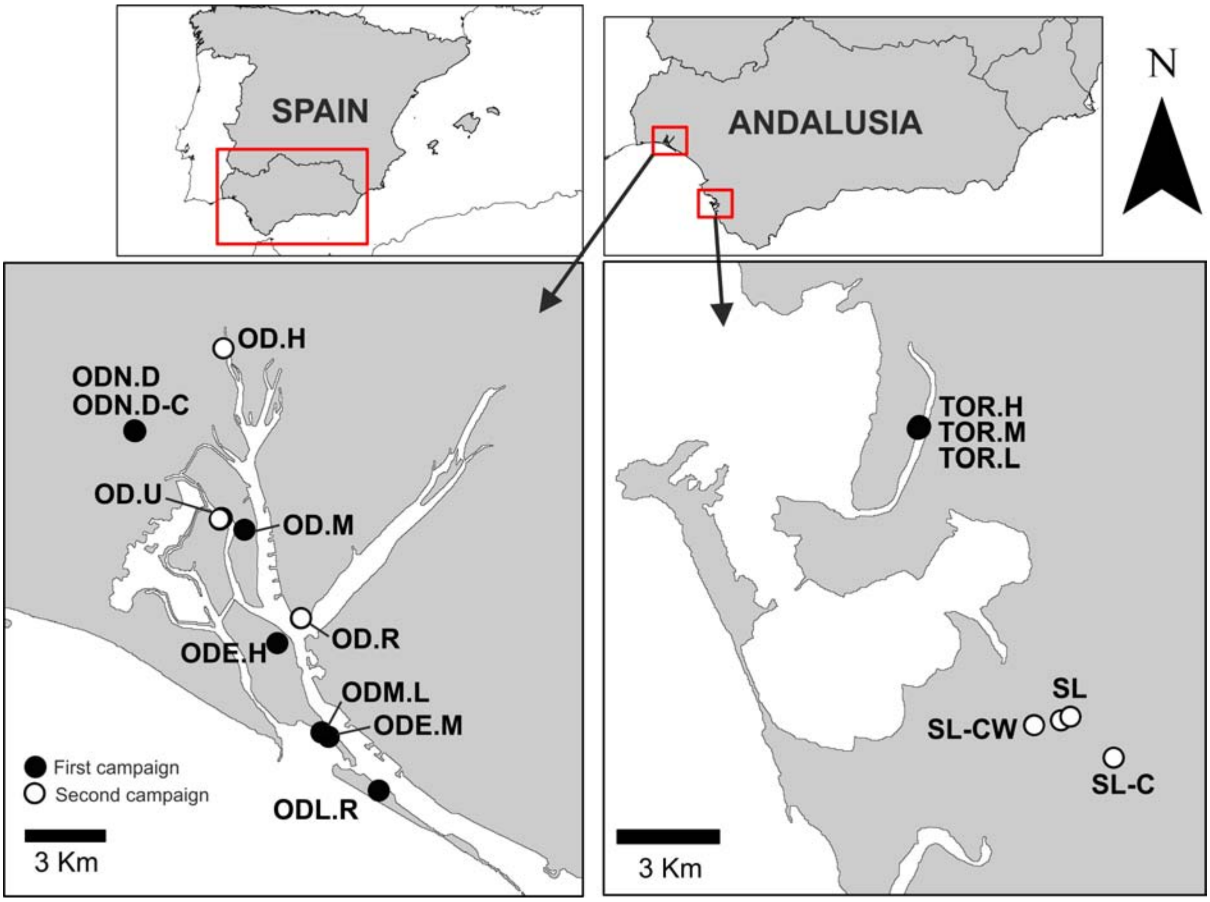

Fig. 2.1. Location of the saltmarsh stations sampled in 2016 and reported in this study (in Black), and in 2018 (in white), to be reported in the next C2 deliverable.

2.1.1. *Sampling the sediment carbon stocks*

In each selected station we obtained 3 replicate sediment samples, which consisted in manual gravity cores (21 to 159 cm long), with the exception of ODN.D-C, were only 2 sediment cores were taken. Additionally, in stations ODE.H and ODN.DV, one gravity core was substituted by a vertical profile.

2.1.2. *Other carbon compartments*

Most of the blue carbon in saltmarshes is accumulated in their sediments. Nevertheless, the IPCC protocols for carbon sinks and emissions always include the evaluation of the carbon pool sequestered in the plant standing stocks (above and belowground plant biomass). Therefore, at each vegetated station we obtained 3 replicate plant biomass samples (within quadrats of 20x20cm, up to 2 cm thick belowground.

Table 2.1 Saltmarsh stations, coordinates and typologies studied in these report.

Region /Province	Natura 2000 SAC	Location	Coordinates		Categories	Code
El Odiel	ES0000025	El Manto Isle	37º 10,460` N	6º55,865'W	Low marsh, vegetated, healthy Marine part	ODM.L
El Odiel	ES0000025	El Manto Isle	37º 10,460` N	6º55,865'W	Low marsh, un-vegetated, healthy Marine part	ODM.L-C
El Odiel	ES0000025	El Saltés	37º 12,228'	6º 57,081'	High marsh, vegetated, healthy Mid part	ODE.H
El Odiel	ES0000025	El Manto Isle	37º 10,373'N	6º 55,690'W	Intermediate marsh, vegetated, healthy Marine part	ODE.M
El Odiel	ES0000025	Llanos de Bacuta	37.24160ºN	6.96730ºW	Intermediate marsh, vegetated, re-wetted Mid part	ODB.Z
El Odiel	ES0000025	Northen Odiel	37.27347ºN	7.01543ºW	High continentalized marsh, vegetated High part	ODN.D
El Odiel	ES0000025	Northen Odiel	37.27347ºN	7.01543ºW	High continentalized marsh, unvegetated, degraded (sterile marsh) High part	ODN.D-C
El Odiel	ES0000025	El Manto Isle	37º 09,310'N	6º 54,357'W	Low marsh, vegetated, planted (living shoreline) Marine part	ODL.R
Los Toruños	ES0000140	San Pedro River	36º 32,923'N	6º 12,597'W	Low marsh, vegetated, healthy Marine Part	TOR.L
Los Toruños	ES0000140	San Pedro River	36º 32,923'N	6º 12,597'W	Low marsh, unvegetated, healthy Marine part	TOR.L-C
Los Toruños	ES0000140	San Pedro River	36º 32,923'N	6º 12,600'W	Intermediate marsh, vegetated, healthy Marine part	TOR.M
Los Toruños	ES0000140	San Pedro River	36º 32,919'N	6º 12,613'W	High marsh, vegetated, healthy, Marine part	TOR.H

In total, during 2016, we sampled 12 stations in the 2 saltmarshes: 4 in Cadiz bay (area of Los Toruños), and 8 stations in Odiel saltmarsh (Huelva province). We collected 37 manual and 2 vertical profiles. As well as 32 biomass samples, and samples of the various dominant plant species growing in each area, in order to measure the primary producers isotopic signal (to try establishing the main total organic carbon – TOC – contributors to the sink). The results for the isotopic signals are not part of this deliverable. They will be used in future elaborations of the data in the form of scientific manuscripts, as well as in the second deliverable of this action. Full details on the sites and stations sampled, are available in the LIFE BN Deliverable A3 (Anejo A3 Deliverable Resultados muestreos en marismas andaluzas.pdf, 2017).

2.2. **Laboratory analyses**

2.2.1. *Sub-sampling, parameters and analyses on sediment cores*

Two out of three cores per station were subsampled in the field, at 6 to 8 levels, through 3-cm holes pre-made along the cores, at 5-10 cm intervals for the top samples and 25 for the bottom ones. The third core was brought to the laboratory, where it was cut open longitudinally. One hemicore was subsampled in 1 to 2 cm-thick slices, which were dried at 50ºC and subsequently weighted (for full details on subsampling procedures see LIFE BN, 2017 Deliverable A3). The other hemicore was kept as a back up, and stored in darckness at 4º C.

Each dry-weighted subsample was disaggregated and coarse shells and stones (>2 mm) and gravel were separated and weighted. The sediment fraction below 2 mm plus the COM were the ones included in chemical analyses.

In one core per station, the accretion rates of the sediment for recent times (<100 years) were estimated in the top 30 cm, using the ^{210}Pb technique. The rest of the core was dated at one or two levels selected between the top 50 cm and the bottom.

Total Organic Matter (TOM) was measured in all the sediment subsamples, from 0 to 30 cm core depth, and in every other sample thereafter. Total Organic Carbon (TOC) and Total Inorganic Carbon (TIC) were measured on at most 12 subsamples, evenly selected along the core (See Fig. 2.4).

a. Geochemical and biomass analysis

A 3-4 g fine (< 2mm) sediment aliquot was digested with 35 % H_2O_2 in order to remove Sediment Organic Matter (SOM), then dried and sieved through a 1 mm, and analyzed in a laser difraction particle analyzer (Mastersizer 2000) to obtain the grain size distribution for small fractions: <0,063 mm (silt and clay), 0,063-0,25 (fine sand), 0,25-0,5 (medium sand), 0,5-1 (coarse sand). TOM was determined as the weight lost in another aliquot of ca. 3g sediment sample, combusted at 450ºC during 5 hours (see Annex C1-C2_ analysis protocols.docx for more details). In 10 to 12 subsamples per core, around 1 g of sediment (< 2mm) was digested by adding HCl 1M until cessation of bubbling. The digestate was centrifuged and rinsed with MQ-water until pH 7 before drying at 50ºC. Weight difference before and after the digestion plus the weight of the shells > 2mm was assumed to be the carbonate content. From this, TIC was calculated. Accuracy and precision were monitored using a certified carbonate standard (SETOC 776 from WEPAL). The digested sediment aliquot was used to measure Total Organic Carbon (TOC) at the IATC-CSIC center in Granada, using a mass-spectrometer and a IRMS (Isotopes Ratio Mass Spectrometer) for subsequent isotopic analysis.

The 3 biomass replicates for each station were washed and sorted into necromass (largely leaf litter) and biomass (leaves, rhizomes and roots). Those fractions were dried and weighed.

b. Lead (^{210}Pb) and radiocarbon (^{14}C) dating

From the 30 first cm from each replicates A core (cores subsampled in full at each station), aliquots of 5 g of ground sediment samples were sent to the Unit of Physics of Radiations from the Autonomous University of Barcelona (UAB) to estimate recent sediment accretion rates from ^{210}Pb in excess, through measurement of its daughter element 210Pb. In the same core, we selected 2-3 bulk samples for carbon dating. Carbon datings were performed by accelerator mass spectrometry (DirectAMS - Accium BioSciences), using a NEC Pelletron 500 kV AMS. See Annex C1-C2_ analysis protocols.docx for more details.

2.3. Numerical procedures

2.3.1. *Corrections for core compression*

A decompression factor was applied to all cores presenting less than 30 % compression. The factor was obtained using a simple exponential function ($y=ab^x$) under the assumption that compression is maximum in the top and minimum in the bottom of the core. The function is fitted between two points, (y1, x1) and (y2, x2), being y1 the length of the core minus the penetration depth of the corer, x1=y1; y2 is set to 0.1 and x2 is again the penetration depth of the corer. The resulting equation is then used to calculate a correction factor where ‘x’ is the observed depth. Then: the corrected (or decompressed) sample depth is the observed depth minus the correction factor. Cores with compressions between 30-40 % were decompressed as the above but using 1 for y2 instead of 0.1. Those cores with a compression exceeding 40 % were decompressed following a linear model ($y=mx+b$), that is, considering a constant compression across the core.

The volume of the subsamples (slices) taken from the cores was calculated after the mathematical core decompression. For the cores subsampled in the field through pre-made holes, the volume taken in the field was corrected applying the % volume increase that would have experienced the slice aligned at the level were each hole was located.

2.3.2. *Estimating TOC from TOM*

Because it is well established that TOM and TOC in saltmarsh soils are highly correlated, TOC analysis were only performed on some of the samples, allowing us to fit a linear regression and infer TOC content in the remaining samples, using the equation obtained (R^2 = 0.95 to 0.54; p <0.002; Table 2.2.).

Organic carbon stocks per unit area - The TOC density in each subsample was calculated from the sample bulk density (D) and TOC content: *TOC density (g/m^3) =D*(TOC%/100)*. This value was then multiplied by the area of the subsample (½ of the corer cross section) to express the stock per square area (cm^2, m^2, ha, etc.). The total stock per core was computed by adding the TOC content per unit area of all subsample slices and to 1 m core thickness (for inter-stations and inter-studies comparation purposes). For those cores subsampled in the field (i.e, those for which only a few subsamples were taken along the core through the premade holes), the average TOC between succesive subsamples was integrated along the core length between both subsamples. The TOC content per unit area was added along the whole core and also to 1m sediment thickness, for the abovementioned comparative purposes.

Table 2.2. Regressions and correlation coefficients between Carbon and organic matter contents in each station.

Station	Total amount of samples	Samples analyzed for TOC	Equation	R^2
TOR.L	77	17	y = 0.2891x - 0.5065	0.74
TORL-C	48	24	y = 0.2978x - 0.7709	0.64
TOR.M	49	13	y = 0.5534x - 1.6236	0.7
TOR.H	39	7	y = 0.2983x + 0.2043	0.78
ODM.L	68	23	y = 0.1852x + 0.4135	0.61
ODM.L-C	41	13	y = 0.1103x + 0.9136	0.54
ODE.H	56	21	y = 0.1912x + 0.0098	0.82
ODE.M	48	22	y = 0.3121x - 0.3828	0.80
ODB.Z	59	24	y = 0.1727x + 0.6219	0.61
ODN.D	90	23	y = 0.2793x - 0.1258	0.88
ODN.D-C	41	16	y = 0.2585x - 0.0604	0.92
ODL.R	75	13	y = 0.3546x - 0.2192	0.95

2.3.3. *Chronological models, accretion, stocks and fluxes*

c. Chronological models

Replicate cores A for each station were dated with radiocarbon and lead, in order to estimate the TOC flux to the soil (i.e., the rates of organic carbon sequestration) on them. Radiocarbon ages were used primarily for the models and were combined with the ^{210}Pb technique to fine-tune the chronology of the sediments for the last 100 years. The models were elaborated using the “rbacon” package for R software (Blaauw and Christen, 2011). The age of the top most subsample of the core (the year of sampling: 2016 or 2017), was also considered in the model.

Accretion rates

The rhythm at which the soil accreted was calculated as the length of core accreted per year.

Average carbon stock and dispersion for each station were estimated by constructing a “consensus core” from the three replicates. For that, average and standard deviation of TOC density was calculated from replicated subsamples. We considered as such, the sediment subsamples from the three replicate cores that had been taken at similar sediment depth levels. In the levels whithout replicated values, the TOC density value of the principal core (replicate A), was adopted. Standard deviation of the averaged sediment levels was also calculated. These standard deviations were combined though their coefficient of variation to estimate standard deviation of the carbon stock per unit area, at each replicated level. The average these standard deviations of C stocks, conceptually equivalent to the standard deviation among groups in an ANOVA, was used as estimate of Carbon stock horizontal variability within the station.

The long-term carbon fluxes into the sink were estimated by multiplying the carbon content of each sample by its accretion rate. The carbon fluxes have been estimated from the dated core of each station. In its whole length and for the last 100 years. The sequestration rates for any specific period of time (in a context of e.g., the elaboration of carbn offset projects) can be easily calculated by multiplying the average of the accretion rates for the desired period of years.

2.3.4. *Upscaling: from areal to global estimates*

During the course of Action A1 (Cartography and characterization of habitats by AMAyA for Odiel, and by the contracted enterprise Biogeos, for Cadiz Bay), a thematic cartography was compiled, integrating a number of sources and new observations undertaken in this project. GIS software allowed us to obtain the total areas covered by the various saltmarsh typologies for which the areal carbon stocks and fluxes have been estimated in this study (Table 2.2).

Global estimates were therefore calculated by multiplying the representative organic carbon stocks and fluxes of each typology by the area occupied by that typology. A detailed description and discussion of the distribution of these global estimates is out of the scope of this deliverable.

3. Results and Discussion

The assessment of the organic carbon stocks and sequestration rates made for tidal saltmarshes in this study is probably amongst the most detailed studies performed to date.

In Odiel and Cádiz saltmarshes, over 135 linear meters of coastal soils (37 cores), from 2 sites and 12 stations, bearing or not a vegetation cover, have been scrutinized visually, physically and chemically.

As grand summary, the average stock accumulated in the top meter of non degraded saltmarsh soils in Andalusia amounts to 359 ± 109(SE) tCO_2/ha, ranging from 218 to 609 tCO_2/ha, in the Odiel low vegetated and re-wetted medium marshes, respectively (table 3.1, Fig. 3.1). This stock has been accumulating at the healthy saltmarsh in the last century at an average rate of 0.81 ± 0.19 tCO_2/ha yr^{-1}, ranging from negative values in the eroding low un-vegetated marsh of Los Toruños (Cadiz Bay) to 2.08 tCO_2/ha yr^{-1} in the neighbouring vegetated mid marsh, respectively (Fig. 3.1).

Scaling up these numbers by assigning the corresponding stocks and fluxes obtained in the field to the total area occupied by each bottom type in both saltmarshes (table 3.2), the weighted total stocks and fluxes for both sites are of 2.8 $MtCO_2$ and 8 $ktCO_2$ yr^{-1}, respectively.

Extending such aereal stocks and fluxes to the rest of tidal saltmarshes present in Andalusia (around 50.341 ha more, Vasquez-Loarte, 2017), we estimate a global stock of 21.3 ± 6.5 Mt CO_2 in the top 1m sediment layer, and an average C flux to the sediment of 53 ± 12 Kt CO_2 yr^{-1} in the last century. These are probably underestimates, as the sediment organic carbon seem to continue far beyond the 1 meter sediment thickness.

Comparing aerial pictures from 1956 to 2013, Vasquez-Loarte (2017) estimated that 41% of Andalusian coastal saltmarshes have been lost (2% per year on average between 1956 and 1998, and 1% per year on average from 1998 to 2013). This would suppose a concomitant loss of the carbon stocks and sink capacity of these areas, depending on the nature of the land use change. The main causes of saltmarsh loss have been agriculture (75%), salt industry (10%) and urban sprawl (5%).

A gigantic number of uncertainties and difficulties still prevail, most notably i) the types of saltmarsh explored are limited with respect to the large natural variability, especially with respect to different typologies of degraded saltmarshes, ii) the limited spatial information on the extent of different saltmarsh typologies in other andalusian coastal marshes, iii) the need to delimit the possible role of carbonate precipitation as a source of CO_2 to the atmosphere, iv) the need to explore the magnitude and sign of CH_4 and N_2O fluxes, depending on salinity regime and organic and nutrient inputs in soils and watersheds, or v) the complexity of determining the loss of service following different types of habitat destruction, to mention some. Nevertheless, the various typologies assessed here, constitute an important step forward in providing sound criteria for saltmarsh management and for deciding the best settings to guarantee the success of eventual compensation projects, both in restoration and in emissions avoidance initiatives.

Table 3.1. Carbon stocks and fluxes in the different saltmarsh stations studied, saltmarsh types, surface of each type of wild saltmarsh at each saltmarsh site, and of all the tidal saltmarshes in Andalusia (combining data from A1 from Odiel and Cadiz Bay with results from Vasquez-Loarte for the rest of saltmarshes). The extension for Dry, reweted and planted Odiel types cannot be assessed at this stage of the analysis of the maps available.

Type of bottom	Vegetation Type	Saltmarsh part	Predominant species	Code	Area (ha)	tCO_2/ha	SE	tCO_2/ ha yr	SE	$ktCO_2$	SE	$ktCO_2$/ yr	SE
Odiel wild	High Vegetated	medium	Several, eveness	ODE.H	1045.5	265.0	100.4	0.63	0.11	459.96	190.82	0.79	0.18
	Medium Vegetated	marine	Sarcocornia sp.	ODE.M	1029.2	424.4	128.2	1.32	0.17	436.75	131.99	1.36	0.17
	Low unvegetated	marine	-	ODM.L-C	75.1	461.6	74.6	1.10	0.12	658.47	106.39	1.57	0.17
	Low vegetated	marine	Spartina maritima	ODM.L	1426.4	217.6	91.6	0.38	0.13	16.34	6.87	0.03	0.01
Odiel dry	High continentalized	High	Several, eveness	ODND		374.2	145.0	0.89	0.53				
	Sterile marsh	High	-	ODND-C		213.7	75.4	0.81	0.36				
Odiel reweted	Medium vegetated	medium	Sarcocornia sp	ODB.Z		609.5	170.0	1.04	0.09				
Odiel planted	Medium living shoreline	marine	Sarcocornia sp.	ODL.R		56.4	24.4	6.64	2.00				
Cadiz bay wild	High vegetated	marine	Several, eveness	TOR.H	407.1	286.8	107.8	0.14	0.00	116.79	43.88	0.26	0.05
	Medium vegetated	marine	Sarchocornia sp.	TOR.M	844.8	565.3	134.3	2.08	0.39	477.62	113.47	1.76	0.33
	Low unvegetated	marine	-	TOR.L-C	95.5	297.5	95.2	negative		589.91	188.80	2.18	0.23
	Low vegetated	marine	Spartina maritima	TOR.L	1983.0	232.3	79.2	0.51	0.16	22.17	7.56	0.05	0.02
Total /mean		In Andalusia			59351.1					21301	6483	52.8	12.2
Total / Mean		Odiel and Cadiz			6906.6	359	109	0.89	0.21	2778	790	8.0	1.2

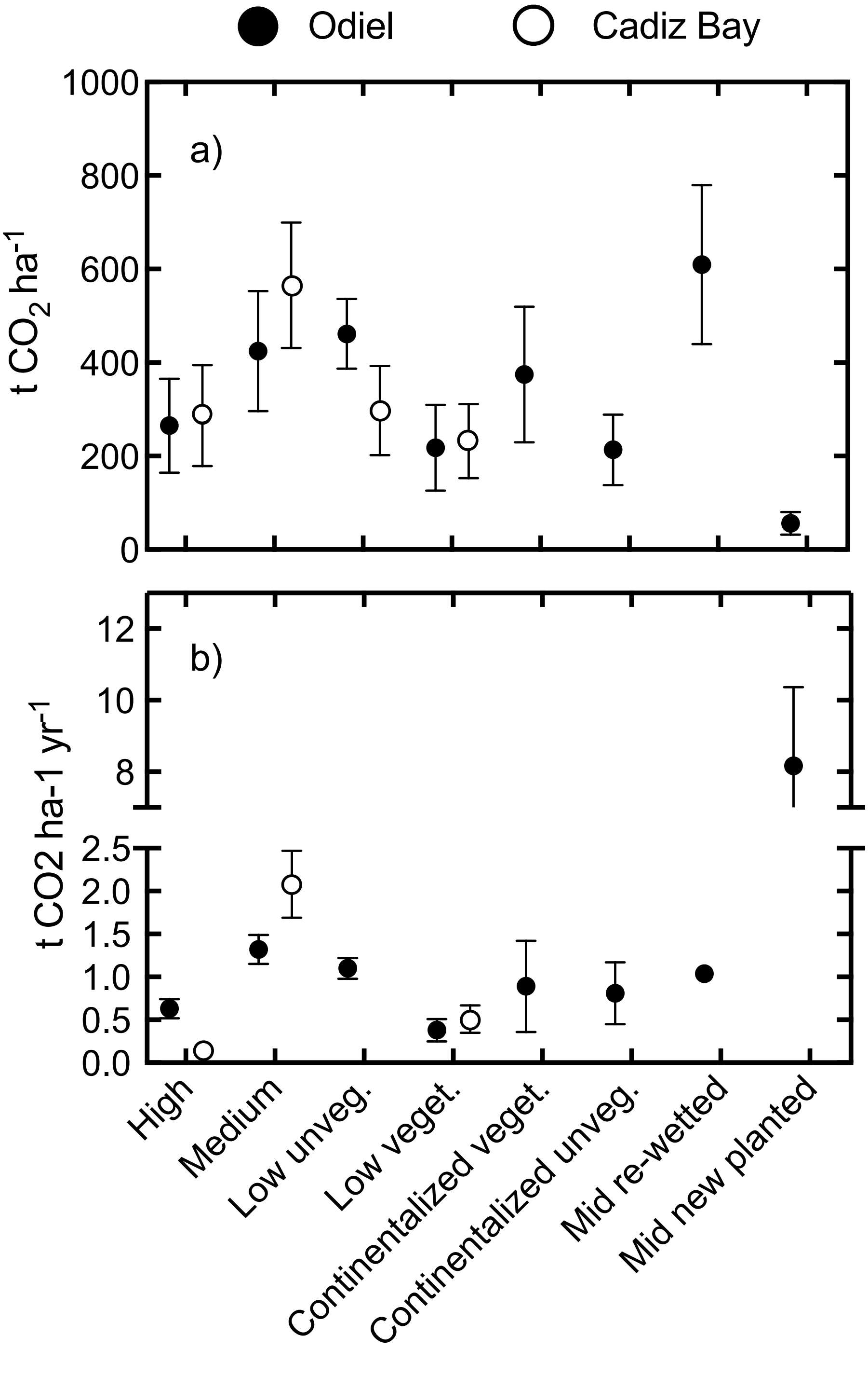

Fig. 3.1. Variability in a) organic carbon stocks in the first meter sediment and b) organic carbon fluxes in the last century, expressed in tonnes of CO_2 per hectare, and tonnes of CO_2 entering the sediment per hectare and year. Dots represent the average stock values per station or the average flux per 100 years in the main core, and bars represent standard errors. Black dots represent estimates in Odiel saltmarsh stations, and white dots in Cadiz Bay (Los Toruños) saltmarsh station.

3.1. **Main geochemical variables estimated**

Data on bulk density, sediment accretion rate, total organic matter, total organic carbon, total organic carbon flux, total inorganic carbon, and granulometric distribution are characterized and plotted against sediment depth and age (see Annex III). Grainsize distribution is similar on all stations, with predominant mud and fine sands along the whole core, with the exception of the planted station of Odiel (ODL.R), which is sandy almost in all its profile, excepting the top 10 cm. The low porosity of the sediment would contribute to the conservation of organic matter, by reducing oxygen penetration (Sawstrom et al, 2016). Bulk density increases with depth, as expected due to soil consolidation and compresion, except in stations ODN.D, ODN.D-C and ODB.Z, which only increase in density in their top centimeters. These are the stations which are or have been disconnected from the tidal regime. Organic matter distribution shows large variablility among depths and stations, reflecting the high temporal and spatial dinamism of the ecosystem and of sediment carbon degradation. Organic matter does not systematically decrease with sediment depth. This indicates that the carbon sink continues beyond the sediment thickness that we have reached. Nevertheless, the lack of a monotonous decline in sediment carbon content, precludes extrapolation of data to estimate the total carbon stock.

3.1.1. *The complex interplay between horizontal variability and conservation status*

The suspected (hypothesized) variability in Carbon stocks and fluxes associated to saltmarsh tidal regime and its associated vegetation exists, and this horizontal variability seems to be more important than differences between sites. Nevertheless, within Odiel saltmarsh there's also an important horizontal variability, which probably has to do with the antiquity of the saltmarsh and/or its depositional dynamics:

In Los Toruños, and in the marine and low parts of the Odiel estuary, which are also the youngest (Borrego, 1997), the highest carbon stocks and fluxes are observed in the natural midmarsh areas (ODE.M: 424.4 $\pm$ 128.2(SE) tCO_2 ha^{-1}, 1.32 $\pm$ 0.17(SE) tCO_2 $ha^{-1}yr^{-1}$ and TOR.M: 565.3 $\pm$ 134.3(SE) tCO_2 ha^{-1}, 2.08 $\pm$ 0.39(SE) tCO_2 $ha^{-1}yr^{-1}$), while carbon stocks and fluxes in high (ODE.H: 265.0 $\pm$ 100.4(SE) tCO_2 ha^{-1}, 0.63 $\pm$ 0.11(SE) tCO_2 $ha^{-1}yr^{-1}$ and TOR.H: 286.8 $\pm$ 107.8(SE) tCO_2 ha^{-1}, 0.14 $\pm$ 0.00(SE) tCO_2 $ha^{-1}yr^{-1}$) and low vegetated saltmarsh are lower, and similar between them (ODM.L: 217.6 $\pm$ 91.6(SE) tCO_2 ha^{-1}, 0.38 $\pm$ 0.13(SE) tCO_2 $ha^{-1}yr^{-1}$ and TOR.L: 232.3 $\pm$ 79.2(SE) tCO_2 ha^{-1}, 0.51 $\pm$ 0.16 , Figs 3.1, 3.2 and table 3.1). In turn, low un-vegetated marsh had carbon stocks and fluxes similar to those in the mid-marsh, in the case of Odiel (ODM.L-C: 461.6 $\pm$ 74.6(SE) tCO_2 ha^{-1}, 1.10 $\pm$ 0.12(SE) tCO_2 $ha^{-1}yr^{-1}$), while in the low un-vegetated of Los Toruños, the carbon stock was lower (297.5 $\pm$ 95.2(SE) tCO_2 ha^{-1}), and similar to that in the high saltmarsh, while carbon flux was presumably towards the atmosphere, as patterns of ^{210}Pb change in the top 30 cm of sediment revealed an erosive process, corroborated in the literature (Gutierrez-Mas et al, 2015). Given that the other 3 pairs of stations are very similar between Los Toruños (Cadiz Bay) and Odiel, the lower C stock detected in the un-vegetated low saltmarsh in los Toruños, as compared with its equivalent in

Odiel, suggests that the erosion process in Los Toruños has also affected to the sediment C stock.

Unexpectedly, carbon stocks in the un-vegetated low marsh of Odiel was higher than in the low marsh vegetated with *Spartina maritima*, despite it has been demonstrated experimentally that this plant increases sediment accretion rate (Castillo and Figueroa, 2009). The vertical profile of organic carbon in the low marsh vegetated stations suggest that *S. maritima* (annex III), could contribute to reduce the sediment carbon stock in the top layers, probably by enhancing organic matter mineralization by its aerobic rhizosphere, which is maintained through pumping oxygen through the plant roots (Duarte et al, 2009).

The ^{210}Pb and XRF sediment profiles indicated that the low un-vegetated marsh in Los Toruños (Cadiz bay) is under erosion, but it didn't give us quantitative information on the erosion rate. Nevertheless, there is previous information indicating that the low part of the river San Pedro is under erosion (Benavente et al, 2006, Gutierrez-Mas and García-López, 2015), this maybe has increased since the loss of *Z. noltei* and *S. maritima* meadows in the low intertidal (Brun et al 2003; Gutierrez-Mas and García-López, 2015), as both species retain sediments (Castillo et al, 1999). In fact, in the adjacent vegetated station (TOR.L), accretion rates were positive (0.51 $\pm$ 0.16 tCO_2 ha^{-1} yr^{-1}; Table 3.1, Fig. 3.1), indicating that these plants are locally reducing erosion. So that, the carbon flux could not be estimated for the un-vegetated low marsh station TOR.L-C, but we may suppose that the erosion is producing net emissions of CO_2 to the atmosphere.

Nevertheless, we also have found high carbon stocks and fluxes in the recently (since 2005) re-wetted area of the islet Llanos de Bacuta (ODB.Z), which is situated in the medium part of the estuary. This area has been dry during at least several decades and now has been colonized by mid-marsh vegetation. Despite it has been disconnected from the tidal regime for several decades, it's C stocks are similar to those found in the natural midmarsh ODE.M, situated down river, in the marine part of the estuary.

Similarly, an area of continentalized saltmarsh, situated in the high estuary, despite it is now totally disconnected from the tidal regime (but receiving intermittent rainwater runoff), also has carbon stocks and fluxes comparable to those of the natural mid-marsh in the marine part of the estuary; at least when it is vegetated (ODN.D, Fig. 3.1, Table 3.1), while in the area that has lost the vegetation (ODN.D-C), the sediment carbon stock is still similar to the carbon stock and flux observed in the natural high marsh, situated in the medium part of the estuary (ODE.H).

Finally, an Odiel area situated in the marine estuary sand bar, which was planted with mid-marsh vegetation on sands in 2012 (ODL.R), after some coastal works (such constructed saltmarsh habitats are called "living shoreline", Davis et al, 2015). Four years later, it has the lowest sediment carbon stocks (54.4 $\pm$ 24.4 t CO_2 ha^{-1}), but the highest carbon flux to the sediment of all stations surveyed (86.6 $\pm$ 2.0 t CO_2 $ha^{-1}yr^{-1}$; Table 3.1, Fig. 3.1), owing to a fast initial sediment accretion rate (1.8 $\pm$ 0.2 cm yr^{-1}), c.a. 7 times greater than in natural mid-marsh. The ODL.R station carbon flux measured is within the range found for other living shorelines in USA (Davis et al, 2015). These results indicate that the carbon sink ecosystem service of saltmarshes can be rapidly set up, although it decreases with time since the saltmarsh onset, and is expected to stabilize, after few decades, into typical carbon flux rates of natural saltmarshes (Davis et al, 2015).

3.1.2. *Advancing the upscaling of the estimates: from areal to regional*

Once the C stocks and sequestration rates per unit surface have been calculated for the various saltmarsh typologies, the next step is assigning to each one of those typologies the area they represent in the Andalusian coasts. These kind of estimates are key as they set reference values for the natural resource/ecological service under study, that are the basis for establishing management plans or for assigning them an instrumental value. In this case, the value of a ton of CO_2 is well defined in the regular carbon markets (EU Emissions Trading System - EU ETS) or in the voluntary markets (Ullman et al., 2013).

As an example, if a rate of saltmarsh loss has been determined, then the global economic loss in terms of CO_2 not captured or emitted can also be estimated. Reciprocally, if a compensation project reduces that rate or stops it, the stocks and sequestration capacity that have been saved could be certified as carbon credits and the potential global benefit of conservation actions could be estimated.

The upscaling of the areal results to global estimates is not a primary goal for the present report but given that a substantial amount of the results from A1 are becoming available at this very moment, it was considered useful to make a first attempt at providing global numbers of carbon stocks and fluxes for the main gradients established at the regional level. Refinements will follow in forthcoming deliverables during 2019.

The task of upscaling discrete field observations to a large area of ecosystem is hampered by a number of challenges. On the one hand, delimiting the total area the values from 3 replicate cores is representative of, is particularly complicated. The sedimentation rates in a saltmarsh vary spatially, and may not be the same that we have estimated in our stations, in other parts of the low and mid saltmarsh. Fortunately there is some spatial information on sediment accretion rates in Cadiz Bay and Odiel (Ligero et al, 2010, Jimenez-Arias et al, 2016, Castillo et al, 1999), which will be used to modulate the upscalling of carbon fluxes in the next report.

Taking into account only the surface estimates of low, mid and high saltmarsh, obtained from thematic cartographies of Cadiz Bay and Odiel saltmarshes (A1 deliverables), and not taking into account the surface of degraded saltmarshes, nor subtidal channels or active and abandoned salinas, we have estimated that the CO_2 stocks accumulated in the top sediment meter of present Odiel saltmarshes is of 1.57 ± 0.44(SE) Mt CO_2 , and would sequester carbon at an average rate of 3.8 ± 0.5(SE) Kt CO_2 yr^{-1} during the last century (Table 3.1). In Cadiz Bay saltmarsh, the top meter sediment C stock would be of 1.21 ± 0.35 (SE) Mt CO_2, and would sequester 4.2 ± 0.6(SE) Kt CO_2 yr^{-1} in average during the last century (Table 3.1).

Possible emissions of other GHG, like N_2O or CH_4 have not yet been taken into account in this first assessment, nor the possible stoichiometric effect of $CaCO_3$ precipitation. This balance of GHG emissions and sequestration will be ellaborated in the next report (Deliverable C2.2), based in data from the litterature for these or similar sites, as well as from our data on TIC sediment content and information from A1 action about environmental pressures on Odiel and Cadiz Bay saltmarshes.

For example, recent data on the N_2O emmissions from the Sancti Petri and San Pedro channels (Burgos et al, 2017), extended to all the Cadiz Bay subtidal channels, indicate that 1.8 ± 2.9 Kt CO_2eq yr^{-1} could be released annually to the atmosphere, and so should be substracted from the global CO_2 sequestration rate of Cadiz Saltmarshes. However, our present global budget on GHG balance of this Natura 2000 site still lacks information on C sequestration/emission by 4579 ha of active and abandoned salinas, 817 ha of channels and 1102 ha of degraded saltmarsh, as well as 2408 ha of aquaculture ponds constructed on ancient salinas, which, if eutrophicated, are also potential emitters of GHG N_2O and CH_4.

In the same way, we need to provide figures of potential CH_4 emissions in the high part of the Odiel saltmarsh, where marine influence is lower, and salinity drops below the 18 ppt thresold defined by Poffenbarger et al (2011), below which, CH_4 emissions start to be significant. The High part of the Odiel saltmarsh, north to the Odiel Bridge, is a mesohaline saltmarsh with salinities ranging from 10 to 25 ppm.

All these figures will be assessed in the next deliverable, through new data obtained from the second Life Blue Natura campaign (held in November 2018), as well as from information available in the scientific litterature, in order to obtain a global estimate of GHG emission/sequestration balance in Odiel and Cadiz Bay.

Fortunately, the large experience and knowledge accumulated by the AMAyA team through the various projects they have led on Andalusian seagrasses, and the monitoring programs funded by the Andalusian Autonomous Government, helped to significantly overcome this limitation. This expertise has led to the elaboration of a series of GIS layers compiling and integrating all the cartographic information on sea bottoms available for the Andalusian coasts (see Action A1 deliverables). This integration of the mapping efforts yields a total area occupied by saltmarsh of 50,341 ha (not including Odiel nor Cadiz areas) and 3,577 ha and 5,434 ha for Odiel and Cadiz, respectively (Table 3.3.).

3.2. Implications of these results for carbon offsetting projects and other project actions

The natural areas exhibiting the highest carbon burial rates were those covered with *Sarcocornia spp*. and *Salicornia spp*., which sediments are submerged daily during high tide. This marsh band seems the strongest carbon sequestration reactor of the ecosystem.

The fact that the C stock in the high marsh (which was formerly a midmarsh) is lower than in the mid marsh is probably due to long-term carbon mineralization processes. Mid marsh usually transforms in high marsh at the scale of several centuries (Borrego, 1997), so these mineralization processes probably take place very slowly (i.e. after 100 years) and so do not invalidate the relatively large importance of the mid-marsh band for climate change mitigation, which typically takes into account carbon sequestered for at least 1 century.

Despite that, the finding of great carbon stocks upstream, suggests that the highest carbon stocks could be linked to the age and long-term stability of the saltmarsh at the scale of millenia. As tidal marshes are most often associated to sand bar growth in estuaries, the long-term temporal dynamics of sediment accumulation in these areas is probably key to predict where are the highest sediment carbon stocks accumulated, which should be protected, in order to prevent the switch of the saltmarsh ecosystem from net sink to net emmiter of GHG.

Projects increasing sediment carbon fluxes and stocks, through re-wetting replanting or reducing coastal erosion, for example, would generate more carbon credits in areas where there are large stocks accumulated, under risk of being mineralized. On the other hand, intermittent re-wetting of dry ancient saltmarsh soils has been shown to enhance carbon mineralization (Borken and Matzner, 2009). This means that when considering the conservation of ancient carbon deposits in transformed saltmarsh soils, re-wetting would be an option if we intend to regenerate the natural saltmarsh dynamics. For example, using ancient saltmarsh soils for irrigated agriculture is expected to increase carbon emissions from such soils (Borken and Matzner, 2009).

Protecting saltmarsh from erosion through better coastal management and also through reforestation of the low intertidal with *S. maritima* and *Z. noltei* could also generate carbon credits, which could help to finance such conservation and restoration projects. A potential candidate place to implement it, would be the river San Pedro.

Creating new saltmarsh through afforestation may also produce significant carbon credits, owing to the high carbon fluxes to the sediment produced by the vegetation, in addition to the biomass compartment in itself. On dry un-vegetated saltmarsh soils (known as "sterile saltmarshes"), formed by aridity and excess of soil salinity, the restoration of the vegetal cover would require the previous restoration of the tidal regime.

Last, but not least, improving water quality through reducing eutrophication would be an important management measure, which not only would diminish risks for the local population, but also would improve GHG flux of N_2O and CH_4 in saltmarshes (well managed saltmarsh watersheds may even be net sinks of N_2O, Burgos et al, 2017), so they don't counterbalance saltmarsh net C sequestration.

LIFE Blue Natura is an Andalusian Blue Carbon 'accounting effort' pursuing the implementation of BC initiatives in the carbon markets in the form of conservation (emissions avoided) and restoration (reforestation) projects. In the recent agreements reached in Paris, the Parties committed to ‘conserve and enhance, as appropriate, sinks and reservoirs of greenhouse gasses’. The article refers to another specific article (4.1, d) of the UNFCCC referring to the natural carbon sinks ‘biomass, forests, and oceans, as well as other terrestrial, coastal and marine ecosystems’.

The reason why seagrass meadows, saltmarshes and mangroves exhibit a notorious incomplete status at the national inventories is fundamentally the lack of i) sufficiently accurate and extensive quantifications of the carbon stocks and fluxes and ii) the lack of a clear path to monetization and accounting rules. The present results contribute to bridge this knowledge gap, for tidal marshes.

3.2.1. *Quality estimates: basis for an efficient implementation of Blue Carbon initiatives*

It is therefore pertinent to remind here that the main goal of this study is to provide numbers of stocks and fluxes of organic carbon associated to the sink of Andalusian saltmarshes to serve as the basis for the elaboration of i) an economical valorization of the Blue Carbon in Andalusia (Deliverable C3 - IUCN), ii) elaboration of the Certification Andalusian Standard for conservation projects of seagrass meadows (Deliverable C4 - CMAOT), iii) elaboration of a manual for the certification of Blue Carbon projects derived from conservation and restoration actions on seagrass meadows (Deliverable C5 - IUCN), iv) dialog and elaboration of carbon compensation projects for the conservation and restoration of seagrass meadows (Deliverable C6 - IUCN), and v) elaboration of a catalogue of conservation projects for *Posidonia oceanica* (Deliverable C7 - CMAOT).

3.2.2. *A ‘big push’ by the Andalusian Government*

In October 8th this year, the Andalusian Parliament approved the Law for Climate Change with unprecedented additions. In its Title V (Emissions mitigation), Chapter 1 (Objectives and measures for the mitigation of emissions), the Article 37, Item 2 says: ‘It will be considered as carbon emissions offset projects, all those dealing with afforestation, reforestation, restoration, and conservation of the extant forests and wooded lands, littoral ecosystems, those dealing with the conservation or restoration of wetlands, seagrass meadows and analogous areas’. This parliamentary initiative opens the door for seagrass meadows to be object for conservation and restoration projects in that autonomous community.

3.2.3. *News from the European Parliament*

The 27th November this year, the European Parliament Intergroup on ‘Climate Change, Biodiversity, and Sustainable Development, organized the session ‘Blue Carbon in EU Policy’. During this session, the results of LIFE Blue Natura were shown demonstrating that the conservation and restoration of EU Blue Carbon ecosystems could be economically sustainable, given the large stocks they accumulate (7.7 $GtCO_2$/EU BC; Blue Carbon in EU Climate Policy, 27 November 2018). The Members of the Parliament hosting the event acknowledged that, “The role of Blue Carbon is a key in reducing emissions and supporting

climate action, as we are now discussing about implementing the Paris Agreement and the Paris rulebook. According to the MEP, legislation is a driving force and we have the responsibility to move from reflection to action, including Blue carbon in the EU climate agenda. Destroying ecosystems contributes to the release of CO_2 they absorbed for years or centuries. Although the role of blue carbon ecosystems is well recognized by scientists, a gap analysis is needed to identify research and financial needs, as well as to identify priorities and the way to transfer knowledge across sectors. With reference to the latter, the Life Blue Natura project serves as an example to examine the missing knowledge, moreover as a pilot to transfer the experience to the wider region. There is a need to improving the dialogue within the EU, to jointly find solutions and share good practices. At the European level, the Mediterranean region offers plenty of best practices". Maria Spyrakis (MEP).
The conclusions made direct references to the project LIFE Blue Natura, as an example to follow at the EU level, on how to clear the path for implementation of BC initiatives.

4. Conclusions, recommendations and future work

Target for any conservation or restoration carbon offset project in Andalusia.

The size of the carbon sink in the top meter of Andalusian saltmarshes is of 21.3 $\pm$ 6.5 Mt CO_2 in the top meter sediment layer, and the annual average flux to the sediment is 53 $\pm$ 12 Kt CO_2 yr^{-1}.

A sound methodology to determining the CO_2 emissions resulting from the degradation or destruction of saltmarsh habitat is still lacking.

Carbon offset projects based on saltmarshes should focus on recovery of degraded saltmarshes and reducing erosion of the low marsh, through 1) better management of the coastal sedimentary dynamics, 2) re-wetting and replanting dessicated areas that have lost vegetation and 3) improving watershed quality to reduce eutrophication, which, by introducing nutrients and labile organic matter to the system, may enhance GHG emissions from the saltmarsh and/or estuary channels. Healthy mid marsh areas have shown to exhibit the largest stocks and fluxes of all the marshes surveyed in this project.

The main obstacles to bring the carbon locked by saltmarshes to the carbon markets are: 1. lack of quality scientific information (mapping, stocks and fluxes quantification, quantification of the impact of habitat loss in the stock), 2. lack of a sound certification standard and verification method for carbon offset projects, and 3. from the two first, lack of clear policies for the implementation of the Blue Carbon in the national inventories.

Future efforts in action C2 will be in the direction of:

- Obtaining estimates of changes in the carbon stock and flux with new land use change categories, which are relevant for the areas studied: artisanal salinas, abandoned salinas with tidal influence and abandoned salinas with low tidal influence.
- Improving the coverage of the horizontal variability in carbon stocks and fluxes in the studied saltmarshes
- Integration these new stocks and fluxes estimates with the spatial information of the cartographies generated in action A1 in collaboration with the partner AMAyA
- Integrate litterature-based estimates of CH_4 and N_2O fluxes in both saltmarshes studied, into their global estimates of GHG stocks and fluxes.
- Develop models of changes in GHG stocks and fluxes with some land-use changes, as well as with erosion.

In general, future BC research should be directed to remove the barriers cited above: 1. ensuring a good knowledge of the extension of the saltmarsh habitat and its different characteristics, 2. quantifying the stocks and fluxes of the different types identified. Using aerial imagery where practicable, and ground truthing surveys would be the necessary fields methods to combine, 3. performing *in situ* or mesocosms experiments to determine the impact of different types of degradation of the habitat in the loss of stock, 4. put all the knowledge and methods above to establish effective monitoring programmes and verification methods, 5. with sound knowledge and methods, implementing BC in the national policies will be smoother, 6. advertise the BC resource as an attractive marketable asset among carbon trading companies and emitters, with emphasis in those looking for an added value (voluntary markets).

5. Literature cited

For the sake of simplicity, the literature cited in this report only considers the main works that are key to the various aspects dealt with. The list below is therefore far from being exhaustive.

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Annex A1.7_Deliverable_Cadiz Bay Cartography. About to be published in the project webpage

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Finally, thanks to Rosa Mendoza Castellon, Life Blue Natura project Director, for steering this complex project with her wise ‘savoir faire’. We know, not an easy task.

Annex I: Saltmarsh organic carbon stocks

Table AI.1. Results for organic carbon stocks (Blue Carbon) from the various cores sampled in Los Toruños, and Marismas del Odiel in September/October 2016 (Actions A3, C2). For site codes, see legend of Table 3.1. 'Observed', stands for the entire core sampled.

Annex I (Carbon stocks)

C stocks		ODM.L		ODM.L-C		ODE.H		ODE.M		ODB.Z		ODN.D	
		Average	SD	Average	Standar Deviation	Average	SD	Average	SD	Average	SD	Average	SD
1 m	kg/m^2	5.93	3.53	12.28	2.81	7.22	3.87	11.56	4.94	16.61	6.55	12.80	6.21
	t/ha	59.30	35.28	122.83	28.07	72.21	38.69	115.63	49.42	166.07	65.49	127.99	62.08
Observed	kg/m^2	19.97	10.77	23.03	5.26	7.77	4.16	13.26	5.86	20.30	7.04	10.20	5.59
	t/ha	199.72	107.68	230.29	52.62	77.73	41.64	132.58	58.60	202.96	70.44	101.95	55.86
	Length (cm)	2.59		121.90		119.40		118.20		123.40		124.00	

C stocks		ODN.D-C		ODL.R		TOR.L		TOR.L-C		TOR.H		TOR.M	
		Average	SD	Average	SD	Average	SD	Average	SD	Average	SD	Average	SD
1 m	kg/m^2	5.91	2.93	1.53	0.93	6.33	3.05	8.11	3.67	8.11	4.39	15.62	5.25
	t/ha	59.08	29.28	15.29	9.27	63.29	30.54	81.06	36.69	81.08	43.90	156.18	52.48
Observed	kg/m^2	7.57	3.75	1.53	0.93	8.49	4.18	10.19	4.42	11.10	6.01	27.75	8.77
	t/ha	75.69	37.51	15.29	9.27	84.89	41.79	101.92	44.21	111.02	60.11	277.49	87.70
	Length (cm)	120.00		93.90		186.30		126.40		131.00		165.80	

Annex II: Saltmarsh organic carbon fluxes

Table AII.1. Organic carbon fluxes (Blue Carbon) from the various cores sampled in Los Toruños, and Marismas del Odiel in September/October 2016 (Actions A3, C2). For site codes, see legend of Table 3.1.

Annex II (Carbon fluxes) 1 A 210Pb decay curve could not be calculated, acreation rates were calculated from 14C datings only

C Fluxes		ODM.L		ODM.L-C		ODE.H		ODE.M		ODB.Z		ODN.D	
		Average	SE	Average	SE	Average	SE	Average	SE	Average	SE	Average	SE
Whole core	Length (cm)	162		122		120		123		124		124	
	Age (cal. y BP)	1180		762		535		429		1265		3029	
	Kg TOC/m^2/y	0.011	0.003	0.024	0.002	0.010	0.001	0.031	0.002	0.019	0.002	0.006	0.002
	t TOC/ha/y	0.112	0.027	0.239	0.016	0.105	0.010	0.307	0.019	0.188	0.015	0.062	0.022
Last 100 years	Length (cm)	27		30		29		50		12		18	
	Kg TOC/m^2/y	0.010	0.004	0.030	0.003	0.017	0.003	0.036	0.005	0.028	0.002	0.024	0.014
	t TOC/ha/y	0.104	0.036	0.300	0.032	0.171	0.030	0.361	0.046	0.284	0.024	0.241	0.145

C Fluxes		ODN.D-C		ODL.R 1		TOR.L		TOR.L-C 1		TOR.H 1		TOR.M	
		Average	SE	Average	SE	Average	SE	Average	SE	Average	SE	Average	SE
Whole core	Length (cm)	120		77		106		126		104		168	
	Age (cal. y BP)	1600		770		909		1846		1037		1134	
	Kg TOC/m^2/y	0.009	0.002			0.010	0.001	0.006	0.000	0.009	0.002	0.029	0.004
	t TOC/ha/y	0.087	0.024			0.095	0.013	0.060	0.005	0.088	0.022	0.295	0.037
Last 100 years	Length (cm)	25				26		11		17		35	
	Kg TOC/m^2/y	0.022	0.010	0.223	0.060	0.014	0.004	0.004	0.003	0.004		0.057	0.011
	t TOC/ha/y	0.219	0.097	2.226	0.599	0.139	0.044	0.041	0.026	0.04		0.566	0.106

Annex III: Density, SAR, TOM, TOC, TOC fluxes, TIC and Granulometry distribution per station

This annex compiles all age and depth profiles for all saltmarsh stations, showing bulk density (gDW/cm^3), sediment accretion rate (SAR, mm/yr), total organic matter (TOM, %), total organic carbon (TOC, t/ha), total organic carbon flux (TOC flux, t/ha yr), total inorganic carbon (TIC, t/ha), total inorganic carbon flux (TIC flux, t/ha yr) and granulometric distribution, from the longest core of each station. Age and depth distribution of bulk density (gDW/cm^3), sediment accretion rate (SAR, mm/yr), total organic matter (TOM, %), total organic carbon (TOC, t/ha), total organic carbon flux (TOCflux, t/ha yr), total inorganic carbon (TIC, t/ha) and granulometric distribution, from the longest core of each station.

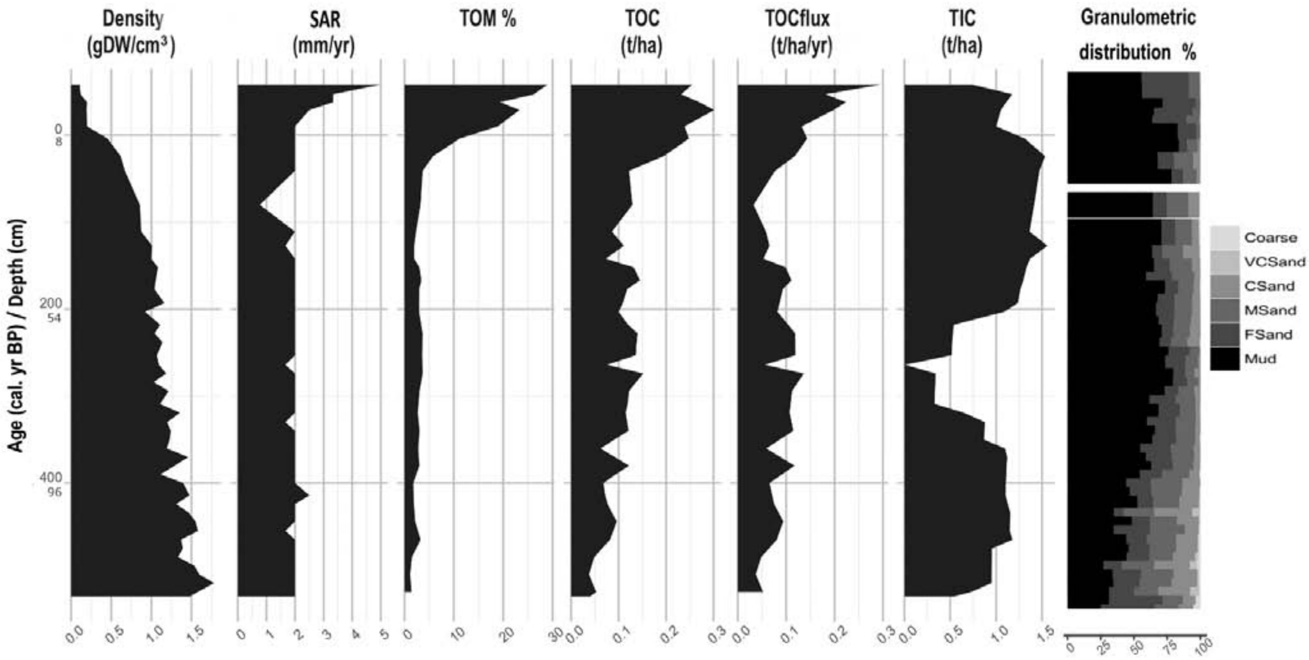

Figure AIII.1.: age and depth distribution on ODE.H_A core (high saltmarsh) of soil density, sediment accretion rate, total organic matter, total organic carbon, total organic carbon flux, total inorganic carbon, and grain size distribution (coarse, >2mm; very coarse sands, 1-2 mm; coarse sands, 1-0.5 mm; medium sands, 0.5-0.25; fine sands, 0.25-0.063; and mud, <0.063mm). For site codes, see legend of Table 3.1.

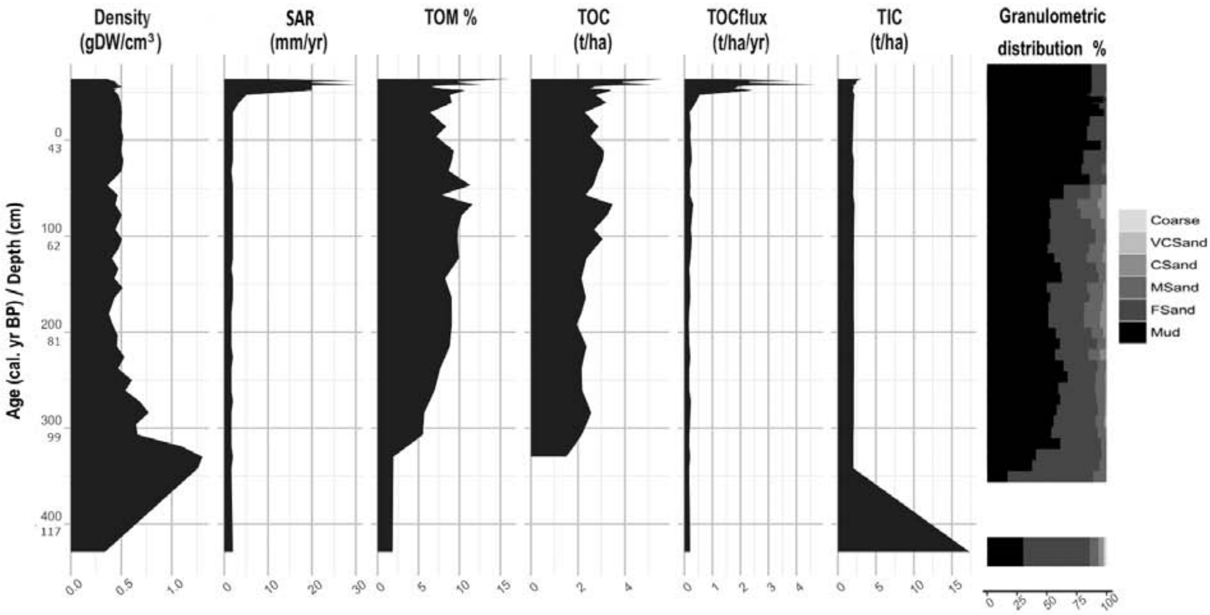

Figure AIII.2.: age and depth distribution on ODE.M_A core (medium saltmarsh) of soil density, sediment accretion rate, total organic matter, total organic carbon, total organic carbon flux, total inorganic carbon, and grain size distribution (coarse, >2mm; very coarse sands, 1-2 mm; coarse sands, 1-0.5 mm; medium sands, 0.5-0.25; fine sands, 0.25-0.063; and mud, <0.063mm). For site codes, see legend of Table 3.1.

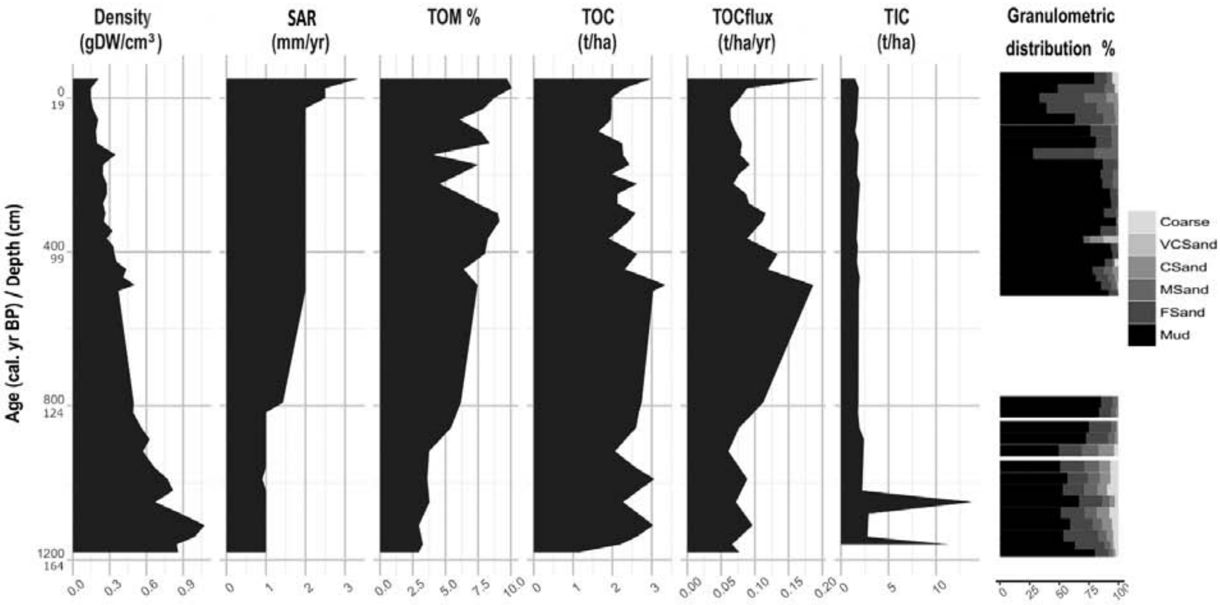

Figure AIII.3.: age and depth distribution on ODE.L_A core (low saltmarsh) of soil density, sediment accretion rate, total organic matter, total organic carbon, total organic carbon flux, total inorganic carbon, and grain size distribution (coarse, >2mm; very coarse sands, 1-2 mm; coarse sands, 1-0.5 mm; medium sands, 0.5-0.25; fine sands, 0.25-0.063; and mud, <0.063mm). For site codes, see legend of Table 3.1.

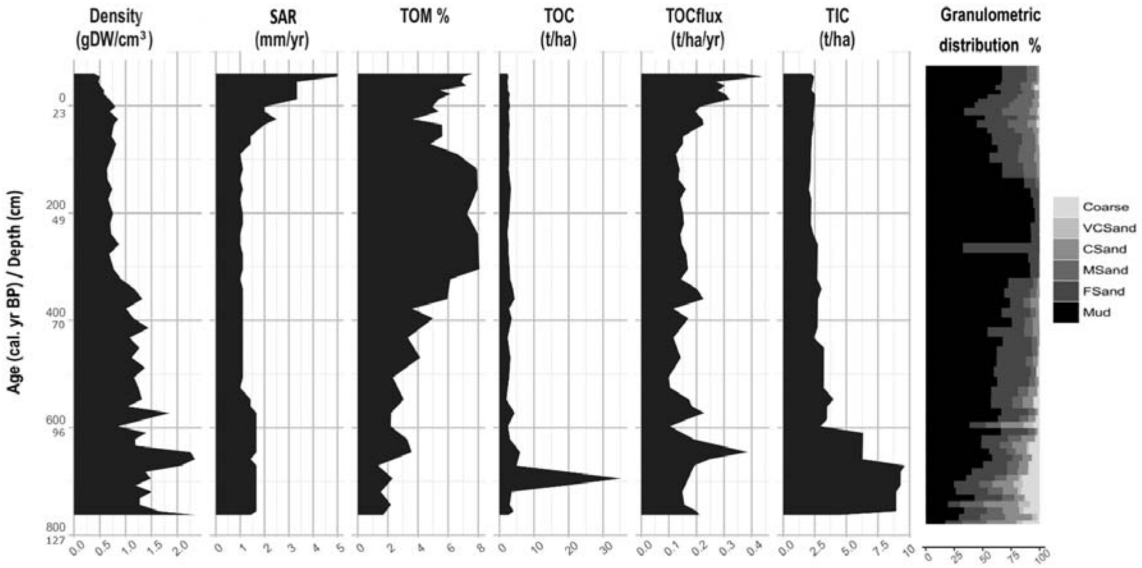

Figure AIII.4.: age and depth distribution on ODE.L-C_A core (low not vegetated saltmarsh) of soil density, sediment accretion rate, total organic matter, total organic carbon, total organic carbon flux, total inorganic carbon, and grain size distribution (coarse, >2mm; very coarse sands, 1-2 mm; coarse sands, 1-0.5 mm; medium sands, 0.5-0.25; fine sands, 0.25-0.063; and mud, <0.063mm). For site codes, see legend of Table 3.1.

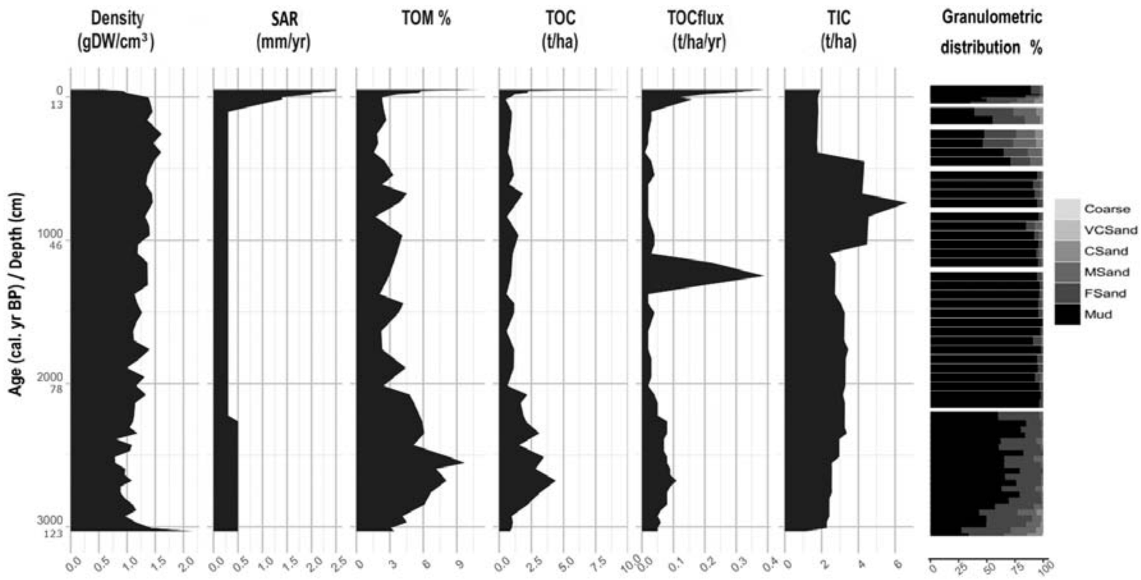

Figure AIII.5: age and depth distribution on ODN.D core (continentalized high saltmarsh unfrequently flooded with spring high tides, hence with low tidal influence; probably not as degraded as initially supposed) of soil density, sediment accretion rate, total organic matter, total organic carbon, total organic carbon flux, total inorganic carbon, and grain size distribution (coarse, >2mm; very coarse sands, 1-2 mm; coarse sands, 1-0.5 mm; medium sands, 0.5-0.25; fine sands, 0.25-0.063; and mud, <0.063mm). For site codes, see legend of Table 3.1. For site codes, see legend of Table 3.1.

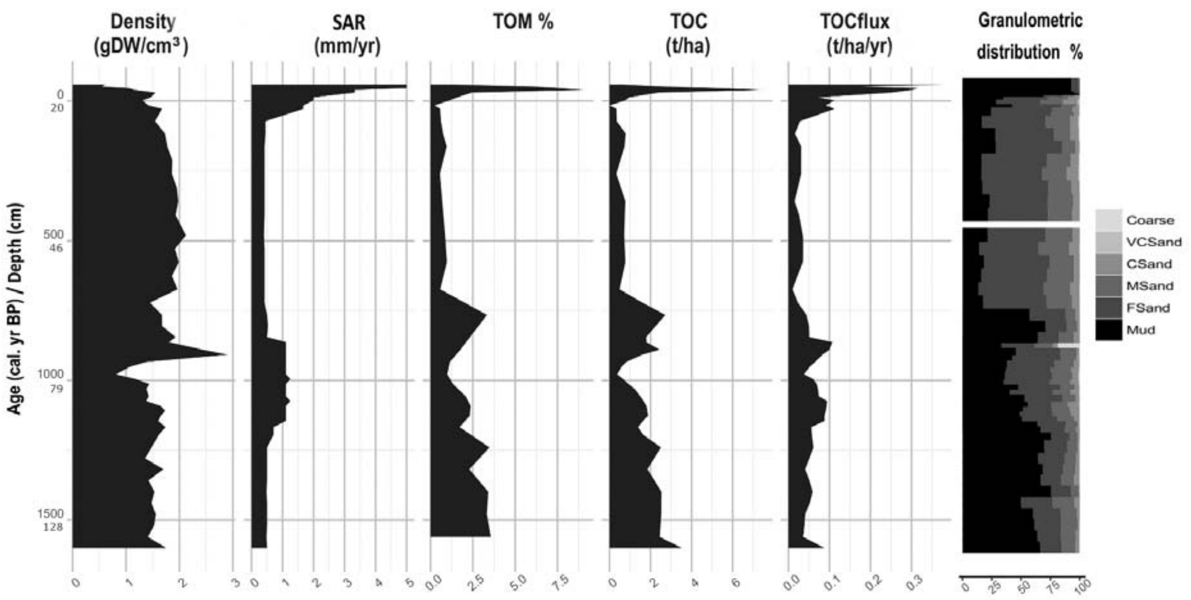

Figure AIII.5: age and depth distribution on ODN.D-C core (mid saltmarsh degraded by high salinity) of soil density, sediment accretion rate, total organic matter, total organic carbon, total organic carbon flux, total inorganic carbon, and grain size distribution (coarse, >2mm; very coarse sands, 1-2 mm; coarse sands, 1-0.5 mm; medium sands, 0.5-0.25; fine sands, 0.25-0.063; and mud, <0.063mm). For site codes, see legend of Table 3.1.

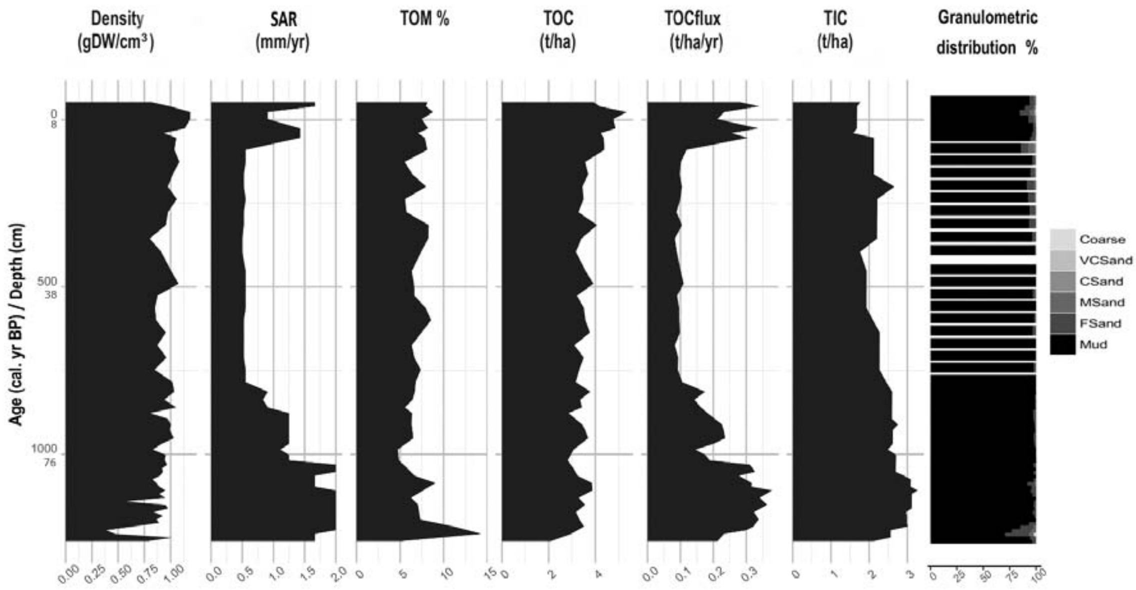

Figure IIIA.6: age and depth distribution on ODB.Z_A core (mid saltmarsh re-connected to the tidal cycle) of soil density, sediment accretion rate, total organic matter, total organic carbon, total organic carbon flux, total inorganic carbon, and grain size distribution (coarse, >2mm; very coarse sands, 1-2 mm; coarse sands, 1-0.5 mm; medium sands, 0.5-0.25; fine sands, 0.25-0.063; and mud, <0.063mm). For site codes, see legend of Table 3.1.

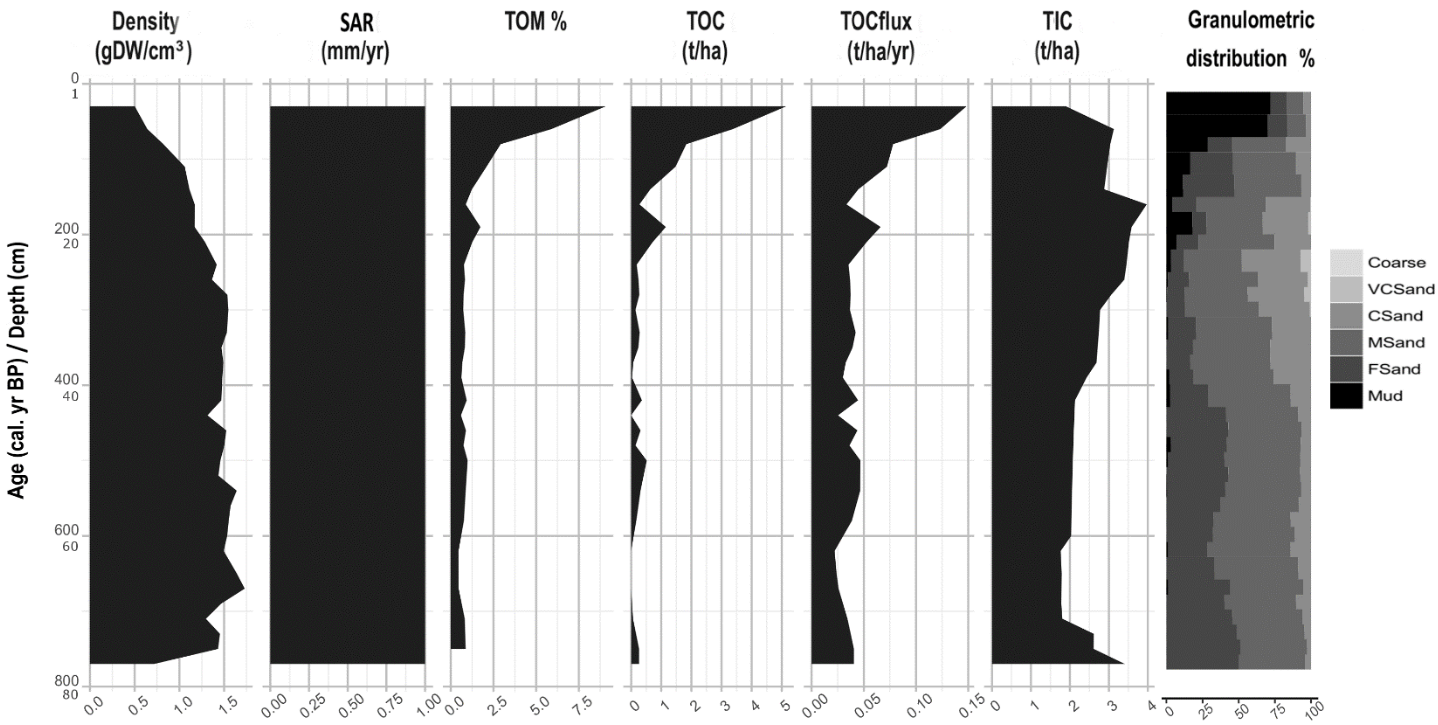

Figure AIII.7.: age and depth distribution on ODL.R_A core (medium saltmarsh re-planted – CEPSA 'sealine' dismantling restoration works) of soil density, sediment accretion rate, total organic matter, total organic carbon, total organic carbon flux, total inorganic carbon, and grain size distribution (coarse, >2mm; very coarse sands, 1-2 mm; coarse sands, 1-0.5 mm; medium sands, 0.5-0.25; fine sands, 0.25-0.063; and mud, <0.063mm). For site codes, see legend of Table 3.1.

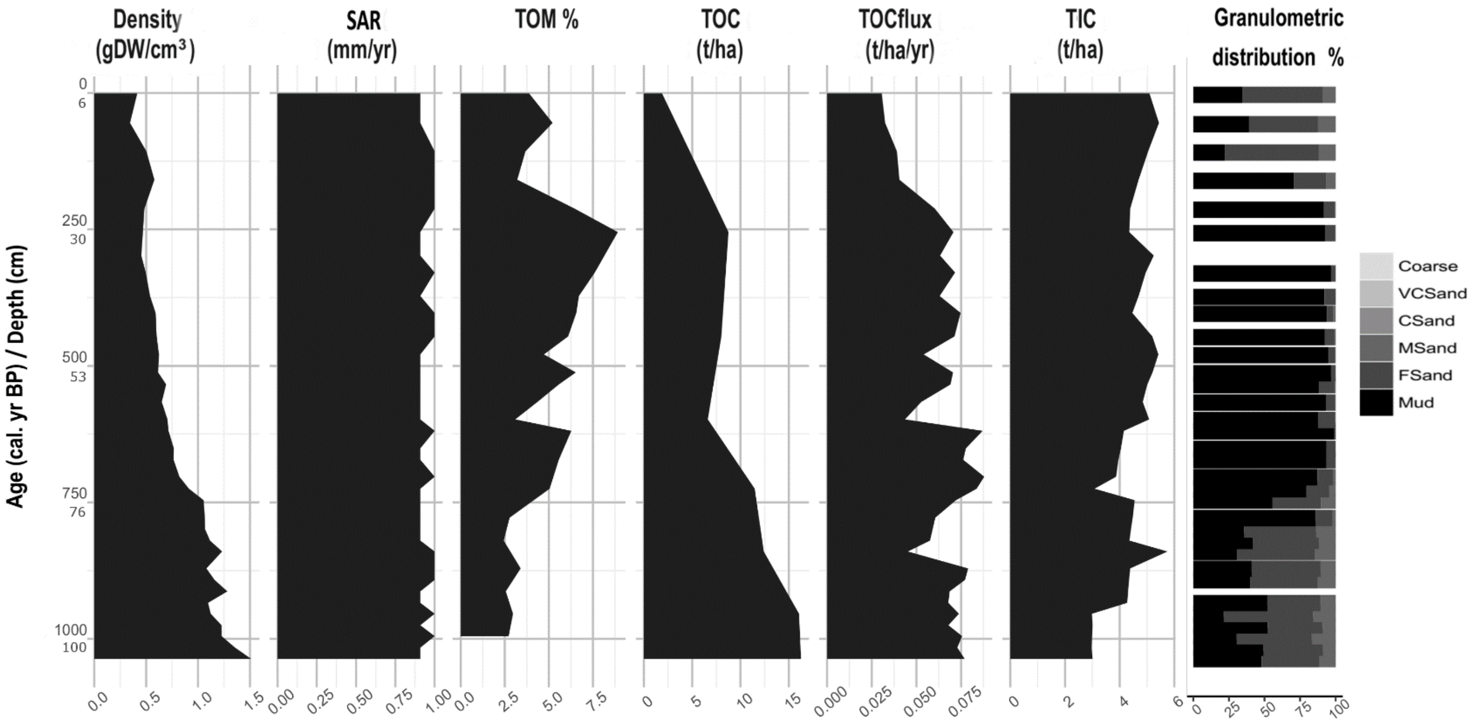

Figure AIII.8.: age and depth distribution on TOR.H_A core (high saltmarsh) of soil density, sediment accretion rate, total organic matter, total organic carbon, total organic carbon flux, total inorganic carbon, and grain size distribution (coarse, >2mm; very coarse sands, 1-2 mm; coarse sands, 1-0.5 mm; medium sands, 0.5-0.25; fine sands, 0.25-0.063; and mud, <0.063mm). For site codes, see legend of Table 3.1.

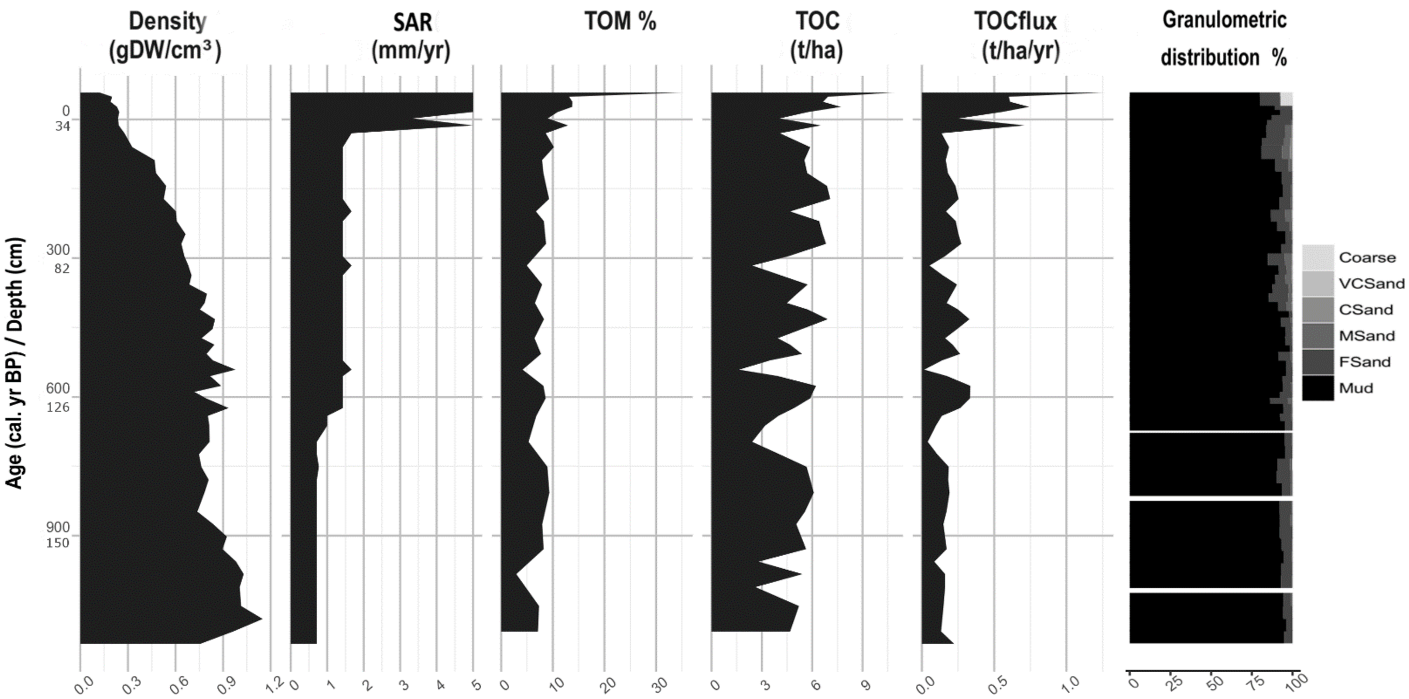

Figure AIII.9.: age and depth distribution on TOR.M_A core (medium saltmarsh) of soil density, sediment accretion rate, total organic matter, total organic carbon, total organic carbon flux, total inorganic carbon, and grain size distribution (coarse, >2mm; very coarse sands, 1-2 mm; coarse sands, 1-0.5 mm; medium sands, 0.5-0.25; fine sands, 0.25-0.063; and mud, <0.063mm). For site codes, see legend of Table 3.1.

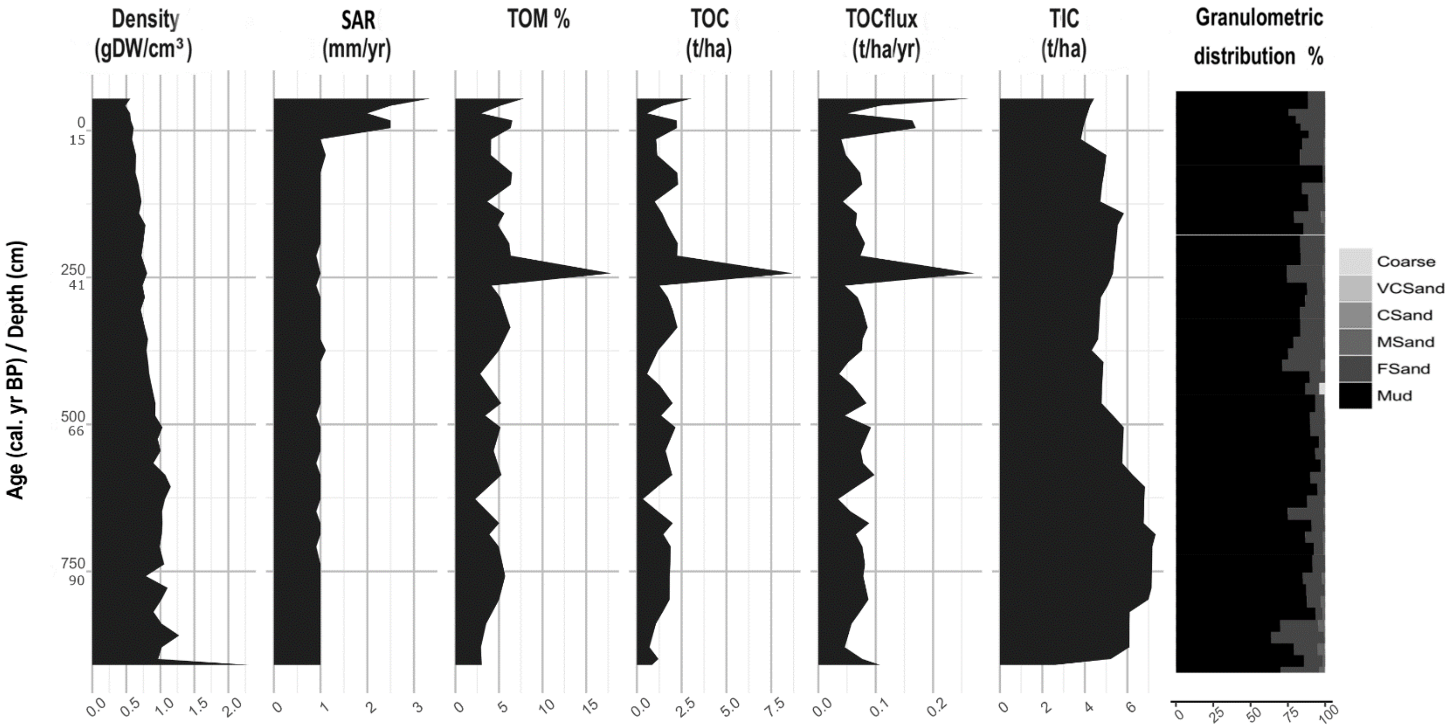

Figure 10: age and depth distribution on TOR.L_B core (low saltmarsh) of soil density, sediment accretion rate, total organic matter, total organic carbon, total organic carbon flux, total inorganic carbon, and grain size distribution (coarse, >2mm; very coarse sands, 1-2 mm; coarse sands, 1-0.5 mm; medium sands, 0.5-0.25; fine sands, 0.25-0.063; and mud, <0.063mm).

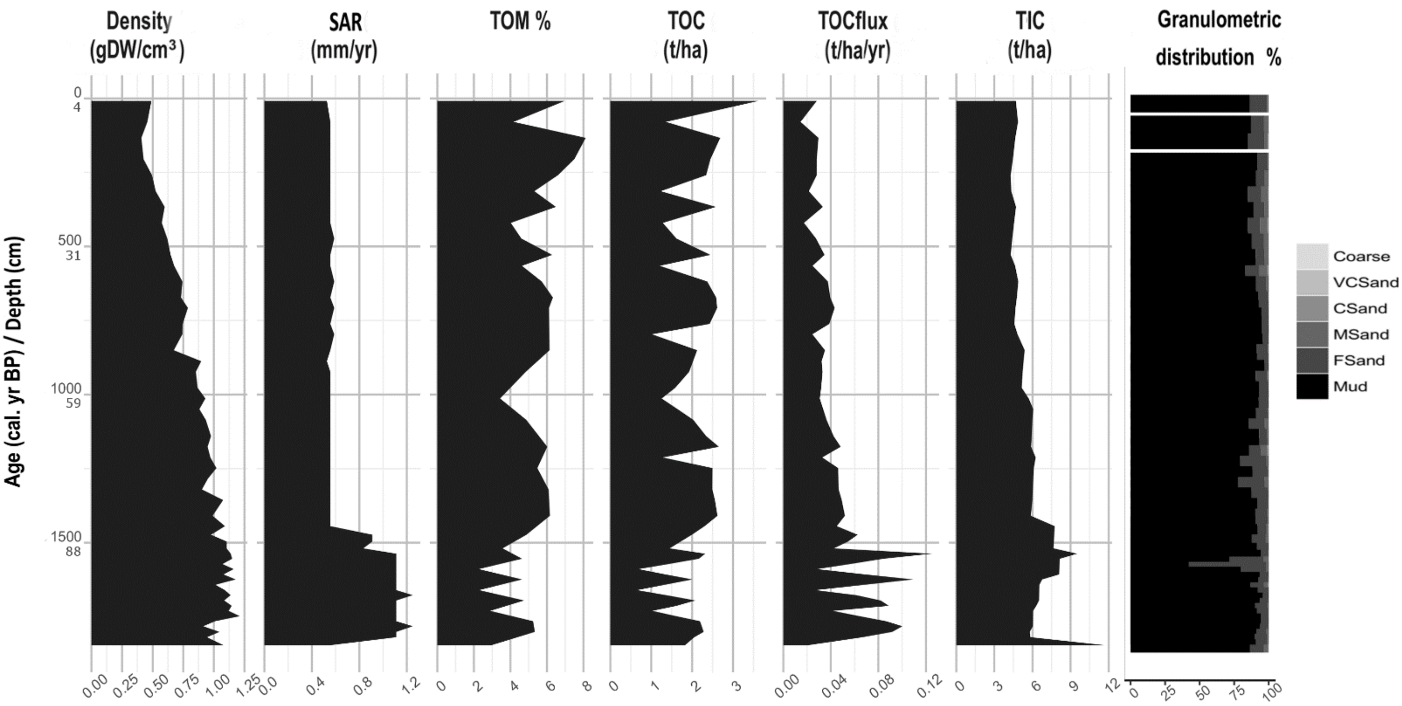

Figure 11: age and depth distribution on TOR.L-C_A core (low not vegetated saltmarsh) of soil density, sediment accretion rate, total organic matter, total organic carbon, total organic carbon flux, total inorganic carbon, and grain size distribution (coarse, >2mm; very coarse sands, 1-2 mm; coarse sands, 1-0.5 mm; medium sands, 0.5-0.25; fine sands, 0.25-0.063; and mud, <0.063mm).

Annex II: Issues affecting the reliability of the estimates

Although the estimates of Blue Carbon stocks and fluxes performed in this study are probably the most detailed ones in the EU and probably beyond, there is a number of important limitations and uncertainties that affect them. They are related to the sample size, to field sampling and laboratory techniques, and even to conceptual aspects. Although some of them have been already introduced above, some of the most critical are listed and commented in this annex.

a. Sampling effort

The huge extension and complexity of seagrass ecosystems implies simplifications to adjust the sampling effort to the material and human resources available. Sample size limitations have to be overcome through (1) a detailed analysis and interpretation of the local conditions and temporal variation across key cores and stations and (2) the knowledge of experts with a large history of personal direct observations in the study sites. Not all environmental conditions or meadow categories were present at every region, site or station. Also, small seagrasses, could not be sampled on all its geographical range. So very often, any attempt to perform a complete factorial analysis is simply not feasible.

b. Dating techniques limitations

Dating the soil samples is key to estimate the long-term carbon sequestration rates of the meadows. The two techniques used in this study were radiocarbon ^{14}C and lead ^{210}Pb.
Radiocarbon dating is used for material that is expected to be older than 200 yr. As the date we need to estimate is that when the soil layer was deposited, we have to assume that organic matter from the layer we are using for the dating, must have been produced at that time. Particularly in the lowest sections of the cores, it is not rare that macro-debris of seagrass cannot be found. In these cases, an alternative is to send an aliquot of bulk sediment to the laboratory for a dating of the total organic carbon contained in the sample.
It is known that the choice of the material to be dated has repercussions on the radiocarbon ages (Belshe et al., 2017).
To check for this, we dated a layer of the core BA.S_A using both plant debris and bulk sediment. The dates obtained differed nothing less than ~2500 yr! So dating bulk samples in this study was discarded and the dating of those deep layers of the sediment not showing enough macro-debris of plant material was abandoned.
The ^{210}Pb dating technique is used for the top most layers of the soil, i.e., for the recent history of the meadow (0-200 yr), and depend on a good chronological sequence that allows to get a consistent ^{210}Pb radioactive decay curve. This technique is finer than the ^{14}C and fails when the top cm of the core under study has suffered a stratigraphic alteration. This alteration can mainly happen as a consequence of i) inadequate sampling techniques, ii) alterations during core transport (in SCUBA, once on board, once on the road, etc.), iii) in situ resuspension of the sediments due to currents or wave action, or iv) to bioturbation. In this study, the ^{210}Pb curves for some of the cores showed incoherencies in the top layers, not allowing for a proper elaboration of the chronological model (see annex II.). For these cores, the chronological model was elaborated based on radiocarbon ages.

c. Core decompression correction

As explained in Materials and Methods, and in the deliverable of action A2, two different coring methods were used: vibrocoring, which does not lead to core compression (but may alter the 50 top cm of core), and manual coring, which does. Although the compression does not affect the estimation of global core carbon stock or flux, knowing the actual amount of material up to the first meter depth or accreted in the last 100 years is essential to standardize carbon stock and fluxes spatially and temporally. The ^{210}Pb was not applied in the vibrocores, but only in the manual cores.
Some mathematical methods have been pondered to better estimate the real depth of the material. The Coastal Blue Carbon Manual (Howard et al., 2014) recommends calculating a "compaction correction factor" that distributes the compression equally through the entire core. Although this is a very straightforward solution, there are at least two ways in which the material would not be equally compressed. First, changes in the material with depth may lead to differential, idiosyncratic resistance to compression. Second, the topmost layers are subjected to the compacting force for a longer time during the coring operation than the deeper ones, so the compaction would often decrease from the surface to the deeper layers.
To detect the first case, it would be necessary to measure core-shortening several times during coring into the sediment, which significantly increases sampling effort when extracting lot of cores, especially scuba diving at deep stations, making it not feasible. So in this study, as in any other BC quantification study, compression was measured based on the final compression parameters (i.e., once the corer has arrived to its maximum depth). As for the second factor, Morton and White (1997) showed that logarithmic core shortening is the most

common on wetland sediments. Thus, instead of the linear decompression recommended by Howard et al. (2014), we decided to follow Morton and White (1997) and fit a logarithmic curve to decompress our cores by default. However, we found problems decompressing in this way the highly compressed cores. The issue is that the logarithmic model assumes, unrealistically, that the material can be infinitely compressed, but any material can reach a maximum beyond which it does not compress further. So our method tends to overestimate compression in the shallowest core layers. This is why, after some tests, we decided to use a logarithmic correction with y_2 = 0.1 below 30 % of compression, from 30-40 % we also fitted a logarithmic correction, but with y_2 = 1 (which moderates the logarithmic curve slope growth towards the core top, reducing decompression in those sections); while for compressions above 40 %, we decided to apply linear decompression.
Compression is a limiting factor on the methodology. Carbon stocks in the top meter without compression correction can be overestimated up to 60% according to our data.

d. Estimates variability

From the three cores taken on each station the longest one was used as standard and the two shortest ones were subsampled in the field. Some of the replicates did not reach 1 m. To calculate the mean and the standard deviation among cores in the station, they must reach the same depth. The first approximation would be to extrapolate the stock at 1 m. Since the carbon on seagrass soils often follow a logarithmic decline function with depth, the sediment carbon content in the deeper centimeters can be estimated fitting this function, assuming the input of carbon and degradation to be stable; but in several cores, no logarithmic decline of carbon content with depth was detected.
If the replicates length was superior to 80 cm, the remaining 20 cm until the meter was assumed to have the same carbon density as the last section sampled. If not, the deviation between the replicates was calculated using the carbon above the maximum depth of the shortest core.
Differences in core length are an unavoidable issue, so the approximation above is the only one possible and certainly the resulting standard deviations reliable. We include this section for practical purposes and to highlight once again the complexity of works involved in inventorying carbon stocks and fluxes.

e. Carbonate precipitation as possible CO_2 source

Calcification process release 0.63 net molecules of CO_2 for each mol deposited at the average sea pH (Smith 2013). The higher carbonate production was found on Santibáñez bay, where there is shellfish exploitation. Although presence of seagrass favor shellfish communities, these higher carbonates production was more related to the closure of the bay than with any characteristic depending on the seagrass. The average CO_2 content from carbonates in the sediments of *P. oceanica* healthy meadows analysed in this study was of 1,371 ± 334 tCO_2/ha, in the top m of sediment, accumulated at a rate of 1.24 tCO_2/ha yr. Following the rule above, this would imply a 'sink offset' of about 822 tCO_2/ha at 0.74 tCO_2/ha yr or 2.5 $MtCO_2$ at 2,269 tCO_2/yr for the entire Andalusia. Because not all the carbonates stored in seagrass soils have actually been precipitated in situ (i.e., an unknown fraction has been imported from adjacent waters or from the land), that potential offset cannot be yet applied until new methods allow to distinguish with certainty the locally precipitated carbonates (Macready et al., 2017).

f. CH_4 and N_2O emmissions

CH4 emissions may be significant in saltmarshes with salinities below 18 ppt (Poffenbarger et al, 2011). Therefore. Some parts of the continentalized high marsh of Odiel may have salinity levels below this threshold. In the next report, we will estimate, using data from the litterature for similar areas, the possible emissions of this part of the Odiel saltmarsh, and will include these figures in the global estimate of carbon sink capacity of this natural park. High inputs of labile organic matter may also enhance emissions of this GHG.

Eutrophication may increase saltmarsh emissions of N_2O (Burgos et al, 2017).

g. Scaling-up for global estimates

Most of the obstacles to achieve a satisfactory global estimate for the Andalusian carbon stocks and fluxes associated to saltmarshes have been discussed in several instances over this report.

Annex V: The Tier Concept

“The IPCC has classified the methodological approaches in three different Tiers, according to the quantity of information required, and the degree of analytical complexity (IPCC, 2003, 2006).

Tier 1 - Employs the gain-loss method described in the IPCC Guidelines and the default emission factors and other parameters provided by the IPCC. There may be simplifying assumptions about some carbon pools. Tier 1 methodologies may be combined with spatially explicit activity data derived from remote sensing. The stock change method is not applicable at Tier 1 because of data requirements (GPG2003).

Tier 2 - Generally uses the same methodological approach as Tier 1 but applies emission factors and other parameters which are specific to the country. Country-specific emission factors and parameters are those more appropriate to the forests, climatic regions and land use systems in that country. More highly stratified activity data may be needed in Tier 2 to correspond with country-specific emission factors and parameters for specific regions and specialised land-use categories. Tiers 2 and 3 can also apply stock change methodologies that use plot data provided by NFIs.

Tier 3 – At Tier 3, higher-order methods include models and can utilize plot data provided by NFIs tailored to address national circumstances. Properly implemented, these methods can provide estimates of greater certainty than lower tiers, and can have a closer link between biomass and soil carbon dynamics. Such systems may be GIS-based combinations of forest age, class/production systems with connections to soil modules, integrating several types of monitoring and data. Areas where a land-use change occurs are tracked over time. These systems may include a climate dependency, and provide estimates with inter-annual variability.

Progressing from Tier 1 to Tier 3 generally represents a reduction in the uncertainty of GHG estimates, though at a cost of an increase in the complexity of measurement processes and analyses. Lower Tier methods may be combined with higher Tiers for pools which are less significant. There is no need to progress through each Tier to reach Tier 3. In many circumstances it may be simpler and more cost-effective to transition from Tier 1 to 3 directly than produce a Tier 2 system that then needs to be replaced. Data collected for developing a Tier 3 system may be used to develop interim Tier 2 estimates.”

Source: REDDcompass.org

https://www.reddcompass.org/mgd-content-v1/dita-webhelp/en/Box1.html