Supplementary Material

Carbon accumulation and storage in a temperate coastal lagoon under the influence of recent climate change (Northwestern Adriatic Sea)

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S1 Supporting Tables

Table S1. Comparison of geochronology between the results from $^{210}Pb_{ex}$ and THg concentrations profiles.

	Habitat	Hg deposition	
		1958	**1978**
Geochronology from $^{210}Pb_{ex}$	Saltmarsh	1957.0 ± 3.5	1976.0 ± 1.9
	Impact	1956.5 ± 3.0	1984.1 ± 1.0

Table S2. Location of sampling stations and list of the presented parameters for the saltmarsh habitat and impact habitat surface sediments. The data set is freely available and is accessible at SEANOE. https://doi.org/10.17882/73534.

Sampling ID	Latitude (N)	Longitude (E)	OC (%)	$\delta^{13}OC$ (‰)	TN (%)	C/N	
1	44°52036	12°25747	2.62	-21.00	0.31	9.95	saltmarsh habitat
2	44°52403	12°26386	2.56	-19.07	0.27	11.09	
3	44°52097	12°26723	2.07	-21.87	0.29	8.35	
4	44°5136	12°26054	1.42	-19.99	0.24	6.92	
5	44°51195	12°26281	1.04	-18.21	0.15	7.97	
6	44°51254	12°25661	1.64	-20.24	0.24	8.04	
1	44°47651	12°24943	2.75	-22.30	0.419	7.66	impacted habitat
2	44°47702	12°24748	1.41	-26.81	0.150	10.99	
3	44°47689	12°24576	3.53	-22.60	0.466	8.83	
4	44°48157	12°24992	0.68	-24.00	0.091	8.80	
5	44°4816	12°25315	2.48	-20.91	0.414	6.98	
6	44°47824	12°25043	2.72	-23.41	0.359	8.85	

Table S3. Location of sampling stations and list of the presented parameters for the saltmarsh habitat and impact habitat sediment cores. The data set is freely available and is accessible at SEANOE. https://doi.org/10.17882/73534.

Sampling ID	Latitude (N)	Longitude (E)	layer (cm)	OC (%)	$\delta^{13}C$ (‰)	TN (%)	C/N
1	44°5136	12°26054	0-1	1.38	-19.19	0.219	7.33
			1-2	1.23	-19.30	0.217	6.62
			2-3	1.00	-19.48	0.133	8.84
			3-4	0.82	-19.67	0.104	9.14
			4-5	0.76	-19.78	0.109	8.12
			5-6	0.70	-19.89	0.095	8.63
			6-7	0.60	-19.91	0.074	9.47
			7-8	0.52	-21.69	0.056	10.99
			8-9	0.49	-20.56	0.062	9.15
			9-10	0.48	-21.15	0.060	9.26
			10-11	0.62	-22.19	0.057	12.73
			11-12	0.46	-21.57	0.076	7.02
			12-14	0.42	-20.37	0.057	8.51
			14-16	0.40	-20.95	0.062	7.41
			16-18	0.44	-21.95	0.057	9.10
			18-20	0.49	-21.09	0.059	9.80
			20-22	0.44	-20.58	0.062	8.33
			22-24	0.38	-21.07	0.048	9.14
2	44°51195	12°26281	0-1	1.17	-17.74	0.179	7.63
			1-2	1.16	-19.23	0.176	7.72
			2-3	1.15	-20.14	0.162	8.29
			3-4	1.05	-19.62	0.124	9.90
			4-5	1.13	-19.89	0.163	8.14
			5-6	1.31	-19.54	0.164	9.35
			6-7	1.21	-20.25	0.154	9.19
			7-8	1.11	-19.37	0.126	10.34
			8-9	1.12	-19.58	0.129	10.14
			9-10	0.84	-19.71	0.091	10.72
			10-11	0.56	-18.41	0.083	7.88
			11-12	0.28	-20.06	0.051	6.32

			12-13	0.24	-18.47	0.039	7.01
			13-14	0.22	-19.42	0.038	6.75
			14-15	0.23	-18.56	0.035	7.48
			15-16	0.45	-18.58	0.033	15.80
			16-17	0.29	-19.27	0.022	15.24
			17-18	0.32	-19.48	0.054	7.00
			18-19	0.44	-19.11	0.062	8.22
			19-20	0.59	-18.80	0.049	13.98
3	44°47651	12°24943	0-1	3.21	-23.07	0.418	8.95
			1-2	2.81	-22.12	0.454	7.22
			2-3	3.20	-22.63	0.445	8.38
			3-4	3.45	-22.47	0.484	8.32
			4-5	3.34	-22.09	0.476	8.17
			5-6	3.22	-22.85	0.493	7.63
			6-7	3.23	-24.20	0.454	8.31
			7-8	2.97	-24.29	0.405	8.55
			8-9	2.75	-25.06	0.338	9.48
			9-10	2.82	-25.90	0.343	9.60
			10-11	2.60	-24.63	0.338	8.99
			11-12	2.64	-25.63	0.331	9.32
			12-13	2.76	-25.28	0.363	8.86
			13-14	3.09	-26.26	0.341	10.56
			14-15	2.94	-26.10	0.351	9.79
			15-16	3.13	-25.09	0.346	10.53
			16-17	2.06	-23.83	0.362	6.64
			17-18	2.99	-25.44	0.378	9.22
			18-19	3.32	-25.94	0.381	10.15
			19-20	3.74	-25.80	0.443	9.84
4	44°47689	12°24576	0-1	2.95	-23.13	0.434	7.93
			1-2	2.65	-22.76	0.458	6.74
			2-3	2.99	-23.50	0.435	8.01
			3-4	2.91	-24.13	0.384	8.83
			4-5	3.00	-24.43	0.430	8.14
			5-6	3.12	-23.69	0.487	7.48
			6-7	2.99	-24.21	0.450	7.75
			7-8	2.83	-24.43	0.436	7.57

8-9	2.75	-26.34	0.351	9.13
9-10	2.53	-27.02	0.337	8.76
10-11	2.74	-27.21	0.334	9.58
11-12	2.80	-26.08	0.350	9.34
12-13	2.93	-25.81	0.378	9.05
13-14	3.11	-26.44	0.381	9.52
14-15	3.14	-24.42	0.436	8.39
15-16	3.35	-25.79	0.414	9.43
16-17	3.40	-25.58	0.431	9.21
17-18	3.47	-25.02	0.444	9.12
18-19	3.94	-24.73	0.405	11.33
19-20	2.71	-26.71	0.340	9.28

Table S4. Probability distributions of the proportional contributions of three sources to the sediment organic carbon in four cores from the saltmarsh habitat (core 1 and 2) and the impacted habitat (core 2 and 4) and in three time periods: means, standard deviation and percentiles estimated by the MixSIAR model.

Core	Period	Source	Mean	Standard deviation	Percentiles						
					2.5th	5th	25th	50th	75th	95th	97.5th
1	before 1957	marine phytoplankton	0.45	0.17	0.03	0.07	0.37	0.49	0.57	0.65	0.68
		riv./est. phytoplankton	0.19	0.04	0.12	0.13	0.17	0.19	0.21	0.26	0.27
		Juncus	0.36	0.16	0.15	0.17	0.25	0.32	0.44	0.72	0.77
	1957-1977	marine phytoplankton	0.51	0.19	0.02	0.06	0.43	0.56	0.64	0.72	0.75
		riv./est. phytoplankton	0.17	0.04	0.11	0.12	0.14	0.17	0.19	0.23	0.25
		Juncus	0.32	0.18	0.11	0.13	0.20	0.27	0.39	0.75	0.80
	after 1977	marine phytoplankton	0.71	0.20	0.05	0.22	0.67	0.77	0.83	0.89	0.90
		riv./est. phytoplankton	0.08	0.02	0.04	0.05	0.06	0.07	0.09	0.12	0.13
		Juncus	0.22	0.19	0.04	0.05	0.11	0.16	0.25	0.67	0.84
2	before 1957	marine phytoplankton	0.50	0.21	0.01	0.05	0.41	0.56	0.66	0.75	0.77
		riv./est. phytoplankton	0.06	0.03	0.01	0.02	0.03	0.05	0.07	0.12	0.13
		Juncus	0.44	0.20	0.19	0.21	0.30	0.38	0.53	0.88	0.93
	1957-1977	marine phytoplankton	0.56	0.22	0.01	0.03	0.48	0.63	0.72	0.81	0.83
		riv./est. phytoplankton	0.05	0.03	0.01	0.01	0.03	0.04	0.07	0.11	0.12
		Juncus	0.39	0.21	0.13	0.16	0.24	0.32	0.47	0.89	0.94
	after 1977	marine phytoplankton	0.73	0.22	0.02	0.15	0.69	0.80	0.87	0.93	0.94
		riv./est. phytoplankton	0.02	0.01	0.00	0.01	0.01	0.02	0.03	0.05	0.06
		Juncus	0.25	0.22	0.05	0.06	0.11	0.18	0.29	0.82	0.94
3	before 1957	marine phytoplankton	0.18	0.08	0.02	0.04	0.12	0.18	0.23	0.29	0.31
		riv./est. phytoplankton	0.55	0.05	0.47	0.48	0.52	0.55	0.59	0.64	0.65
		Juncus	0.27	0.08	0.15	0.16	0.22	0.26	0.32	0.41	0.44
	1957-1977	marine phytoplankton	0.21	0.09	0.02	0.04	0.16	0.22	0.28	0.35	0.37
		riv./est. phytoplankton	0.53	0.05	0.44	0.45	0.50	0.53	0.56	0.61	0.63
		Juncus	0.26	0.09	0.12	0.14	0.19	0.24	0.30	0.43	0.46
	after 1977	marine phytoplankton	0.43	0.13	0.07	0.17	0.38	0.46	0.52	0.59	0.61
		riv./est. phytoplankton	0.34	0.04	0.27	0.28	0.31	0.34	0.36	0.41	0.42
		Juncus	0.23	0.12	0.08	0.09	0.15	0.20	0.28	0.48	0.57
4	before 1957	marine phytoplankton	0.12	0.07	0.01	0.02	0.07	0.12	0.17	0.24	0.26
		riv./est. phytoplankton	0.61	0.05	0.51	0.53	0.57	0.61	0.64	0.69	0.71
		Juncus	0.27	0.07	0.14	0.16	0.21	0.26	0.32	0.39	0.41
	1957-1977	marine phytoplankton	0.15	0.08	0.01	0.02	0.09	0.15	0.21	0.28	0.30
		riv./est. phytoplankton	0.59	0.05	0.50	0.51	0.56	0.59	0.63	0.68	0.70
		Juncus	0.26	0.08	0.12	0.14	0.20	0.25	0.31	0.40	0.43
	after 1977	marine phytoplankton	0.33	0.13	0.03	0.07	0.26	0.35	0.42	0.50	0.52
		riv./est. phytoplankton	0.42	0.05	0.34	0.35	0.39	0.42	0.45	0.50	0.52
		Juncus	0.25	0.12	0.09	0.11	0.17	0.23	0.32	0.50	0.55

Table S5. Main results of redundancy analysis (RDA). Explanatory variables are climatic data: sea surface temperature (SST) and sea level. Response variables are organic carbon properties of dated sections of four sediment cores.

		Saltmarsh habitat		Impact habitat	
		Core 1	Core 2	Core 3	Core 4
Partitioning of variance	constrained	66%	40%	48%	38%
	unconstrained	34%	60%	52%	62%
	RDA1 (total)	64%	36%	42%	34%
	RDA2 (total)	2%	4%	7%	4%
	RDA1 (constrained)	97%	91%	86%	90%
	RDA2 (constrained)	3%	9%	14%	10%
RDA1 scores	SST	0.58	0.56	0.24	0.35
	sea level	0.88	0.74	0.79	0.76
	total nitrogen (TN)	1.12	1.28	1.11	1.07
	organic carbon (OC)	1.17	1.03	0.24	− 0.42
	$\delta^{13}C$	1.08	0.08	1.45	1.15
	C/N	− 0.65	− 1.03	− 1.31	− 1.35
	CAR	1.07	0.52	− 0.52	− 0.64
RDA2 scores	SST	0.29	0.30	− 0.48	− 0.40
	sea level	− 0.07	− 0.12	− 0.10	− 0.02
	total nitrogen (TN)	0.42	− 0.09	0.69	0.63
	organic carbon (OC)	0.51	− 0.20	1.04	1.05
	$\delta^{13}C$	− 0.30	0.95	− 0.38	0.04
	C/N	0.54	− 0.43	0.09	0.32
	CAR	− 0.37	− 0.40	0.67	− 0.23
P values	RDA model (overall)	0.002	0.077	0.005	0.008
	SST	0.442	0.120	0.092	0.129
	sea level	0.005	0.128	0.001	0.007

S2 Supporting Figures

Four Sea Surface Temperature (SST) gridded data sets have been retrieved with the aim to obtain a robust estimate of the long term temperature variation of the sea water entering and exiting the coastal lagoon under investigation to be used for the multivariate analysis:

- The HadISST (https://www.metoffice.gov.uk/hadobs/hadisst/) is a unique combination of monthly globally complete fields of SST and sea ice concentration on a 1 degree latitude-longitude grid from 1871 reconstructed using a two stage reduced-space optimal interpolation procedure (Rayner et al., 2003). SST data are taken from the Met Office Marine Data Bank (MDB), including in situ data received through the Global Telecommunications System (GTS) and monthly median SSTs for 1871–1995 from the International Comprehensive Ocean-Atmosphere Data Set (ICOADS).
- The ERSST (Extended Reconstructed Sea Surface Temperature) version 5 dataset (Huang et al. 2017, https://doi.org/10.7289/V5T72FNM) is a global monthly sea surface temperature dataset spanning the time period from 1854 to present, derived from the International Comprehensive Ocean-Atmosphere Dataset (ICOADS). It is produced on a 2 degree latitude-longitude grid with spatial completeness enhanced using statistical methods.
- The COBE-SST (https://ds.data.jma.go.jp/tcc/tcc/products/elnino/cobesst/cobe-sst.html) data are available from 1891 to the latest month on a 1 x 1 degree latitude-longitude grid. The monthly data are the average of daily fields obtained through an optimum interpolation method (Ishii et al., 2005).
- The CMEMS reference product (hereafter CMEMS SST) is the longest satellite SST data time series (1982–2018) at 4 km resolution available in the region and consists of daily (nighttime), high-resolution, reprocessed gap-free SST maps (REP L4) covering the Mediterranean Sea, based on Pathfinder v.5.2 (PFV52) Advanced Very High Resolution Radiometer (AVHRR) data (Pisano et al., 2016). The data are interpolated through an optimal interpolation algorithm on the original Pathfinder 0.0417x0.0417 degree latitude-longitude grid.

A preliminary consistency analysis of the three centennial monthly SST time series with CMEMS SST (shown in in Figure S1a) presents a pronounced positive temperature bias with respect to the reference CMEMS SST time series. The centennial monthly SST data have minimum values ranging from 10°C to 12°C and maximum values ranging from 24°C to 27°C, while CMEMS SST minimum values are between 4°C and 8°C and maximum values vary between 22°C and 26°C. The computed SST monthly climatologies (Figure S1c) present a synchronous seasonal cycle with minimum SST values in February and maximum values in August, confirming a consistent warm bias, more pronounced during winter than summer months with respect to CMEMS SST. The wider seasonal cycle of CMEMS SST can be explained by the high resolution of the observation-based satellite product that resolves the largest temperature variability which characterize the shallow coastal region under investigation. Centennial gridded SST products do not resolve such high temperature variability due to the few in situ observations in the coastal region used for the optimal interpolation. Moreover, according to Pisano et al. (2020) the Mediterranean SST positive trend computed from CMEMS SST is characterized by a zonal gradient with the highest values in the Eastern basin and a temporal variability at both decadal and seasonal time scales. The warming appears more intense during summer than in winter, which could also explain the amplified seasonal cycle of CMEMS SST in Figure S1c with respect to the others computed over longer time periods.

The monthly anomalies computed subtracting from each time series the relative climatological seasonal cycle (Figure S1b), normalize the monthly time series that consequently fluctuate consistently between ±3°C. This preliminary outcome suggests the consistency among the four SST data sets and the potential usability of SST anomalies to characterize the long term SST variations of the domain under investigation.

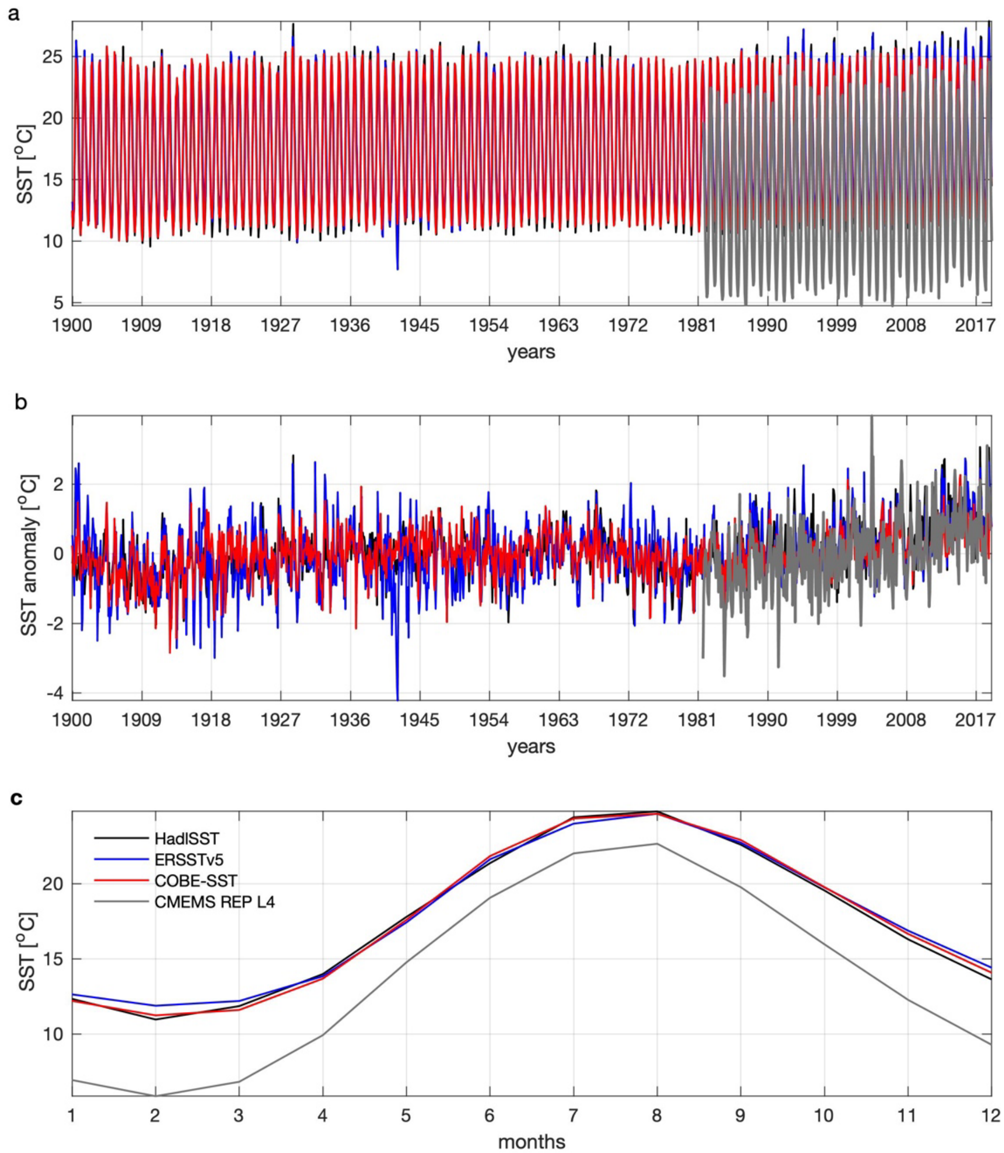

Figure S1. (a) Monthly SST time series from datasets reported in Table 1. (b) Monthly SST anomalies computed subtracting the monthly climatology from its relative time series. (c) Monthly SST climatology computed from the monthly time series.

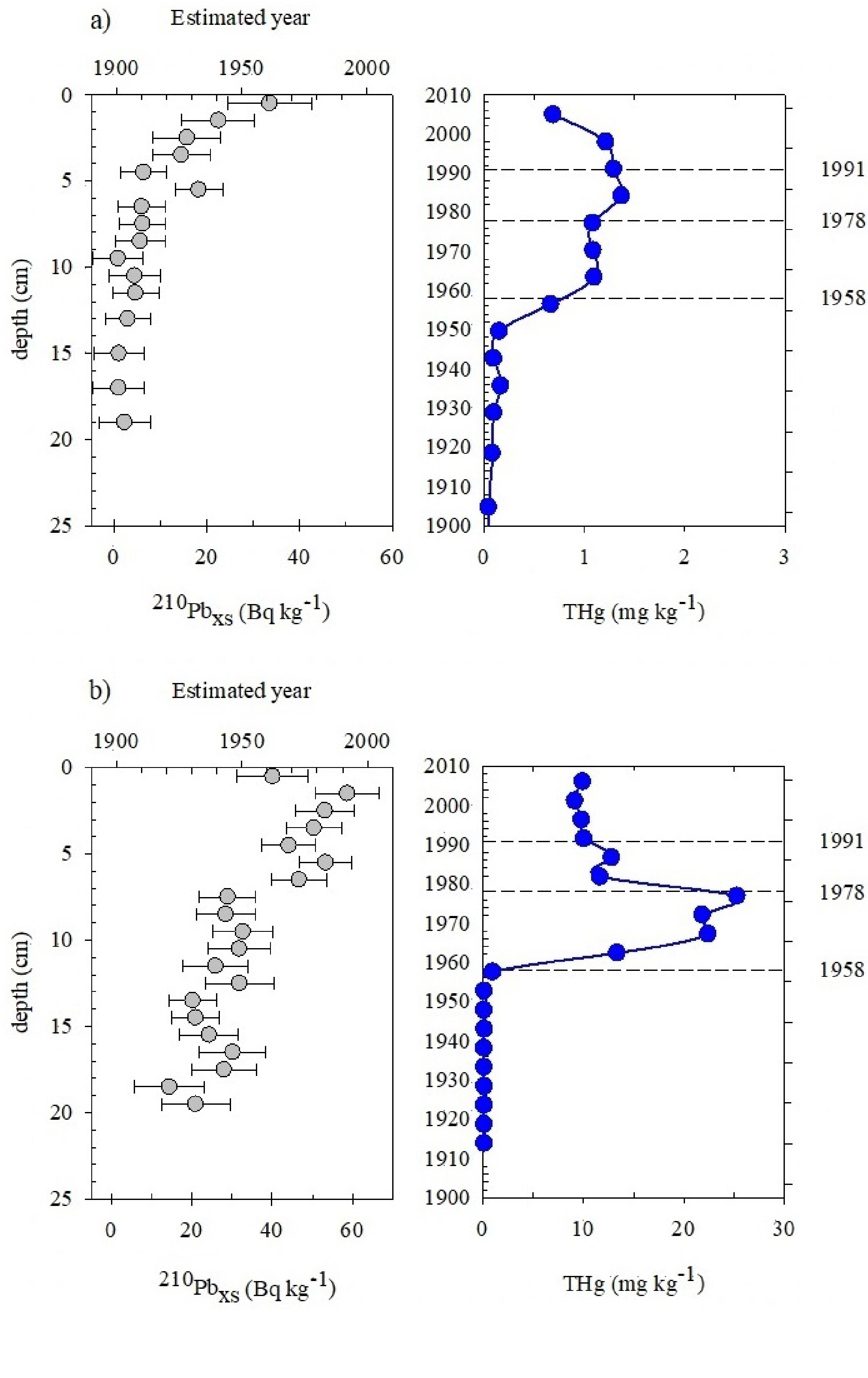

Figure S2. Geochronology of sediment cores estimated from the $^{210}Pb_{ex}$ CF-CS model and THg time marker: a) saltmarsh habitat and b) impacted habitat.