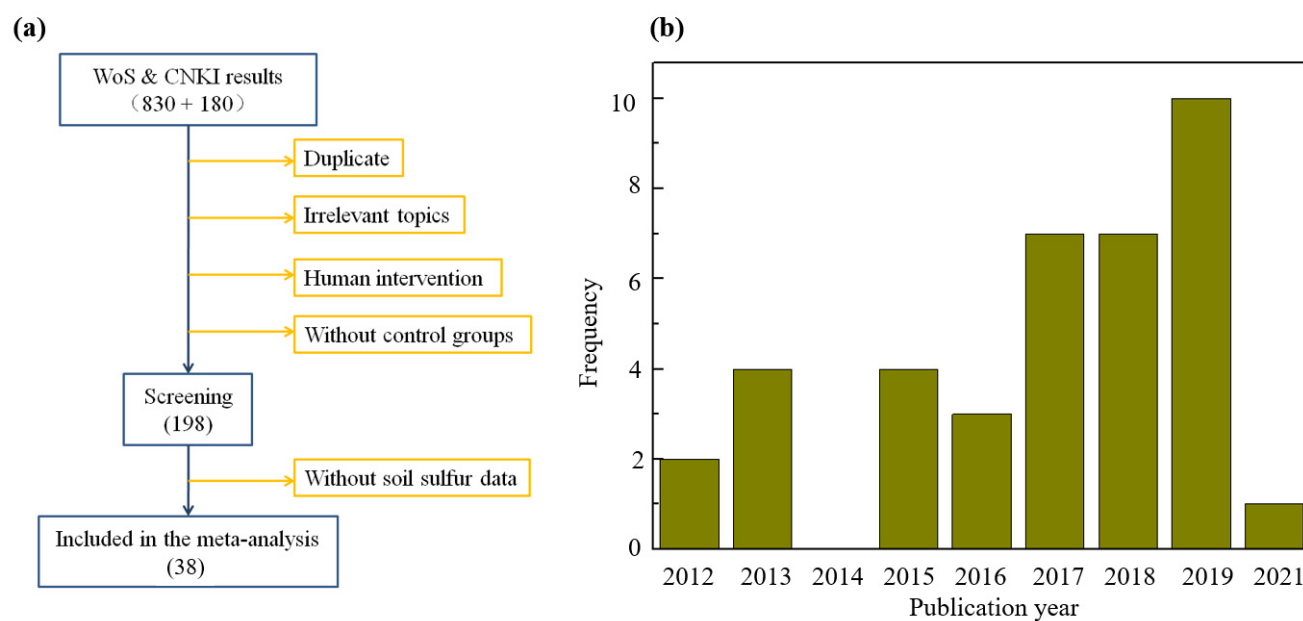


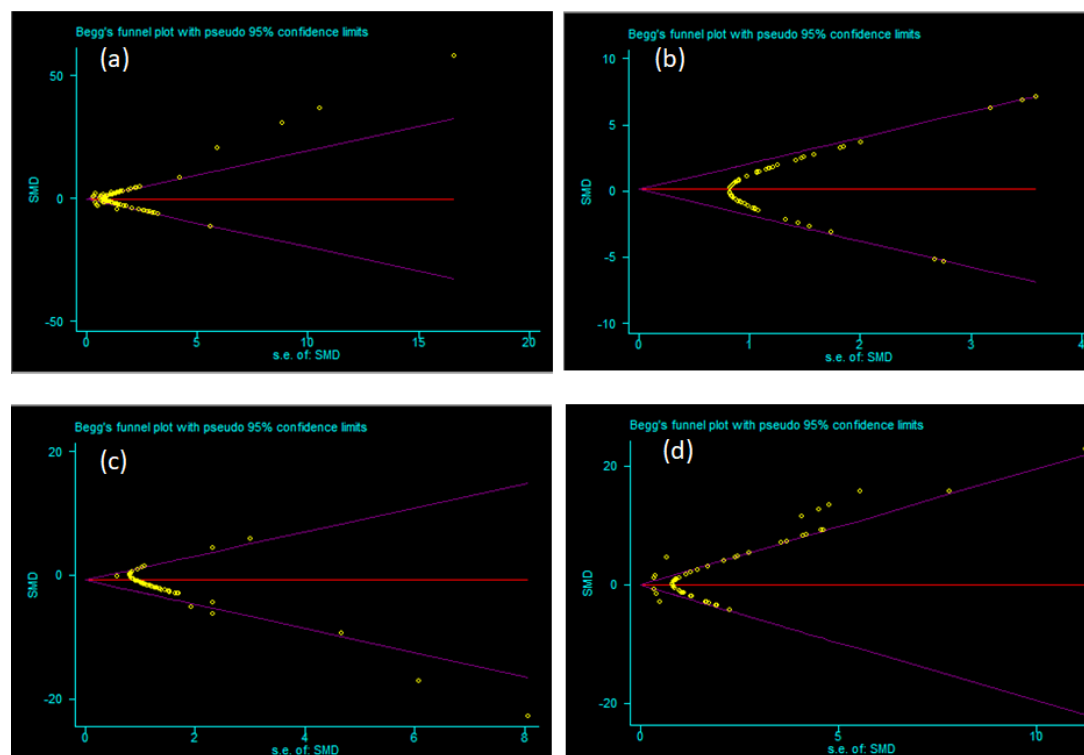
# *Spartina alterniflora* Invaded Coastal Wetlands by Raising Soil Sulfur Contents: A Meta-Analysis

Zhenzhen Zhao, Liyu Cheng, Chiquan He, Feifei Wang, Jialin Liu, Yuanhang Li, Xueping Chen, Xiaoyan Liu, Gaoming Lv and Daoyuan Wang

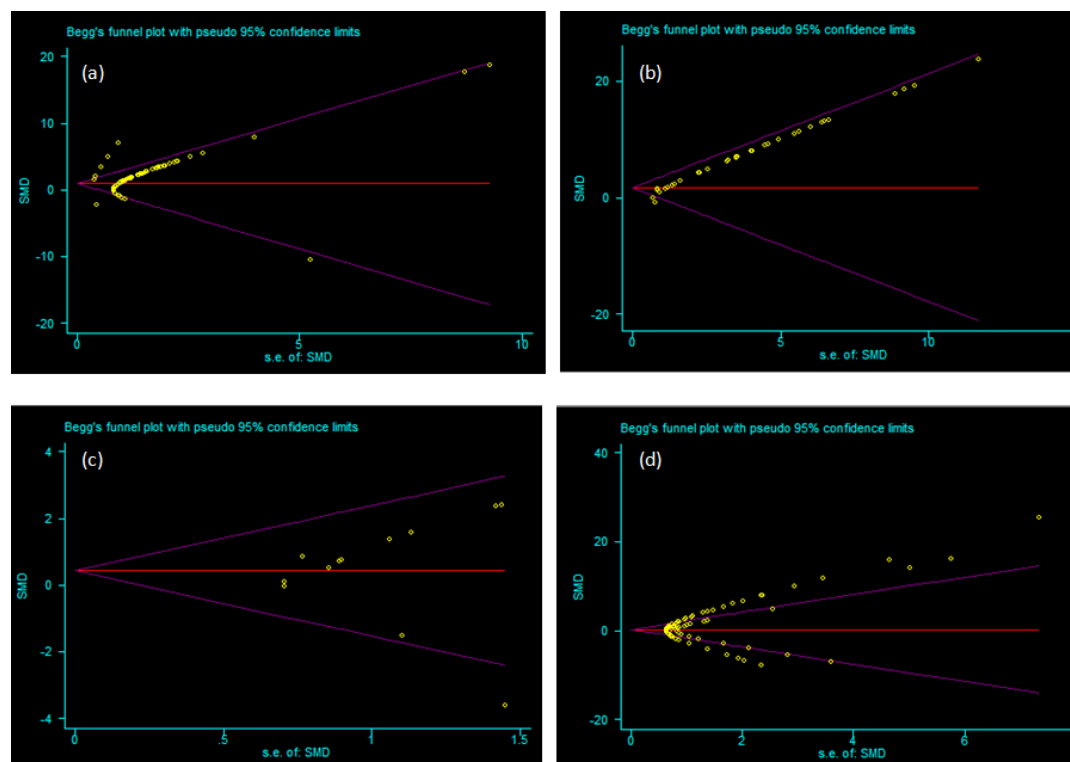
## Supplementary Materials



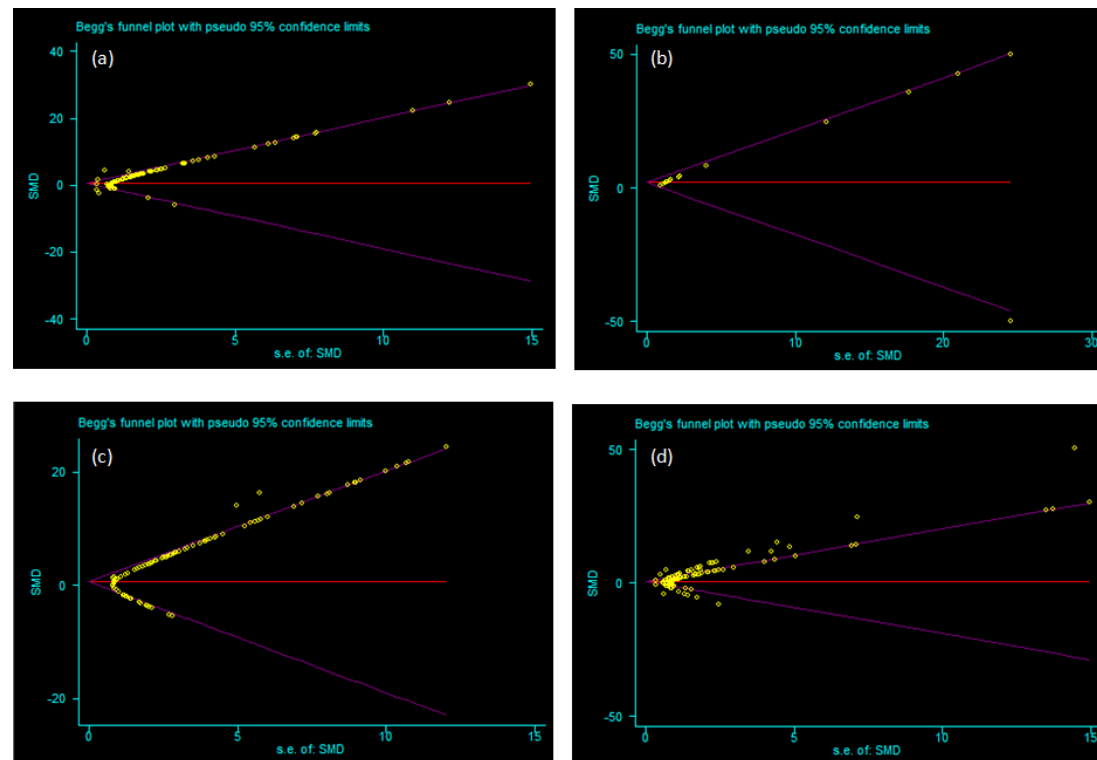
**Figure S1.** (a) The screening process used in the meta-analysis. Each yellow box represents studies screened out which did not meet the criteria.; (b) Evidence on the response of soil sulfur content after *S. alterniflora* invasion was synthesized in our database of researches published between 2012 and 2019 (The research published in 2021 was an unpublished study of our team when we did the meta-analysis). The most recent year in our database (2019) had the most published articles (n = 10).



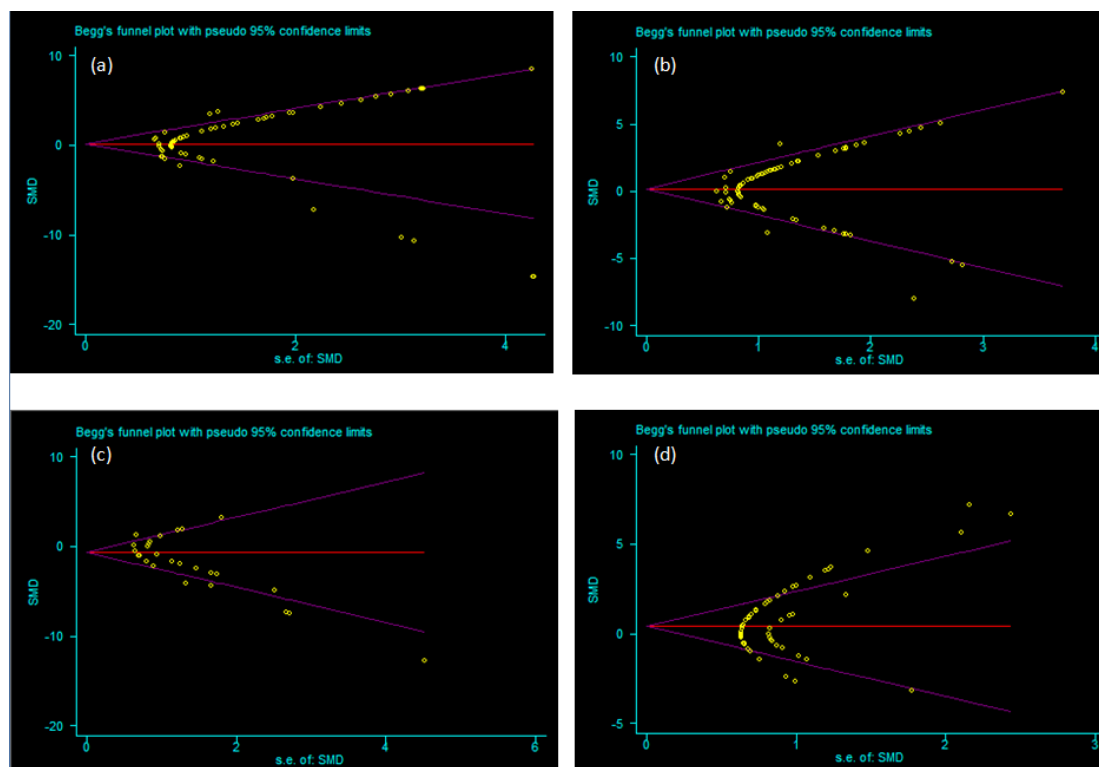
**Figure S2.** Funnel plots of the meta-analysis of the effect of *S. alterniflora* on soil (a) pH, (b) electric conductivity, (c) bulk density and (d) salinity.



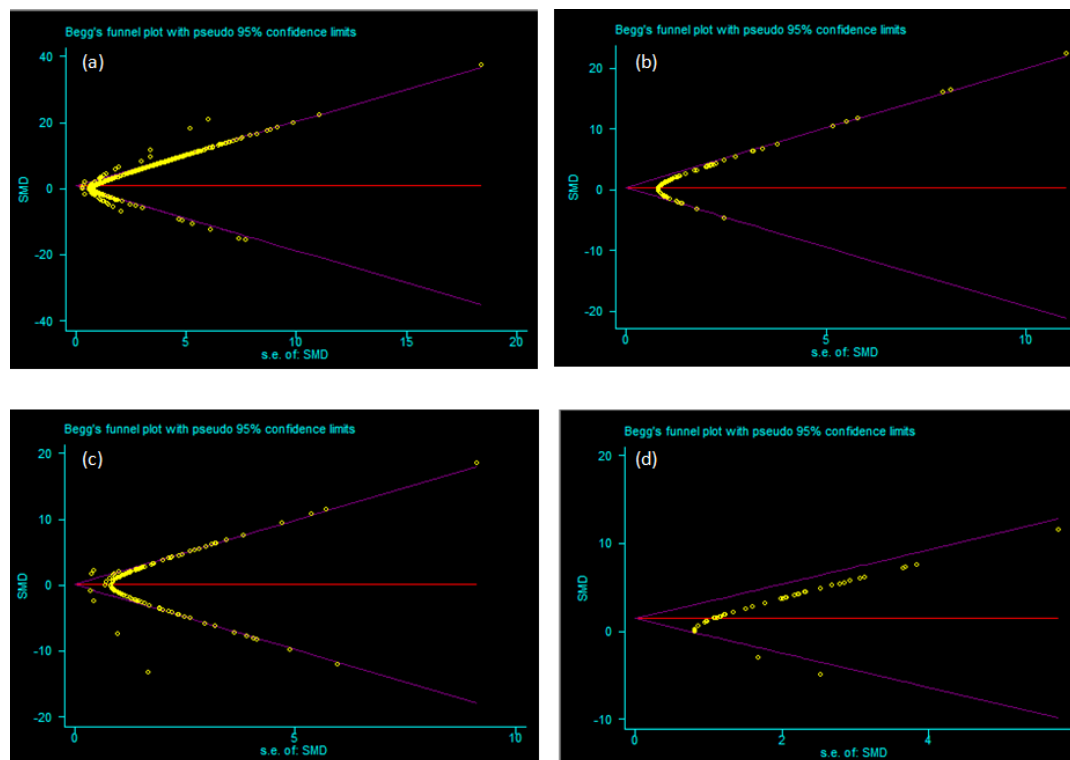
**Figure S3.** Funnel plots of the meta-analysis of the effect of *S. alterniflora* on (a) soil water content, (b) aboveground biomass, (c) underground biomass and (d) total carbon.



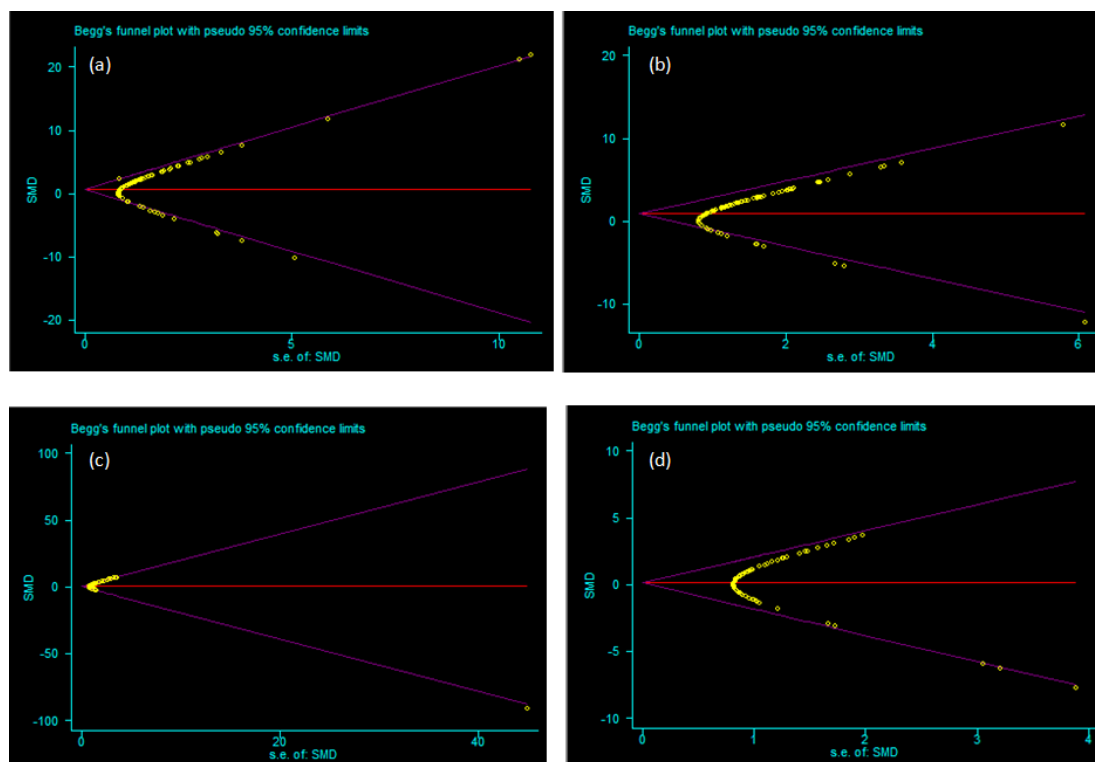
**Figure S4.** Funnel plots of the meta-analysis of the effect of *S. alterniflora* on soil (a) organic carbon, (b) microbial biomass carbon, (c) organic matter, and (d) total nitrogen.



**Figure S5.** Funnel plots of the meta-analysis of the effect of *S. alterniflora* on soil (a)  $\text{NH}_4^+$ , (b)  $\text{NO}_3^-$ , (c) C/N ratios, and (d) total phosphorous.



**Figure S6.** Funnel plots of the meta-analysis of the effect of *S. alterniflora* on soil (a) total sulfur, (b) available sulfur, (c)  $\text{SO}_4^{2-}$ , and (d)  $\text{S}^{2-}$ .



**Figure S7.** Funnel plots of the meta-analysis of the effect of *S. alterniflora* on soil (a) H<sub>2</sub>O-S, (b) Adsorbed-S, (c) HCl-Soluble-S, and (d) HCl-Volatile-S.

**Table S1.** Basic information including literature source, site location, native species, native species life form, temperature, precipitation, sample years and soil properties extracted from the articles used in the meta-analysis. A “/” was for information not offered in the articles. (MF: mud flat; EC: electrical conductivity TC: total carbon; TN: total nitrogen; SOC: total organic matter; OM: organic matter; TP: total phosphorous; AP: available phosphorous; TK: total kalium; C/N: the ratio of soil carbon and nitrogen; SMBC: soil microbial biomass carbon; SMBN: soil microbial biomass nitrogen; TS: total sulfur; AS: available sulfur; DMS: dimethyl sulfide.

No.	Author	Year	Journal	Language	Location	Native Species	Native Species Life Forms	Site	Tem (°C)	Pre (mm)	sample year	Soil Properties
1	Shijie Bai	2013	Applied Microbiology and Biotechnology	English	Zhangjiang, Fujian	<i>Aegiceras corniculatum</i> , <i>Kenaelia candel</i> , <i>Aricennia marina</i> ,	woody	23°53'–23°56' N 117°24'–117°30' E	21.2	1714	2010	pH, Salinity, TC, TN, C/N
2	Naishun Bu	2017	Resources and Environment in the Yangtze Basin	Chinese	Chongming, Shanghai	<i>Phragmites australis</i> , <i>Scirpus mariqueter</i> ,	herbal	31°25'–31°38'N 121°50'–122°05'E	15.3	1022	2011	pH, EC, Aboveground biomass, Water content, SOC, SO <sub>4</sub> <sup>2−</sup>
3	Quan Chen	2018	Ecological Research	English	Zhanjiang, Guangdong	<i>Avicennia marina</i> ,	woody	20°14'–21°35'N 109°40'–110°35'E	22.3	1500–2000	2015	pH, Soil density, Salinity, Underground biomass, TC, OM, TN, C/N, TP, TS,
4	Xue Ping Chen	2018	Journal of Microbiology	English	Chongming, Shanghai	<i>Phragmites australis</i>	herbal	31°25'–31°38'N 121°50'–122°05'E	15.3	1022	/	pH, Salinity, TC, SOC, SMBC, TN, SO <sub>4</sub> <sup>2−</sup>
5	Jun Cui	2017	Wetlands	English	Yancheng, Jiangsu	<i>Suaeda salsa</i> , <i>Phragmites australis</i> , MF	herbal	/	14	1000	/	pH, Salinity, Water content, SOC, TN, TS, SO <sub>4</sub> <sup>2−</sup>
6	Dengzhou Gao	2019	Plant and Soil	English	Dongtan, Shanghai	<i>Scirpus mariqueter</i> , <i>Phragmites australis</i> , MF	herbal	30°25'–31°38'N 121°50'–122°05'E	/	/	2017, 2018	pH, Soil density, Salinity, SOC, NH <sub>4</sub> <sup>+</sup> , NO <sub>3</sub> <sup>−</sup> , NO <sub>2</sub> <sup>−</sup> , S <sup>2−</sup>
7	Dengzhou Gao	2017	Plant and Soil	English	Shanyutan, Minjiang, Fujian	<i>Cyperus malaccensis</i>	herbal	26°00'–26°03'N 119°34'–119°41'E	19.6	1350	2016	pH, EC, Soil density, Aboveground biomass, Underground biomass, Water content, SOC, TN, NH <sub>4</sub> <sup>+</sup> , NO <sub>3</sub> <sup>−</sup> , S <sup>2−</sup>
8	Gui Feng Gao	2018	Scientific Reports	English	Zhangjiang, Fujian	<i>Kandelia obovata</i> , <i>Avicennia marina</i> , MF	woody	117°24'–117°30'E 23°53'–23°56'N	21.2	1714	2014	pH, EC, Salinity, Water content, TC, SOC, SMBC, OM, C/N, NH <sub>4</sub> <sup>+</sup> , NO <sub>3</sub> <sup>−</sup> , NO <sub>2</sub> <sup>−</sup> ,



													SO <sub>4</sub> <sup>2-</sup> , CO <sub>2</sub> flux, CH <sub>4</sub> flux
9	Tao He	2017	Acta Scientiae Circumstantiae	Chinese	Shanyutan, Minjiang, Fujian	Cyperus malaccensis	herbal	/	19	1300	2015	pH, EC, Water content, OM, TN, TS, H <sub>2</sub> O-S, Adsorbed-S, HCl-Soluble-S, HCl-Volatile-S, Fe	
10	Ping Li	2019	Acta Scientiae Circumstantiae	Chinese	Jiaozhouwan, Shandong	MF	/	36°05'-36°15'N 120°03'-120°25'E	12.2	776	2016	pH, EC, Soil density, Water content, OM, TS, AS, Fe	
11	Xiaofei Li	2019	Plant and Soil	English	the Yangtze Estuary	MF	/	121°5–122°30'E 30°52–31°46'N	/	/	2016	pH, Salinity, Aboveground biomass, Underground biomass, Water content, SOC, SMBC, NH <sub>4</sub> <sup>+</sup> , NO <sub>3</sub> <sup>-</sup> , S <sup>2-</sup>	
12	Li'an Lin	2019	Microbial Ecology	English	Leizhou Peninsula, Guangdong	MF	/	20°55'N, 110°9'E	/	/	2015	SOC, TN, NH <sub>4</sub> <sup>+</sup> , NO <sub>3</sub> <sup>-</sup> , TS	
13	Chuan Tong	2018	Limnology and OceanographY	English	Shanyutan, Minjiang, Fujian	<i>Cyperus malaccensis</i>	herbal	119°34'-119°40'E 26°00'-26°03'N	19.6	1350	2012, 2013	pH, Aboveground biomass, Underground biomass, SOC, TN, TP, SO <sub>4</sub> <sup>2-</sup>	
14	Xiaoyu Tong	2019	The journal of applied ecology	Chinese	Shanyutan, Minjiang, Fujian	MF	/	26°00'—26°03'N 119°34'—119°40'E	19.3	1380	2016	pH, EC, Soil density, Water content, OM, TS, H <sub>2</sub> O-S, Adsorbed-S, HCl-Soluble-S, HCl-Volatile-S	
15	Haitao Wang	2016	Environmental Science and Pollution Research	English	Jiulongjiang, Fujian	<i>Kandelia obovata</i> , MF	woody	24°26'–24°29'N 117°53'–117°55'E	21	1371	2010, 2011	pH, Salinity, TC, TN, C/N, NH <sub>4</sub> <sup>+</sup> , TP, TS,	
16	Zhengyu Wang	2019	Ecological Engineering	English	Jiuduansha, Shanghai	<i>Scirpus mariqueter</i> , MF	herbal	30°10'N, 122°01'E	/	1145	2015, 2016	Salinity, SOC, TN, TS,	
17	Jian Xiang	2015	AtmosphHeric Environment	English	Sheyang, Jiangsu	MF	/	33°30'N, 120°38'E	/	/	2011	pH, Soil density, Aboveground biomass, SOC, TN, SO <sub>4</sub> <sup>2-</sup>	
18	Xiaoqing Yu	2015	Environmental Science and Pollution Research	English	Jiulongjiang, Fujian	<i>Kandelia obovata</i> , MF	woody	117°53'–117°55'E 24°25'–24°29'N	21	1200	2010, 2011	TC, TN, TP, TS	

19	Junji Yuan	2016	Scientific Reports	English	Yancheng, Jiangsu	<i>Suaeda salsa</i> , <i>Phragmites australis</i> , MF	herbal	33°22'N, 120°42'E	12.6	1040	2012	Salinity, Aboveground biomass, SOC, SO <sub>4</sub> <sup>2-</sup>
20	Jemaneh Zeleke	2013	Frontiers in Microbiology	English	Chongming, Shanghai	<i>Phragmites australis</i>	herbal	/	/	/	/	pH, EC, TC, TN, SO <sub>4</sub> <sup>2-</sup>
21	Guangliang Zhang	2019	Science of the Total Environment	English	Yellow River Delta National Nature Reserve	<i>Suaeda salsa</i>	herbal	118°58'–119°20'E 37°36'–37°51'N	11.5–12.4	1500	/	pH, EC, Soil density, Water content, OM, TN, C/N, TP, TS
22	Qiufang Zhang	2013	Canadian Journal of Microbiology	English	Jiulongjiang, Fujian	<i>Cyperus malaccensis</i> , <i>Kandelia candel</i> , MF	herbal woody	24°26'N, 117°54'E	/	/	2009, 2010	pH, TC, TN, NH <sub>4</sub> <sup>+</sup> , NO <sub>3</sub> <sup>-</sup> , TS
23	Yaohong Zhang	2013	Ecological Engineering	English	Wanggang River, Jiangsu	<i>Phragmites australis</i>	herbal	33°12'N, 120°47'E	/	/	2010	Soil density, Aboveground biomass, Underground biomass, SOC, TN, C/N, H <sub>2</sub> O-S
24	Yu Zheng	2017	Ecological Engineering	English	Chongming, Shanghai	<i>Phragmites australis</i> , <i>Scirpus mariqueter</i>	herbal	31°25'–31°38'N 121°50'–122°05'E	15.3	1022	/	pH, Salinity, Water content, TC, SOC, SMBC, TN, SO <sub>4</sub> <sup>2-</sup>
25	Dongxiu Liu	2015	Shanghai University	Chinese	Chongming, Shanghai	<i>Phragmites australis</i> , <i>Scirpus mariqueter</i>	herbal	/	/	/	2008, 2009	pH, TC, SOC, SMBC, TN, SO <sub>4</sub> <sup>2-</sup>
26	Tao He	2018	Fujian Normal University	Chinese	Shanyutan, Minjiang, Fujian	<i>Cyperus malaccensis</i>	herbal	119°34'–119°41'E 25°00'–26°3'N	19	1300	2016	TS, SO <sub>4</sub> <sup>2-</sup> , H <sub>2</sub> O-S, Adsorbed-S, HCl-Soluble-S, HCl-Volatile-S
27	Hengyang Zhang	2018	Shanghai University	Chinese	Jiuduansha, Shanghai	<i>Scirpus mariqueter</i> , MF	herbal	31°09'N, 121°57'E	/	/	2016	Salinity, Aboveground biomass, OM, TN, AP, TS
28	Ping Li	2019	Qingdao University	Chinese	Jiaozhouwan, Shandong	MF	/	36°05'N–36°15'N 120°03'E–120°25'E	12.2	776	2017	pH, EC, Soil density, Water content, TS, H <sub>2</sub> O-S, Adsorbed-S, HCl-Soluble-S, HCl-Volatile-S

29	Chong You	2019	Chinese Journal of Applied and Environmental Biology	Chinese	Duliujian River, Tianjin	<i>Phragmites australis</i> , <i>Suaeda salsa</i>	herbal	/	/	/	2014	pH, Salinity, TC, TN, TP, TS
30	Tao He	2016	Journal of Soil and Water Conservation	Chinese	Shanyutan, Minjiang, Fujian	<i>Cyperus malaccensis</i> , <i>Cyperus compressus</i>	herbal	/	19	1300	2015	pH, EC, Water content, OM, TS
31	Yan Zhang	2017	Wetland Science	Chinese	Jiaozhouwan, Shandong	MF	/	36°1'N-36°15'N 120°3'E-120°25'E	12.2	776	2015	OM, AS
32	Yan Zhang	2017	Qingdao University	Chinese	Jiaozhouwan, Shandong	MF	/	36°1'N-36°15'N 120°3'E-120°25'E	12.2	776	2015, 2016	pH, Soil density, Salinity, Aboveground biomass, Underground biomass, Water content, OM, TS, AS
33	Xiaodong Zhang	2012	Fudan University	Chinese	Chongming, Shanghai	<i>Phragmites australis</i> , MF	herbal	/	/	/	2009, 2010	Aboveground biomass, Underground biomass, TC, SOC, TN, NH <sub>4</sub> <sup>+</sup> , NO <sub>3</sub> <sup>-</sup> , SO <sub>4</sub> <sup>2-</sup> , S <sup>2-</sup>
34	Yufeng Jin	2012	Fujian Normal University	Chinese	Shanyutan, Minjiang, Fujian	<i>Phragmites australis</i> , <i>Cyperus compressus</i>	herbal	119°36'E-119°37'E 26°01'N-26°02'N	19.6	1346	2011	pH, Salinity, Water content, NO <sub>3</sub> <sup>-</sup> , SO <sub>4</sub> <sup>2-</sup>
35	Junji Yuan	2019	Journal of Ecology	English	Yancheng, Jiangsu	MF	/	33°36'N, 120°36'E	/	/	2011	SOC, TN, SO <sub>4</sub> <sup>2-</sup>
36	Junji Yuan	2015	Global Change Biology	English	Yancheng, Jiangsu	<i>Phragmites australis</i> , <i>Suaeda salsa</i>	herbal	33°22'N, 120°42'E	12.6	1040	2012	Salinity, Aboveground biomass, SOC, NH <sub>4</sub> <sup>+</sup> , NO <sub>3</sub> <sup>-</sup> , SO <sub>4</sub> <sup>2-</sup>
37	Quan Chen	2018	Journal of Coastal Research	English	Zhangjiang, Fujian	<i>Avicennia marina</i> , MF	woody	20°14'–21°35' N 109°40'–110°35' E	24-25	1500 - 2000	2015	pH, Soil density, Salinity, TC, OM, TN, C/N, TP, TS
38	Chiquan He	2021	Plant and Soil	English	Jiuduansha, Shanghai	<i>Scirpus mariqueter</i> , MF	herbal	30°10'N, 122°01'E	15-17	1200	2018, 2019	SOC, TN, TP, SO <sub>4</sub> <sup>2-</sup> , S <sup>2-</sup>

### List of Included Articles

1. Bai, S.; Li, J.; He, Z.; Van Nostrand, J.D.; Tian, Y.; Lin, G.; Zhou, J.; Zheng, T. GeoChip-based analysis of the functional gene diversity and metabolic potential of soil microbial communities of mangroves. *Appl. Microbiol. Biotechnol.* **2013**, *97*, 7035–7048.
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10. Li, P.; Xie, W.; Wang, Z.; Yan, Q. Effects of *Spartina alterniflora* invasion on sulfur content temporal and spatial variation in tidal flat wetland of Jiaozhou Bay. *Acta Sci. Circumstantiae* **2019**, *39*, 870–879.
11. Li, X.; Gao, D.; Hou, L.; Liu, M. Soil substrates rather than gene abundance dominate DNRA capacity in the *Spartina alterniflora* ecotones of estuarine and intertidal wetlands. *Plant Soil* **2019**, *436*, 123–140, <https://doi.org/10.1007/s11104-018-03914-w>.
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28. Li, P. Spatial and temporal distribution of inorganic sulfur forms and the influencing factors in the soil of *Spartina alterniflora* in Jiaozhou Bay. Master, Qingdao University, Qingdao, 2019.
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