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Global patterns in mangrove soil carbon stocks and losses

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Table S1 Mangrove soil C stocks. Estimates of mean (± sd) total soil carbon (C) stocks and C stocks per unit area for countries where mangroves occur. Mangrove forest area are based on values from Hamilton and Casey 2016. C stock (Mg ha^{-1}) represent the top 1 m of soil. Countries with an * next to their name are missing soil C data. For these countries total C stocks were estimated using the average global soil C stock per unit area of 283 Mg ha^{-1}. n = number of soil cores from which estimates are based. Data quality score was calculated using Table S3 and S4. Maximum data quality score is 21.

Country	n	Total mangrove area-2014 (km^2)	Soil C stocks (Mg C ha^{-1})	Total soil C stock (Tg C)	Literature cited	Data quality score
Angola*	0	213.27	283	6.04		0
Antigua/Barbuda*	0	1.67	283	0.05		0
Australia	269	3314.68	249.40 ± 154.02	82.67 ± 51.05	1–11	15.8
Bahamas	2	36.77	80.70 ± 14.57	0.30 ± 0.05	12	14.0
Bangladesh	11	1772.67	118.01 ± 28.83	20.92 ± 5.11	13,14	18.2
Barbados*	0	0.06	283	0.002		0
Belize	13	302.02	647.05 ± 69.85	19.54 ± 2.11	15-17	15.2
Benin	3	6.97	234.68 ± 52.29	0.16 ± 0.04	18	18.0
Bermuda*	0	0.02	283	0.001		0
Brazil	41	7662.74	307.79 ± 130.56	235.85 ± 100.04	19-30	15.2
Brunei*	0	103.27	283	2.92		0
Cambodia*	0	320.04	283	9.06		0
Cameroon	6	1112.53	596.64 ± 347.69	66.38 ± 38.68	31,32	15.5
China	34	30.68	186.18 ± 67.29	0.57 ± 0.21	33-39	13.6
Colombia	4	1671.68	448.93 ± 164.23	75.05 ± 27.45	40,41	13.0
Comoros*	0	0.72	283	0.02		0
Congo	3	70.4	470.10 ± 384.74	3.31 ± 2.71	31	16.3
Costa Rica*	0	334.99	283	9.48		0
Cuba*	0	1624.23	283	45.97		0
Democratic Republic of Congo	3	146.09	935.67 ± 84.72	13.67 ± 1.24	31	16.0
Djibouti*	0	0.17	283	0.005		0
Dominican Republic	9	100.63	419.08 ± 88.30	4.22 ± 0.89	42	19.0
Ecuador	12	935.4	327.03 ± 60.58	30.59 ± 5.67	43,44	13.5

Table S1 continued						
Egypt	43	0.01	184.75 ± 54.79	0.0001 ± 0.00	45-47	12.2
El Salvador*	0	236.01	283	6.68		0
Equatorial Guinea*	0	155	283	4.39		0
Eritrea*	0	1.28	283	0.04		0
Fed. States of Micronesia	27	6.92	453.28 ± 243.65	0.31 ± 0.17	13,48-52	15.3
Fiji*	0	400.77	283	11.34		0
French Guiana/Guadeloupe	31	697.78	185.35 ± 129.05	12.93 ± 9.00	53-57	15.9
Gabon	3	1081.23	736.07 ± 192.43	79.59 ± 20.81	31	17.0
Gambia, The*	0	48.05	283	1.36		0
Ghana	3	23.36	245.36 ± 39.76	0.57 ± 0.09	31	13.0
Grenada*	0	1.09	283	0.03		0
Guatemala*	0	253.01	283	7.16		0
Guinea*	0	819.86	283	23.20		0
Guinea-Bissau	2	744.71	125.55 ± 56.36	9.35 ± 4.20	58	18.0
Guyana*	0	187.7	283	5.31		0
Haiti*	0	42.31	283	1.20		0
Honduras	18	523.61	397.34 ± 141.93	20.81 ± 7.43	59	17.0
India	160	791.4	252.58 ± 90.51	19.99 ± 7.16	61-74	13.4
Indonesia	40	23142.77	359.19 ± 180.68	831.23 ± 418.14	13,75-79	14.1
Iran*	0	0.04	283	0.001		0
Ivory Coast*	0	22.52	283	0.64		0
Jamaica*	0	43.74	283	1.24		0
Japan	47	7.84	273.99 ± 135.51	0.21 ± 0.11	80-85	12.8
Kenya	48	230.01	445.92 ± 422.41	10.26 ± 9.72	63,86-89	16.1
Liberia*	0	46.97	283	1.33		0
Madagascar	7	849.56	166.58 ± 74.51	14.15 ± 6.33	90,91	16.7
Malaysia	35	4691.5	424.37 ± 399.78	199.10 ± 187.56	92-98	13.8
Maldives*	0	0.3	283	0.01		0
Mexico	38	2985.02	370.35 ± 176.16	110.55 ± 52.58	99-104	16.2
Morocco*	0	0.29	283	0.01		0

Table S1 continued						
Mozambique	6	1223.16	153.07 ± 7.45	18.72 ± 0.91	105,106	17.0
Myanmar*	0	2508.25	283	70.98		0
New Caledonia	7	97.87	400.65 ± 75.72	3.92 ± 0.74	55,107-109	14.4
New Zealand	92	77.35	208.94 ± 52.34	1.62 ± 0.40	110-113	14.4
Nicaragua*	0	552.22	283	15.63		0
Nigeria	11	2653.32	234.74 ± 44.07	62.28 ± 11.69	114	15.0
Oman*	0	0.02	283	0.001		0
Pakistan	3	11.66	180.53 ± 6.86	0.21 ± 0.01	115	11.0
Palau	7	47.87	481.92 ± 84.12	2.31 ± 0.40	49,51	15.7
Panama	10	1323.06	298.95 ± 46.43	39.55 ± 6.14	116	12.0
Papua New Guinea	6	4169.04	140.38 ± 25.04	58.53 ± 10.44	117	11.0
Peru*	0	14.33	283	0.41		0
Philippines	8	2059.75	227.23 ± 162.14	46.80 ± 33.40	118,119	15.0
Puerto Rico*	0	45.94	283	1.30		0
Saudi Arabia	31	0.33	71.47 ± 52.74	0.002 ± 0.001	120	12.0
Senegal	2	155.32	138.92 ± 70.65	2.16 ± 1.10	121	14.0
Seychelles*	0	5.41	283	0.15		0
Sierra Leone*	0	655.32	283	18.55		0
Singapore	1	1.67	329.66 ± NA	0.06 ± NA	122	18.0
Solomon Islands*	0	392.6	283	11.11		0
Somalia*	0	7.83	283	0.22		0
South Africa	7	7.04	234.59 ± 47.29	0.17 ± 0.03	123,124	13.0
Sri Lanka	6	35.22	502.60 ± 163.10	1.77 ± 0.57	62	13.0
St. Vincent/ The Grenadines*	0	0.19	283	0.01		0
Sudan*	0	0.01	283	0.0003		0
Suriname*	0	509.77	283	14.43		0
Taiwan	3	0.81	122.21 ± 30.81	0.01 ± 0.00	125,126	11.0
Tanzania	30	478.23	243.48 ± 82.73	11.64 ± 3.96	127-130	15.2
Thailand	14	1875.62	245.87 ± 81.82	46.12 ± 15.35	85,131-133	12.6

Table S1 continued						
Timor-Leste	7	8.44	211.59 ± 84.97	0.18 ± 0.07	134	15.0
Togo*	0	0.61	283	0.02		0
Trinidad and Tobago*	0	51.42	283	1.46		0
Turks and Caicos Islands*	0	0.15	283	0.004		0
United Arab Emirates*	0	0.28	283	0.01		0
USA	45	1553.37	381.80 ± 187.82	59.29 ± 29.17	120,135-142	15.1
Vanuatu*	0	10.09	283	0.29		0
Venezuela	15	2400.86	314.74 ± 114.43	75.57 ± 27.47	143-145	12.8
Vietnam	6	706.41	173.58 ± 26.17	12.26 ± 1.85	85,119,146	14.3
Yemen*	0	0.14	283	0.004		0

Table S2. Potential annual CO_2 emissions from mangrove soils. Mean (± sd) potential annual soil C loss and CO_2 emissions as a result of mangrove deforestation. Mangrove forest loss is based on values from Hamilton and Casey 2016. Estimates of potential CO_2 emissions are based on peer reviewed literature showing that, on average, 43% soil C stocks down to 1 m are remineralized as a result of disturbances to mangrove forests. Potential CO_2 emissions at 100% remineralization represents the estimated maximum annual emissions.

Country	Annual mangrove loss (km^2)	Potential annual C loss at 43% remineralization (Gg C yr^{-1})	Potential annual CO_2 emissions at 43% remineralization (Gg CO_2e yr^{-1})	Potential annual CO_2 emissions at 100% remineralization (Gg CO_2e yr^{-1})
Angola*	0.277	3.37	12.37	28.769
Antigua/Barbuda*	0	0	0	0
Australia	0.994	10.66 ± 6.58	39.12 ± 24.16	90.835
Bahamas	0.022	0.08 ± 0.01	0.28 ± 0.05	0.654
Bangladesh	0	0	0	0
Barbados*	0	0	0	0
Belize	0.272	7.57 ± 0.82	27.77 ± 3.00	64.586
Benin	0.001	0.01 ± 0.00	0.04 ± 0.01	0.086
Bermuda*	0	0	0	0
Brazil	3.831	50.70 ± 21.51	186.08 ± 78.93	433.041
Brunei*	0.072	0.88	3.22	7.478
Cambodia*	1.184	14.41	52.88	122.971
Cameroon	0.445	11.42 ± 6.65	41.90 ± 24.42	97.499
China	0.052	0.42 ± 0.15	1.53 ± 0.55	3.550
Colombia	0.167	3.22 ± 1.18	11.83 ± 4.33	27.519
Comoros*	0	0	0	0
Congo	0.042	0.85 ± 0.69	3.12 ± 2.55	7.245
Costa Rica*	0.234	2.85	10.45	24.303
Cuba*	0.1	1.22	4.47	10.386
Democratic Republic of Congo	0.234	9.41 ± 0.85	34.55 ± 3.13	80.353
Djibouti*	0	0	0	0
Dominican Republic	0.04	0.72 ± 0.15	2.65 ± 0.56	6.151
Ecuador	0.187	2.63 ± 0.49	9.65 ± 1.79	22.442

Table S2 continued				
Egypt	0	0	0	0
El Salvador*	0.071	0.86	3.17	7.374
Equatorial Guinea*	0.109	1.33	4.87	11.321
Eritrea*	0.001	0.01	0.04	0.104
Fed. States of Micronesia	0.003	0.06 ± 0.03	0.21 ± 0.12	0.499
Fiji*	0.08	0.97	3.57	8.309
French Guiana/Guadeloupe	0.628	5.01 ± 3.49	18.37 ± 12.79	42.638
Gabon	0.432	13.67 ± 3.57	50.18 ± 13.12	116.688
Gambia, The*	0	0	0	0
Ghana	0.0724	0.76 ± 0.12	2.803 ± 0.45	6.519
Grenada*	0.003	0.04	0.13	0.312
Guatemala*	1.341	16.32	59.89	139.278
Guinea*	0.164	2.00	7.32	17.033
Guinea-Bissau	0	0	0	0
Guyana*	0.038	0.46	1.70	3.947
Haiti*	0.008	0.10	0.36	0.831
Honduras	0.89	15.21 ± 5.43	55.81 ± 19.93	129.672
India	2.137	23.21 ± 8.32	85.18 ± 30.53	198.423
Indonesia	60.171	929.34 ± 467.49	3410.69 ± 1715.69	7931.820
Iran*	0	0	0	0
Ivory Coast*	0.047	0.57	2.10	4.881
Jamaica*	0.052	0.63	2.32	5.401
Japan	0.005	0.06 ± 0.03	0.22 ± 0.11	0.503
Kenya	0.023	0.44 ± 0.42	1.62 ± 1.53	3.765
Liberia*	0.019	0.23	0.85	1.973
Madagascar	0.17	1.22 ± 0.54	4.47 ± 2.00	10.419
Malaysia	19.235	351.00 ± 330.66	1288.18 ± 1213.53	2993.120
Maldives*	0	0	0	0

Table S2 continued				
Mexico	2.388	38.03 ± 18.09	139.57 ± 66.39	324.267
Morocco*	0	0	0	0
Mozambique	0.245	1.61 ± 0.08	5.92 ± 0.29	13.757
Myanmar*	17.558	213.66	784.14	1823.591
New Caledonia	0.049	0.84 ± 0.16	3.10 ± 0.59	7.211
New Zealand	0.077	0.69 ± 0.17	2.54 ± 0.64	5.906
Nicaragua*	0.331	4.03	14.78	34.378
Nigeria	0.265	2.67 ± 0.50	9.82 ± 1.84	22.855
Oman*	0	0	0	0
Pakistan	0.002	0.02 ± 0.00	0.06 ± 0.00	0.133
Palau	0.01	0.21 ± 0.04	0.76 ± 0.13	1.769
Panama	0.265	3.41 ± 0.53	12.50 ± 1.94	29.079
Papua New Guinea	1.668	10.07 ± 1.80	36.95 ± 6.59	85.702
Peru*	0.004	0.05	0.18	0.415
Philippines	2.266	22.14 ± 15.80	81.26 ± 57.98	188.778
Puerto Rico*	0.009	0.11	0.40	0.935
Saudi Arabia	0	0	0	0
Senegal	0	0	0	0
Seychelles*	0	0	0	0
Sierra Leone*	0	0	0	0
Singapore	0	0	0	0
Solomon Islands*	0.157	1.91	7.01	16.306
Somalia*	0	0	0	0
South Africa	0.006	0.06 ± 0.01	0.22 ± 0.04	0.517
Sri Lanka	0.035	0.76 ± 0.25	2.78 ± 0.90	6.461
St. Vincent/ The Grenadines*	0	0	0	0
Sudan*	0	0	0	0
Suriname*	0.918	11.17	41.00	95.344
Taiwan	0.002	0.01 ± 0.00	0.04 ± 0.01	0.090

Table S2 continued				
Tanzania	0.191	2.00 ± 0.68	7.34 ± 2.49	17.104
Thailand	3.751	39.66 ± 13.20	145.54 ± 48.43	338.648
Timor-Leste	0.009	0.08 ± 0.03	0.30 ± 0.12	0.700
Togo*	0	0	0	0
Trinidad & Tobago*	0.129	1.57	5.76	13.398
Turks & Caicos Islands*	0	0	0	0
United Arab Emirates*	0	0	0	0
USA	3.417	56.10 ± 27.60	205.88 ± 101.28	479.043
Vanuatu*	0	0	0	0
Venezuela	0.96	12.99 ± 4.72	47.68 ± 17.34	110.981
Vietnam	0.706	5.27 ± 0.79	19.34 ± 2.92	45.084
Yemen*	0	0	0	0
Total	**129.2714**	**1917.00**	**7034.00**	**16325.149**

Table S3 Data quality scoring matrix. Scores for quality of carbon stock data, quality of down-core data, quality of bulk density data, and publication quality are averaged across all soil cores from that country. Maximum total quality score is 21. NA= not applicable.

	Individual point data			
	3	**2**	**1**	**0**
Quality of C stock data	C stock data present or calculable for individual cores	C stock data is an average of multiple sites	NA	NA
Quality of down core C stock data	C stocks given or calculable down to 80-100 cm depth in the soil	C stocks given or calculable to 41-79 cm depth and then extrapolated	Stocks extrapolated from surface (< 40 cm) soils	NA
Quality of percent organic C data	Original data presented as C density, stocks, or % OC	Original data presented as Loss on Ignition or organic matter content	Original data presented as total carbon	Global average used
Quality of bulk density data	Bulk density given to 100 cm	Bulk density given to <100 cm depth and then extrapolated	Bulk density estimated from a pedotransfer function	NA
Publication quality	Data published in a peer reviewed journal	Data published in a thesis, report or unpublished data	NA	NA

	Global data set			
	3	**2**	**1**	**0**
Extent of genera covered	≥ 70% of mangrove genera represented	30-69% of mangrove genera represented	≤ 30% of mangrove genera represented	Genera of mangroves unknown
Extent of marine eco-regions covered	≥ 70% of the marine eco-regions containing mangroves are represented	30-69% of the marine eco-regions containing mangroves are represented	≤ 30% of the marine eco-regions containing mangroves are represented	NA

Table S4 Data quality scores for countries where mangroves occur. Scores for quality of C stock data, quality of down-core data, quality of bulk density data, and publication quality are averages of all soil cores from that country. Maximum total quality score is 21. See table S3 for scoring matrix

Country	n	Quality of C stock	Quality of down-core data	Quality of %C	Quality of bulk density	Publication quality	Extent of genera covered	Extent of eco-regions covered	Total quality Score
Angola*	0	0	0	0	0	0	0	0	0
Antigua/Barbuda*	0	0	0	0	0	0	0	0	0
Australia	269	2.7	1.6	3.0	2.1	1.4	2.0	3.0	15.8
Bahamas	2	2.0	1.0	3.0	2.0	2.0	1.0	3.0	14.0
Bangladesh	11	2.2	3.0	3.0	3.0	2.0	2.0	3.0	18.2
Barbados*	0	0	0	0	0	0	0	0	0
Belize	13	2.6	1.8	2.7	1.0	2.0	2.0	3.0	15.2
Benin	3	2.0	3.0	3.0	3.0	2.0	2.0	3.0	18.0
Bermuda*	0	0	0	0	0	0	0	0	0
Brazil	41	2.8	1.4	2.9	1.1	2.0	2.0	3.0	15.2
Brunei*	0	0	0	0	0	0	0	0	0
Cambodia*	0	0	0	0	0	0	0	0	0
Cameroon	6	2.0	2.5	3.0	2.0	1.0	2.0	3.0	15.5
China	34	2.1	1.6	2.5	1.4	2.0	2.0	2.0	13.6
Colombia	4	2.3	1.0	2.0	1.8	2.0	2.0	2.0	13.0
Comoros*	0	0	0	0	0	0	0	0	0
Congo	3	2.0	3.0	3.0	3.0	1.3	1.0	3.0	16.3
Costa Rica*	0	0	0	0	0	0	0	0	0
Cuba*	0	0	0	0	0	0	0	0	0
Democratic Republic of Congo	3	2.0	3.0	3.0	3.0	1.0	1.0	3.0	16.0
Djibouti*	0	0	0	0	0	0	0	0	0
Dominican Republic	9	2.0	3.0	3.0	3.0	2.0	3.0	3.0	19.0
Ecuador	12	2.0	2.0	1.0	2.5	2.0	1.0	3.0	13.5
Egypt	43	2.8	1.0	0.4	1.0	2.0	2.0	3.0	12.2

Table S4 continued									
El Salvador*	0	0	0	0	0	0	0	0	0
Equatorial Guinea*	0	0	0	0	0	0	0	0	0
Eritrea*	0	0	0	0	0	0	0	0	0
Fed. States of Micronesia	27	2.0	2.8	2.8	2.8	2.0	2.0	1.0	15.3
Fiji*	0	0	0	0	0	0	0	0	0
French Guiana/ Guadeloupe	31	3.0	2.9	3.0	1.0	2.0	2.0	2.0	15.9
Gabon	3	2.0	3.0	3.0	3.0	1.0	3.0	2.0	17.0
Gambia, The*	0	0	0	0	0	0	0	0	0
Ghana	3	2.0	2.0	3.0	1.0	1.0	2.0	2.0	13.0
Grenada*	0	0	0	0	0	0	0	0	0
Guatemala*	0	0	0	0	0	0	0	0	0
Guinea*	0	0	0	0	0	0	0	0	0
Guinea-Bissau	2	2.0	3.0	3.0	3.0	2.0	2.0	3.0	18.0
Guyana*	0	0	0	0	0	0	0	0	0
Haiti*	0	0	0	0	0	0	0	0	0
Honduras	18	2.0	3.0	3.0	3.0	2.0	2.0	2.0	17.0
India	160	2.5	1.1	2.9	0.9	2.0	2.0	2.0	13.4
Indonesia	40	2.1	2.2	2.7	2.1	2.0	1.0	2.0	14.1
Iran*	0	0	0	0	0	0	0	0	0
Ivory Coast*	0	0	0	0	0	0	0	0	0
Jamaica*	0	0	0	0	0	0	0	0	0
Japan	47	2.1	2.1	2.2	1.5	2.0	1.0	2.0	12.8
Kenya	48	2.9	1.6	3.0	1.6	2.0	3.0	2.0	16.1
Liberia*	0	0	0	0	0	0	0	0	0
Madagascar	7	2.4	2.4	3.0	1.9	2.0	2.0	3.0	16.7
Malaysia	35	2.2	1.5	1.9	1.2	2.0	2.0	3.0	13.8
Maldives*	0	0	0	0	0	0	0	0	0
Mexico	38	2.2	1.9	3.0	2.0	2.0	3.0	2.0	16.2

Table S4 continued									
Morocco*	0	0	0	0	0	0	0	0	0
Mozambique	6	2.0	3.0	3.0	2.8	1.2	3.0	2.0	17.0
Myanmar*	0	0	0	0	0	0	0	0	0
New Caledonia	7	2.7	2.0	2.4	1.3	2.0	1.0	3.0	14.4
New Zealand	92	2.9	1.1	3.0	1.4	2.0	2.0	2.0	14.4
Nicaragua*	0	0	0	0	0	0	0	0	0
Nigeria	11	3.0	1.0	3.0	1.0	2.0	2.0	3.0	15.0
Oman*	0	0	0	0	0	0	0	0	0
Pakistan	3	2.0	1.0	2.0	1.0	2.0	1.0	2.0	11.0
Palau	7	2.0	3.0	3.0	2.7	2.0	1.0	2.0	15.7
Panama	10	2.0	1.0	2.0	2.0	2.0	1.0	2.0	12.0
Papua New Guinea	6	2.0	1.0	3.0	1.0	2.0	1.0	1.0	11.0
Peru*	0	0	0	0	0	0	0	0	0
Philippines	8	2.0	2.5	3.0	2.5	2.0	1.0	2.0	15.0
Puerto Rico*	0	0	0	0	0	0	0	0	0
Saudi Arabia	31	2.0	1.0	2.1	1.9	2.0	2.0	1.0	12.0
Senegal	2	3.0	1.0	3.0	1.0	2.0	2.0	2.0	14.0
Seychelles*	0	0	0	0	0	0	0	0	0
Sierra Leone*	0	0	0	0	0	0	0	0	0
Singapore	1	2.0	3.0	3.0	3.0	2.0	2.0	3.0	18.0
Solomon Islands*	0	0	0	0	0	0	0	0	0
Somalia*	0	0	0	0	0	0	0	0	0
South Africa	7	2.0	2.0	2.0	1.0	2.0	2.0	2.0	13.0
Sri Lanka	6	2.0	1.0	3.0	1.0	2.0	1.0	3.0	13.0
St. Vincent/ The Grenadines*	0	0	0	0	0	0	0	0	0
Sudan*	0	0	0	0	0	0	0	0	0
Suriname*	0	0	0	0	0	0	0	0	0
Taiwan	3	2.3	1.0	1.7	1.0	2.0	1.0	2.0	11.0
Tanzania	30	2.0	1.3	2.8	1.0	2.0	3.0	3.0	15.2

Table S4 continued									
Thailand	14	2.1	1.6	3.0	1.0	2.0	1.0	2.0	12.6
Timor-Leste	7	2.0	2.0	3.0	1.0	2.0	2.0	3.0	15.0
Togo*	0	0	0	0	0	0	0	0	0
Trinidad and Tobago*	0	0	0	0	0	0	0	0	0
Turks and Caicos Islands*	0	0	0	0	0	0	0	0	0
United Arab Emirates*	0	0	0	0	0	0	0	0	0
USA	45	2.2	1.2	2.7	2.0	2.0	3.0	2.0	15.1
Vanuatu*	0	0	0	0	0	0	0	0	0
Venezuela	15	2.0	1.5	1.9	1.4	2.0	2.0	2.0	12.8
Vietnam	6	2.2	2.2	3.0	2.0	2.0	1.0	2.0	14.3
Yemen*	0	0	0	0	0	0	0	0	0

Supplementary Table 5: Effects of different types of disturbances on soil C in mangrove ecosystems.

Core depth range	Disturbance type	Type of disturbance	% loss in soil C	Reference
0-100	Timber Harvest/Urban dev/Pollution	indirect/direct	23	31
0-100	Timber Harvest/Urban dev/Pollution	indirect/direct	10	31
0-100	Timber Harvest/Urban dev/Pollution	indirect/direct	85	31
0-100	Timber Harvest/Urban dev/Pollution	indirect/direct	57	31
0-100	Timber Harvest/Urban dev/Pollution	indirect/direct	16	31
0-100	Timber Harvest/Urban dev/Pollution	indirect/direct	12	31
0-100	Timber Harvest/Urban dev/Pollution	indirect/direct	38	31
0-100	Timber Harvest/Urban dev/Pollution	indirect/direct	31	31
0-20	Water diversions	indirect	59	7
0-25	Aquaculture/Timber	indirect/direct	28	72
0-80	Agriculture	direct	69	58
0-80	Agriculture	direct	48	58
0-100	Aquaculture	direct	54	59
>100	Shrimp Pond	direct	77	42
0-30	Eutrophication	indirect	53	147
0-30	Eutrophication	indirect	57	147
0-20	Water diversions	indirect	40	7
>100	Grazing	indirect	44	103
0-55	Grazing	indirect	20	124
		Average % change in soil C	43	

References

1. Adame, M. F., Reef, R., Herrera-Silveira, J. A. & Lovelock, C. E. Sensitivity of dissolved organic carbon exchange and sediment bacteria to water quality in mangrove forests. *Hydrobiologia* **691,** 239–253 (2012).

2. Allen, D., Dalal, R. C., Rennenberg, H. & Schmidt, S. Seasonal variation in nitrous oxide and methane emissions from subtropical estuary and coastal mangrove sediments, Australia. *Plant Biol.* **13,** 126–133 (2011).

3. Alongi, D. M. The dynamics of benthic nutrient pools and fluxes in tropical mangrove forests. *J. Mar. Res.* 123–148 (1996).

4. Bai, L. The colour of mud: Blue carbon storage in Darwin harbour. (Charles Darwin University, 2012).

5. Alongi, D. ., Tirendi, F. & Clough, B. . Below-ground decomposition of organic matter in forests of the mangroves *Rhizophora stylosa* and *Avicennia marina* along the arid coast of Western Australia. *Aquat. Bot.* **68,** 97–122 (2000).

6. Brunskill, G. J., Orpin, a. R., Zagorskis, I., Woolfe, K. J. & Ellison, J. Geochemistry and particle size of surface sediments of Exmouth Gulf, Northwest Shelf, Australia. *Cont. Shelf Res.* **21,** 157–201 (2001).

7. Howe, A. J., Rodriguez, J. F. & Saco, P. M. Surface evolution and carbon sequestration in disturbed and undisturbed wetland soils of the Hunter estuary, southeast Australia. *Estuar. Coast. Shelf Sci.* **84,** 75–83 (2009).

8. Livesley, S. J. & Andrusiak, S. M. Temperate mangrove and salt marsh sediments are a small methane and nitrous oxide source but important carbon store. *Estuar. Coast. Shelf Sci.* **97,** 19–27 (2012).

9. Matsui, N. Estimated stocks of organic carbon in mangrove roots and sediments in Hinchinbrook channel, Australia. *Mangroves Salt Marshes* **2,** 199–204 (1998).

10. Saintilan, N., Rogers, K., Mazumder, D. & Woodroffe, C. Allochthonous and autochthonous contributions to carbon accumulation and carbon store in southeastern Australian coastal wetlands. *Estuar. Coast. Shelf Sci.* **128,** 84–92 (2013).

11. Sanders, C. J. *et al.* Examining 239þ240 Pu, 210 Pb and historical events to determine carbon, nitrogen and phosphorus burial in mangrove sediments of Moreton. *J. Environ. Radioact.* **151,** 623–629 (2016).

12. Koch, M. S. & Madden, C. J. Patterns of primary production and nutrient availability in a Bahamas lagoon with fringing mangroves. *Mar. Ecol. Prog. Ser.* **219,** 109–119 (2001).

13. Donato, D. C. *et al.* Mangroves among the most carbon-rich forests in the tropics. *Nat. Geosci.* **4,** 293–297 (2011).

14. Rahman, M., Khan, N. I., Hoque, A. K. F. & Ahmed, I. Carbon stock in the Sundarbans mangrove forest: spatial variations in vegetation types and salinity zones. *Wetl. Ecol. Manag.* **23,** 269–283 (2015).

15. McKee, K. L., Fellwe, I. C., Popp, M. & Wanek, W. Mangrove isotopic (15N and 13C) fractionation across a nitrogen and phosphorus limitation gradient. *Ecology* **83,** 1065–1075 (2002).

16. Wooller, M., Smallwood, B., Jacobson, M. & Fogel, M. Carbon and nitrogen stable isotopic variation in *Laguncularia racemosa* (L.) (white mangrove) from Florida and Belize: Implications for trophic level studies. *Hydrobiologia* **13,** 13–23 (2003).

17. Keuskamp, J. A., Feller, I. C., Laanbroek, H. J., Verhoeven, J. T. A. & Hefting, M. M. Short- and long-term effects of nutrient enrichment on microbial exoenzyme activity in mangrove peat. *Soil Biol. Biochem.* **81**, 38–47 (2015).

18. Ajonina, G. N. *et al.* Carbon budget as a tool for assessing mangrove degradation in the western, coastal wetlands complex (Ramsar site 1017) southern Benin, West Africa. *Land/Ocean Interact. Coast. Zo. West Cent. Africa, Estuaries World,* (2014). doi:10.1007/978-3-319-06388-1

19. Ferreira, T. O. et al. Spatial patterns of soil attributes and components in a mangrove system in Southeast Brazil (São Paulo). *J. Soils Sediments* **10,** 995–1006 (2010).

20. Jennerjahn, T. C. & Ittekkot, V. Relevance of mangroves for the production and deposition of organic matter along tropical continental margins. *Naturwissenschaften* **89,** 23–30 (2002).

21. Kristensen, E., Bouillon, S., Dittmar, T. & Marchand, C. Organic carbon dynamics in mangrove ecosystems: A review. *Aquat. Bot.* **89,** 201–219 (2008).

22. Koch, B. P., Lara, J., Kattner, G. & Harder, J. The effect of selective microbial degradation on the composition of mangrove derived pentacyclic triterpenols in surface sediments. *Org. Geochem.* **36,** 273–285 (2005).

23. Lacerda, L. D., Ittekkot, V. & Patchineelam, S. R. Biogeochemistry of mangrove soil organic matter: A comparison between Rhizophora and Avicennia soils in south-eastern Brazil. *Estuarine, Coast.* **40,** 713–720 (1995).

24. Nóbrega, G. N. *et al.* Edaphic factors controlling summer (rainy season) greenhouse gas emissions (CO_2 and CH_4) from semiarid mangrove soils (NE-Brazil). *Sci. Total Environ.* **542,** 685–693 (2016).

25. Otero, X. L., Lucheta, A. R., Ferreira, T. O., Huerta-díaz, M. A. & Lambais, M. R. Archaeal diversity and the extent of iron and manganese pyritization in sediments from a tropical mangrove creek (Cardoso Island, Brazil). *Estuar. Coast. Shelf Sci.* **146,** 1–13 (2014).

26. Pupin, B. & Nahas, E. Microbial populations and activities of mangrove, restinga and Atlantic forest soils from Cardoso Island, Brazil. *J. Appl. Microbiol.* **116,** 851–864 (2013).

27. Sanders, C. J., Smoak, J. M., Naidu, A. S. & Patchineelam, S. R. Recent sediment accumulation in a mangrove forest and its relevance to local sea-level rise (Ilha Grande, Brazil). *J. Coast. Res.* **242,** 533–536 (2008).

28. Sanders, C. J., Smoak, J. M., Naidu, a. S., Sanders, L. M. & Patchineelam, S. R. Organic carbon burial in a mangrove forest, margin and intertidal mud flat. *Estuar. Coast. Shelf Sci.* **90,** 168–172 (2010).

29. Sanders, C. J. *et al.* Mangrove forest sedimentation and its reference to sea level rise, Cananeia, Brazil. *Environ. Earth Sci.* **60,** 1291–1301 (2010).

30. Wasserman, J. C., Figueiredo, A. M. G., Pellegatti, F. & Silva-Filho, E. V. Elemental composition of sediment cores from a mangrove environment using neutron activation analysis. *J. Geochemical Explor.* **72,** 129–146 (2001).

31. Ajonina, G. N. *et al. Carbon pools and multiple benefits of mangroves in Central Africa: Assessment for REDD+*. (2014).

32. Ntyam, S. C. O. Comparative study of the mangrove ecosystems of Douala-Edea Reserve (Cameroon) and Songor Ramsar site (Ghana) using parameters of ecological value. (University of Ghana, 2014).

33. Alongi, D. M. *et al.* Rapid sediment accumulation and microbial mineralization in forests of the mangrove *Kandelia candel* in the Jiulongjiang Estuary, China. *Estuar. Coast. Shelf Sci.* **63,** 605–618 (2005).

34. Bao, H. *et al.* Impact of the conversion of mangroves into aquaculture ponds on the sedimentary organic matter composition in a tidal flat estuary (Hainan Island, China). *Cont. Shelf Res.* **57,** 82–91 (2013).

35. Chen, G. C., Tam, N. F. Y. & Ye, Y. Spatial and seasonal variations of atmospheric N_2O and CO_2 fluxes from a subtropical mangrove swamp and their relationships with soil characteristics. *Soil Biol. Biochem.* **48,** 175–181 (2012).

36. Lu, W. *et al.* Changes in carbon pool and stand structure of a native subtropical mangrove forest after inter-planting with exotic species *Sonneratia apetala*. *PLoS One* **9,** 1–8 (2014).

37. Lunstrum, A. & Chen, L. Soil carbon stocks and accumulation in young mangrove forests. *Soil Biol. Biochem.* **75,** 223–232 (2014).

38. Luo, L. & Gu, J. Seasonal variability of extracellular enzymes involved in carbon mineralization in sediment of a subtropical mangrove wetland. *Geomicrobiology* **32,** 37–41 (2015).

39. Ren, H., Chen, H., Li, Z. & Han, W. Biomass accumulation and carbon storage of four different aged *Sonneratia apetala* plantations in Southern China. *Plant Soil* 279–291 (2010).

40. Cardona, P. & Botero, L. Soil characteristics and vegetation structure in a heavily deteriorated mangrove forest in the Caribbean coast of Colombia. *Biotropica.* **30,** 24-34 (1998).

41. Ruiz-Fernández, A. C., Marrugo-Negrete, J. L., Paternina-Uribe, R. & Pérez-Bernal, L. H. 210Pb-derived sedimentation rates and C_{org} fluxes in Soledad Lagoon (Cispatá Lagoon System, NW Caribbean Coast of Colombia). *Estuaries and Coasts* **34,** 1117–1128 (2011).

42. Kauffman, J. B., Heider, C., Norfolk, J. & Payton, F. Carbon stocks of intact mangroves and carbon emissions arising from their conversion in the Dominican Republic. *Ecol. Appl.* **24,** 518–527 (2014).

43. Delvecchia, A. G. *et al.* Organic carbon inventories in natural and restored Ecuadorian mangrove forests. *PeerJ* 1–18 (2014). doi:10.7717/peerj.388

44. Twilley, R. R. *et al.* Litter dynamics in riverine mangrove forests in the Guayas River estuary, Ecuador. *Oecologia* **111,** 109–122 (1997).

45. Eid, E. M. & Shaltout, K. H. Distribution of soil organic carbon in the mangrove *Avicennia marina* (Forssk) Vierh. along the Egyptian Red Sea Coast. *Reg. Stud. Mar. Sci.* **3,** 76-82 (2015).

46. Madkour, H., Mansour, A. M., Ahmed, A. E. N. & El-Taher, A. Environmental texture and geochemistry of the sediments of a subtropical mangrove ecosystem and surrounding areas, Red Sea Coast, Egypt. *Arab J. Geosci.* **7,** 3427–3440 (2014).

47. Okbah, M. a., Shata, M. a. & Shridah, M. a. Geochemical forms of trace metals in mangrove sediments, Red Sea (Egypt). *Chem. Ecol.* **21,** 23–36 (2005).

48. Cormier, N., Twilley, R. R., Ewel, K. C. & Krauss, K. W. Fine root productivity varies along nitrogen and phosphorus gradients in high-rainfall mangrove forests of Micronesia. *Hydrobiologia* **750,** 69–87 (2015).

49. Donato, D. C., Kauffman, J. B., Mackenzie, R. A., Ainsworth, A. & Pfleeger, A. Z. Whole-island carbon stocks in the tropical Pacific : Implications for mangrove conservation and upland restoration. *J. Environ. Manage.* **97,** 89–96 (2012).

50. Fujimoto, K., Imaya, A., Tabuchi, R. & Kuramoto, S. Belowground carbon storage of Micronesian mangrove forests. *Ecol. Res.* **14,** 409–413 (1999).

51. Kauffman, J. B., Heider, C., Cole, T. G., Dwire, K. A. & Donato, D. C. Ecosystem carbon stocks of Micronesian mangrove forests. *Wetlands* **31,** 343–352 (2011).

52. Ono, K. *et al.* Assessing the carbon compositions and sources of mangrove peat in a tropical mangrove forest on Pohnpei Island, Federated States of Micronesia. *Geoderma* **245–246,** 11–20 (2015).

53. Marchand, C., Lallier-Vergès, E. & Baltzer, F. The composition of sedimentary organic matter in relation to the dynamic features of a mangrove-fringed coast in French Guiana. *Estuar. Coast. Shelf Sci.* **56,** 119–130 (2003).

54. Marchand, C., Baltzer, F., Lallier-Vergès, E. & Alberic, P. Pore-water chemistry in mangrove sediments: relationship with species composition and developmental stages (French Guiana). *Mar. Geol.* **208,** 361–381 (2004).

55. Marchand, C., Disnar, J.-R., Lallier-Vergès, E. & Lottier, N. Early diagenesis of carbohydrates and lignin in mangrove sediments subject to variable redox conditions (French Guiana). *Geochim. Cosmochim. Acta* **69,** 131–142 (2005).

56. Marchand, C., Lallier-Vergès, E., Disnar, J.-R. & Kéravis, D. Organic carbon sources and transformations in mangrove sediments: A Rock-Eval pyrolysis approach. *Org. Geochem.* **39,** 408–421 (2008).

57. Lallier-Verges, E., Perrussel, B. P., Disnar, J.-R. & Baltzer, F. Relationships between environmental conditions and the diagenetic evolution of organic matter derived from higher plants in a modern mangrove swamp system (Guadeloupe, French West Indies). *Org. Geochem.* **29,** 1663–1686 (1998).

58. Andreetta, A., Delgado, A., Lotti, M. & Cerise, S. Land use changes affecting soil organic carbon storage along a mangrove swamp rice chronosequence in the Cacheu and Oio regions. *Agric. Ecosyst. Environ.* **216,** 314–321 (2016).

59. Bhomia, R. K., Kauffman, J. B. & Mcfadden, T. N. Ecosystem carbon stocks of mangrove forests along the Pacific and Caribbean coasts of Honduras. *Wetl. Ecol. Manag.* **24,** 187–201 (2016).

60. Mckee, B. K. L. & Mcginnis, T. E. Hurricane Mitch : Effects on mangrove soil characteristics and root contributions to soil stabilization. USGS Open File Report OFR-02-178 (http://www.nwrc.usgs.gov/hurricane/mitch/mckee%20rpt100702.pdf).

61. Bharathkumar, S., RameshKumar, N., Paul, D. & Nair, S. Characterization of the predominant bacterial population of different mangrove rhizosphere soils using 16S rRNA gene-based single-strand conformation polymorphism (SSCP). *World J. Microb. Biotech.* **24,** 387–394 (2008).

62. Bouillon, S., Rao, A. V. V. S., Koedam, N. & Dehairs, F. Sources of organic carbon in mangrove sediments: Variability and possible ecological implications. *Hydrobiologia* **495,** 33–39 (2003).

63. Bouillon, S. & Boschker, H. T. S. Bacterial carbon sources in coastal sediments: a cross-system analysis based on stable isotope data of biomarkers. *Biogeosciences* 175–185 (2006).

64. Jardine, S. L. & Siikamäki, J. V. A global predictive model of carbon in mangrove soils. *Environ. Res. Lett.* **9,** 104013 (2014).

65. Chakraborty, P., Chakraborty, S., Ramteke, D. & Chennuri, K. Kinetic speciation and bioavailability of copper and nickel in mangrove sediments. *Mar. Pollut. Bull.* **88,** 224–230 (2014).

66. Chanda, A. *et al.* Measuring daytime CO_2 fluxes from the inter-tidal mangrove soils of Indian Sundarbans. *Environ. Earth Sci.* **72,** 417–427 (2014).

67. Chatterjee, M. *et al.* An assessment of trace element contamination in intertidal sediment cores of Sunderban mangrove wetland, India for evaluating sediment quality guidelines. *Environ. Monit. Assess.* **150,** 307–322 (2009).

68. Fernandes, M. C., Nayak, G. N., Pande, A., Volvoikar, S. P. & Dessai, D. R. G. Depositional environment of mudflats and mangroves and bioavailability of selected metals within mudflats in a tropical estuary. *Environ. Earth Sci.* **72,** 1861–1875 (2014).

69. Dominguez, C. *et al.* Quantification and source identification of polycyclic aromatic hydrocarbons in core sediments from Sundarban mangrove. *Arch. Environ. Contam. Toxicol.* **59,** 49–61 (2010).

70. Kathiresan, K., Gomathi, V., Anburaj, R. & Saravanakumar. Impact of mangrove vegetation on seasonal carbon burial and other sediment characteristics in the Vellar-Coleroon estuary , India. *J. For. Res.* **25,** 787–794 (2014).

71. Patil, V., Singh, A. & Naik, N. Estimation of carbon stocks in *Avicennia marina* stand using allometry, CHN analysis, and GIS methods. *Wetlands* **34,** 379–391 (2014).

72. Ranjan, R. K., Routh, J., Ramanathan, A. & Klump, J. V. Elemental and stable isotope records of organic matter input and its fate in the Pichavaram mangrove–estuarine sediments (Tamil Nadu, India). *Mar. Chem.* **126,** 163–172 (2011).

73. Ray, R. *et al.* Carbon sequestration and annual increase of carbon stock in a mangrove forest. *At. Environ.* **45,** 5016–5024 (2011).

74. Sebastian, R. & Chacko, J. Distribution of organic carbon in tropical mangrove sediments (Cochin, India). *Int. J. Environ.* **3,** 303–311 (2006).

75. Alongi, D., Trott, L., Tirendi, F., McKinnon, A. & Undu, M. Growth and development of mangrove forests overlying smothered coral reefs, Sulawesi and Sumatra, Indonesia. *Mar. Ecol. Prog. Ser.* **375,** 97–109 (2008).

76. Brunskill, G. J., Zagorskis, I., Pfitzner, J. & Ellison, J. Sediment and trace element depositional history from the Ajkwa River estuarine mangroves of Irian Jaya (West Papua), Indonesia. *Cont. Shelf Res.* **24,** 2535–2551 (2004).

77. Chen, G. C. *et al.* Rich soil carbon and nitrogen but low atmospheric greenhouse gas fluxes from North Sulawesi mangrove swamps in Indonesia. *Sci. Total Environ.* **487,** 91–96 (2014).

78. Jennerjahn, T. C. *et al.* Biogeochemistry of a tropical river affected by human activities in its catchment : Brantas River estuary and coastal waters of Madura Strait, Java, Indonesia. *Estuar. Coast. Shelf Sci.* **60,** 503–514 (2004).

79. Weiss, C. *et al.* Soil organic carbon stocks in estuarine and marine mangrove ecosystems are driven by nutrient colimitation of P and N. *Ecol. Evol.* 1–14 (2016). doi:10.1002/ece3.2258

80. Khan, N. I., Suwa, R. & Hagihara, A. Carbon and nitrogen pools in a mangrove stand of *Kandelia obovata* (S., L.) Yong: vertical distribution in the soil – vegetation system. *Wetl. Ecol. Manag.* **15,** 141–153 (2007).

81. Mchenga, I. S. S. & Tsuchiya, M. Nutrient dynamics in mangrove crab burrow sediments subjected to anthropogenic input. *J. Sea Res.* **59,** 103–113 (2008).

82. Higashi, T. & Shinagawa, A. Soils of a mangrove forest composed of *Rhizophora mucronata* and *Bruguiera gymnorrhiza* from Ishigaki Island, Japan. *Soil Sci. Plant Nutr.* **31,** 427–435 (1985).

83. Mfilinge, P. L., Atta, N. & Tsuchiya, M. Nutrient dynamics and leaf litter decomposition in a subtropical mangrove forest at Oura Bay, Okinawa, Japan. *Trees* **16,** 172–180 (2002).

84. Sharma, S., Yasuoka, J., Nakamura, T., Watanabe, A. & Nadaoka, K. The role of hydroperiod, soil moisture and distance from the river mouth on soil organic matter in Fukido mangrove forest. *Proc. Int. Conf. Adv. Appl. Sci. Environ. Eng.* 44–48 (2014). doi:10.13140/2.1.2303.2962

85. Tateda, Y., Nhan, D. D., Wattayakorn, G. & Toriumi, H. Preliminary evaluation of organic carbon sedimentation rates in Asian mangrove coastal ecosystems estimated by 210 Pb chronology. *Radioprotection* **40,** 527–532 (2005).

86. Andreetta, A. *et al.* Mangrove carbon sink. Do burrowing crabs contribute to sediment carbon storage? Evidence from a Kenyan mangrove system. *J. Sea Res.* **85,** 524–533 (2014).

87. Gress, S. A., Huxman, M., Kairo, J. G., Muhi, L. M. & Briers, R. A. Evaluating, predicting and mapping belowground carbon stores in Kenyan mangroves. *Glob. Chang. Biol.* **23,** 224-234 (2016).

88. Hemminga, M. A. *et al.* Carbon outwelling from a mangrove forest with adjacent seagrass beds and coral reefs (Gazi Bay, Kenya). **106,** 291–301 (1994).

89. Middelburg, J., Nieuwenhuize, J., Slim, F. & Ohowa, B. Sediment biogeochemistry in an East African mangrove forest (Gazi Bay, Kenya). *Biogeochemistry* **34,** 133–155 (1996).

90. Jones, T. G., Ratsimba, H. R., Ravaoarinorotsihoarana, L., Cripps, G. & Bey, A. Ecological variability and carbon stock estimates of mangrove ecosystems in northwestern Madagascar. *Forests* **5,** 177–205 (2014).

91. Ralison, H. O., Borges, V. A., Dehairs, F., Middelburg, J. J. & Bouillon, S. Organic Carbon biogeochemistry of the Betsiboka estuary (north-western). *Org. Geochem.* **39,** 1649–1658 (2008).

92. Alongi, D. et al. Sediment accumulation and organic material flux in a managed mangrove ecosystem: estimates of land–ocean–atmosphere exchange in peninsular Malaysia. *Mar. Geol.* **208,** 383–402 (2004).

93. Arianto, C. I. *et al.* Soil carbon storage in dominant species of mangrove forest of Sarawak , Malaysia. *Int. J. Phys. Sci.* **10,** 210–214 (2015).

94. Ashton, E. C. & Macintosh, D. J. Preliminary assessment of the plant diversity and community ecology of the Sematan mangrove forest, Sarawak, Malaysia. *For. Ecol. Manag.* **166,** (2002).

95. Hemati, Z., Hossain, M., Emenike, C. U. & Rozainah, M. Z. Rate of carbon storage in soil of natural and degraded mangrove forest in peninsular Malaysia. *Clean Soil, Air, Water* **43,** 614–619 (2015).

96. Pazi, A. M. M., Gandaseca, S., Hamzah, A. H., Tindit, A. E. & Nyangon, L. Soil pH and carbon at different depth in three sones of mangroves forest in Sarawak, Indonesia. *Malaysian For.* **79,** 164–173 (2016).

97. Hossain, M. Carbon pools and fluxes in *Bruguiera parviflora* dominated naturally growing mangrove forest of Peninsular Malaysia. *Wetl. Ecol. Manag.* **22,** 15–23 (2014).

98. Rambok, E., Gandaseca, S., Ahmed, O. H. & Majid, N. M. A. Comparison of selected soil chemical properties of two different mangrove forests in Sarawak. *Am. J. Environ. Sci.* **6,** 438–441 (2010).

99. Adame, M. F. *et al.* Carbon stocks of tropical coastal wetlands within the karstic landscape of the Mexican Caribbean. *PLoS One* **8,** e56569 (2013).

100. Adame, M. F., Santini, N. S., Tovilla, C., Vázquez-Lule, a. & Castro, L. Carbon stocks and soil sequestration rates of riverine mangroves and freshwater wetlands. *Biogeosciences Discuss.* **12,** 1015–1045 (2015).

101. Giani, L., Bashan, Y., Holguin, G. & Strangmann, A. Characteristics and methanogenesis of the Balandra lagoon mangrove soils, Baja California Sur, Mexico. **72,** 149–160 (1996).

102. Gonneea, M. E., Paytan, A. & Herrera-Silveira, J. A. Tracing organic matter sources and carbon burial in mangrove sediments over the past 160 years. *Estuar. Coast. Shelf Sci.* **61,** 211–227 (2004).

103. Kauffman, J. B., Hernandez, H., Jesus, C., Chris, G. & Contreras, W. M. Carbon stocks of mangroves and losses arising from their conversion to cattle pastures in the Pantanos de Centla , Mexico. *Wetl. Ecol. Manag.* **24,** 203–216 (2016).

104. Ramírez-elías, M. A. *et al.* Identification of culturable microbial functional groups isolated from the rhizosphere of four species of mangroves and their biotechnological potential. *Appl. Soil Ecol.* **82,** 1–10 (2014).

105. Sitoe, A. A., Júnior, L., Mandlate, C. & Guedes, B. S. Biomass and carbon stocks of Sofala Bay mangrove forests. *Forests* **5,** 1967–1981 (2014).

106. Stringer, C. E. *et al.* Final Report: The Zambezi River Delta mangrove carbon project : A pilot baseline assessment for REDD+ reporting and monitoring.

107. Leopold, A., Marchand, C., Deborde, J. & Allenbach, M. Temporal variability of CO_2 fluxes at the sediment-air interface in mangroves (New Caledonia). *Sci. Total Environ.* **502,** 617–626 (2015).

108. Marchand, C., Allenbach, M. & Lallier-vergès, E. Relationships between heavy metals distribution and organic matter cycling in mangrove sediments (Conception Bay , New Caledonia). *Geoderma* **160,** 444–456 (2011).

109. Deborde, J., Marchand, C., Molnar, N., Patrona, L. Della & Meziane, T. Concentrations and fraction of carbon, iron, sulfur, nitrogen and phosphorus in mangrove sediments along an intertidal gradient (semi-arid climate, New Caledonia). *J. Mar. Sci. Eng.* **3,** 52–72 (2015).

110. Bulmer, R. H., Schwendenmann, L. & Lundquist, C. J. Sediment CO_2 efflux from cleared and intact temperate mangroves and tidal flats. *Biogeosciences Discuss.* **12,** 3547–3576 (2015).

111. Lovelock, C. E., Sorrell, B. K., Hancock, N., Hua, Q. & Swales, A. Mangrove forest and soil development on a rapidly accreting shore in New Zealand. *Ecosystems* **13,** 437–451 (2010).

112. Woodroffe, D. Studies of a mangrove basin, Tuff Crater, New Zealand: I. mangrove biomass and production of detritus. *Estuar. Coast. Shelf Sci.* **20,** 265–280 (1985).

113. Yang, J. *et al.* Vegetation and sediment characteristics in an expanding mangrove forest in New Zealand. *Estuar. Coast. Shelf Sci.* **134,** 11–18 (2013).

114. Oyo-ita, O. E., Offem, J. O., Ekpo, B. O. & Adie, P. A. Anthropogenic PAHs in mangrove sediments of the Calabar River , SE Niger. *Appl. Geochemistry* **28,** 212–219 (2013).

115. Kristensen, E., Devol, A. H., Ahmed, S. I. & Saleem, M. Preliminary study of benthic metabolism and sulfate reduction in a mangrove swamp of the Indus Delta, Pakistan. *Mar. Ecol. Prog. Ser.* **90,** 287–297 (1992).

116. Lovelock, C. E., Feller, I. C., Mckee, K. L. & Thompson, R. Variation in mangrove forest structure and sediment characteristics in Bocas del Toro, Panama. *Caribb. J. Sci.* **41,** 456–464 (2005).

117. Alongi, D. M., Christoffersen, P. & Tirendi, F. The influence of forest type on microbial-nutrient relationships in tropical mangrove sediments. *J. Exp. Mar. Bio. Ecol.* **171,** 201–223 (1993).

118. Thompson, B. S., Clubbe, C. P., Primavera, J. H., Curnick, D. & Koldewey, H. J. Locally assessing the economic viability of blue carbon: A case study from Panay Island, the Philippines. *Ecosyst. Serv.* **8,** 128–140 (2014).

119. Kennedy, H., Gacia, E., Kennedy, D. P., Papadimitriou, S. & Duarte, C. M. Organic carbon sources to SE Asian coastal sediments. *Estuar. Coast. Shelf Sci.* **60,** 59–68 (2004).

120. Balk, M. *et al.* Nitrate ammonification in mangrove soils: A hidden source of nitrite? *Front. Microbiol.* **6,** 1–10 (2015).

121. Sakho, I. *et al.* A cross-section analysis of sedimentary organic matter in a mangrove ecosystem under dry climate conditions: The Somone estuary, Senegal. *J. African Earth Sci.* **101,** 220–231 (2015).

122. Phang, V. X. H., Chou, L. M. & Friess, D. A. Ecosystem carbon stocks across a tropical intertidal habitat mosaic of mangrove forest, seagrass meadow, mudflat and sandbar. *Earth Surf. Process. Landforms* **40,** 1387–1400 (2016).

123. Hoppe-speer, S. C. L., Adams, J. B. & Rajkaran, A. Response of mangroves to drought and non-tidal conditions in St Lucia Estuar, South Africa. *African J. Aquat. Sciences* **38,** 37–41 (2013).

124. Hoppe-Apeer, S. C. L. & Adams, J. B. Cattle browsing impacts on stunted *Avicennia marina* mangrove trees. *Aquat. Bot.* **121,** 9–15 (2015).

125. Fan, L. *et al.* Effect of sulfate availability on the isotopic signature of reduced sulfurous compounds in the sediments of a subtropical estuary. *Wetlands* **32,** 907–917 (2012).

126. Kao, W., Tsai, H., Shih, C., Tsai, T. & Handley, L. Nutrient contents, d13C and d15N during leaf senescence in the mangrove, *Kandelia candel* (L.) Druce. *Bot. Stud.* **43,** 277–282 (2002).

127. Kristensen, E. *et al.* Emission of CO_2 and CH_4 to the atmosphere by sediments and open waters in two Tanzanian mangrove forests. *Mar. Ecol. Prog. Ser. Ser.* **370,** 53–67 (2008).

128. Lyimo, T. J., Pol, A. & Camp, H. J. M. O. Den. Methane emission, sulphide concentration and redox potential profiles in Mtoni mangrove sediment, Tanzania. *West. Indian Ocean J. Mar. Sci.* **1,** 71–80 (2002).

129. Machiwa, J. F. Distribution and remineralization of organic carbon in sediments of a mangroves stand partly contaminated with sewage waste. *Ambio* **27,** 740–744 (1998).

130. Muzuka, A. N. N. & Shunula, J. P. Stable isotope compositions of organic carbon and nitrogen of two mangrove stands along the Tanzanian coastal zone. *Estuar. Coast. Shelf Sci.* **66,** 447–458 (2006).

131. Alongi, D. *et al.* Organic carbon accumulation and metabolic pathways in sediments of mangrove forests in southern Thailand. *Mar. Geol.* **179,** 85–103 (2001).

132. Kristensen, E., Andersen, F. Ø., Holmboe, N., Holmer, M. & Thongtham, N. Carbon and nitrogen mineralization in sediments of the Bangrong mangrove area, Phuket, Thailand. *Aquat. Microb. Ecol.* **22,** 199–213 (2000).

133. Holmboe, N., Kristensen, E. & Andersen, F. Ø. Anoxic decomposition in sediments from a tropical mangrove forest and the temperate Wadden Sea: Implications of N and P addition experiments. *Estuar. Coast. Shelf Sci*. **53,** 125–140 (2001).

134. Alongi, D. M. *et al.* Uncoupled surface and below-ground soil respiration in mangroves: implications for estimates of dissolved inorganic carbon export. *Biogeochemistry* **109,** 151–162 (2012).

135. Bianchi, T. S. *et al.* Historical reconstruction of mangrove expansion in the Gulf of Mexico : Linking climate change with carbon sequestration in coastal wetlands. *Estuar. Coast. Shelf Sci.* **119,** 7–16 (2013).

136. Breithaupt, J. L., Smoak, J. M., Smith, T. J., I. & Sanders, C. J. Temporal variability of carbon and nutrient burial, sediment accretion, and mass accumulation over the past century in a carbonate platform mangrove forest of the Florida Everglades. *J. Geophys. Res.* **119,** 2032–2048 (2014).

137. Cahoon, D. R. & Lynch, J. C. Vertical accretion and shallow subsidence in a mangrove forest of southwestern Florida, U.S.A. *Mangroves Salt Marshes* **1,** 173–186 (1997).

138. Chambers, L. G. *et al.* Biogeochemical effects of simulated sea level rise on carbon loss in an Everglades mangrove peat soil. *Hydrobiologia* **726,** 195–211 (2014).

139. Callaway, J. C., DeLaune, R. D. & Patrick, W. H. Accretion rates from four coastal wetlands along the Gulf of Mexico. *J. Coast. Res.* **13,** 181–191 (1997).

140. Doughty, C. L. *et al.* Mangrove range expansion rapidly increases coastal wetland carbon storage. *Estuaries and Coasts* **39,** *385-396* (2016). doi:10.1007/s12237-015-9993-8

141. Genthner, F. J. *et al.* Relationships among habitat quality and measured condition variables in Gulf of Mexico mangroves. *Wetl. Ecol. Manag* **21,** 173–191 (2013).

142. Henry, K. M. & Twilley, R. R. Soil development in a coastal Louisiana wetland during a climate-induced vegetation shift from salt marsh to mangrove soil. *J. Coast. Res.* **29,** 1273–1283 (2013).

143. Rivera-Monroy, V. H. et al. Spatial variability of soil nutrients in disturbed riverine mangrove forests at different stages of regeneration in the San Juan River estuary, Venezuela. *Estuaries* **27,** 44–57 (2004).

144. Barreto, M. B. *et al.* Soil organic carbon of mangrove forests (Rhizophora and Avicennia) of the Venezuelan Caribbean coast. *Org. Geochem.* **100,** 51–61 (2016).

145. Vegas-Vilarrúbia, T. *et al.* Tropical histosols of the lower Orinoco Delta, features and preliminary quantification of their carbon storage. *Geoderma* **155,** 280–288 (2010).

146. Tue, N. T., Dung, L. V., Nhua, M. T. & Omori K. Carbon storage of a tropical mangrove forest in Mui Ca Mau National Park, Vietnam. *Catena* **121,**119-126 (2014).

147. Suárez-Abelenda, M., Ferreira, T. O., Camps-Arbestain, M., Rivera-Monroy, V. H. & Macías, F. The effect of nutrient-rich ef fl uents from shrimp farming on mangrove soil carbon storage and geochemistry under semi-arid climate conditions in northern Brazil. *Geoderma* **213,** 551–559 (2014).