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Carbon storage in free water surface constructed wetlands in southern Sweden

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Regards,

Katarzyna Nowak

Abstract

Background Wetlands store significant amounts of carbon through plant respiration and anaerobic peat formation, however, there is little knowledge on which factors affect the carbon storage distribution within wetlands.

Aims To determine how much carbon and nitrogen wetlands can store over time and whether there are patterns of high and low carbon and nitrogen storage within wetlands.

Methods Peat samples of a defined volume, cut out from three constructed wetlands were dried, weighed and analysed for their carbon and nitrogen content. To determine whether there are any patterns in carbon and nitrogen storage distribution or differences between sampling points, their values as well as their ratios were statistically analysed using ANOVA and Kruskal-Wallis.

Results On average 48.94 t C ha^{-1} is stored at the constructed wetland facility which equates 3.06 t C ha^{-1} storage per year. There is no patterns in carbon storage within wetlands, however, the C:N mass ratio is lower at the inlet suggesting that high N concentrations in inflowing water increase~~s~~ N content.

Conclusions The carbon storage found is significantly lower than storage at natural inland and coastal wetlands, however, similar to anthropogenically affected wetlands. Standardisation across studies through using same sampling depths, vegetation cover measurement and climate classification may help to uncover patterns in carbon storage in the future. Focus should be placed on protecting wetlands rather than restoring them as the latter often fails to restore full functionality. This is especially important for cold climate wetlands which store significantly more carbon through slower plant respiration and subsequently slower re-uptake of carbon.

Keywords: carbon storage, constructed wetlands, C:N, peat analysis

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Introduction

Wetlands are ecosystems characterised by having soil that is seasonally or permanently flooded, which favours anoxic microbes and macrophytes specifically adapted to hydric soils (US EPA, 2018). Wetlands are known to provide a variety of ecosystem services such as water purification, flooding relief, biodiversity and soil nutrient regulation (Abe et al., 2014, Leon et al., 2018, Thiere et al., 2009, Wang et al., 2012). What separates them from other ecosystems is that they are a passing point for water that drains from upstream; this water can carry nutrients from agricultural fertilisers and erosion through rainfall as well as plant matter. Wetlands are primarily known for their nitrogen and phosphorus removal abilities. Nitrogen is transformed by the microbes (Chen at el., 2016) to form ammonia/ammonium while phosphorus from decaying organic matter is transformed by microbes to inorganic phosphorus which is then available for uptake by the plants. However, it must also be acknowledged that wetlands can sequester significant amounts of carbon through absorption of carbon dioxide by the plants which eventually decompose and turn into peat (Cao et al., 2017), as can be seen in Figure 1. As our carbon dioxide emissions become more worrisome due to increased industrialisation, we must consider restoring degraded wetlands or creating constructed wetlands as a semi-natural method of carbon storage (Hopkinson et al., 2012). Rewetting of wetlands is known to restore the wetland's natural carbon cycle, although it may take years to return to original carbon storage capacity (Gao et al., 2013). While construction of wetlands may have high starting costs and require extensive labour, with their low maintenance and water purification functions they can be a cost-effective method of passively reducing one of the main greenhouse gases while naturally filtering out excess nutrients. Free water surface wetlands, which will be examined in this project, are usually the cheapest of the four types of wetlands as they do not require much underground work.

Even though the carbon storage function of wetlands has been increasingly acknowledged since the 70s, their drainage and exploitation has in parallel also increased (Naturvårdsverket, 2014). Multi-year studies determining carbon storage in wetlands are scarce and limited to only a few locations, meaning there is lack of scientific data that can be used to persuade governments and communities to invest in wetland restoration and creation. However, the studies carried out so far have shown promising results, estimating that significant portions of carbon emitted globally is being stored in these ecosystems. For example, one review combined data from 1383 wetland soil samples in palustrine wetlands, China, through a combination of real sampling and literature, and concluded that they store ca. 9.945 Gt of carbon (Han et al., 2020). To put that into perspective, China emitted ca. 2.727 Gt of carbon in 2019 (Wong, 2021). In the prairie pothole wetlands in the US, an estimate of between 43 and 66 Mg/hec of carbon is stored, which expanded to its area of about 160,000 km^2 equates to ca. 0.872 Gt of carbon (Tangen et al., 2020). A study comparing restored and untouched wetlands in Illinois, US, found that restored wetlands stored up to 98.34 Mg/hec less carbon, and their nitrogen concentrations hovered at about 2.43 Mg/hec (Chen et al., 2017). The carbon to nitrogen ratio is a useful indicator of soil fertility and through its measurement we can determine whether peatland from wetlands can be cut out and used as fertiliser during maintenance. Qu et al. (2014) found C:N ratios of between 27 and 36g of carbon per gram of nitrogen depending on the age and vegetation type. Liu et al. (2017) found a similar ratio (30:1) in Chinese wetlands. These figures provide us with a solid base for comparison of the concentrations which will be found in southern Sweden. However, the wide variety of variables in both constructed and natural wetlands means that not all wetlands may store the same amount of carbon and nitrogen. Things like geographical location, climate, macrophyte species and water nutrient content are known to influence wetland mechanisms (Yang, 2019, Bernal et al., 2012) and their efficiency may decrease due to the changing climate (Zhou et al., 2007). This means that the more data we obtain from individual wetlands, the more confident we can be about whether they all sequester similar amounts of carbon or whether they are unpredictable.

This study conducts the analysis of soil and root samples from open water surface constructed wetlands in southern Sweden. The wetlands have been constructed 16 years ago and have been planted with emergent vegetation (*Phragmites australis, Glyceria maxima and Phalaris arundinacea)*. The wetlands have been drained and systematic soil/root samples have been cut out and frozen to prevent carbon escape. The samples were analysed to determine whether carbon density differs between different parts of the wetlands and to determine how much total carbon can be stored per unit volume of wetland soil. The soil analyser determines total carbon, however, due to the most likely negligible sources of inorganic carbon in the wetlands, this was assumed to be equivalent to organic carbon.

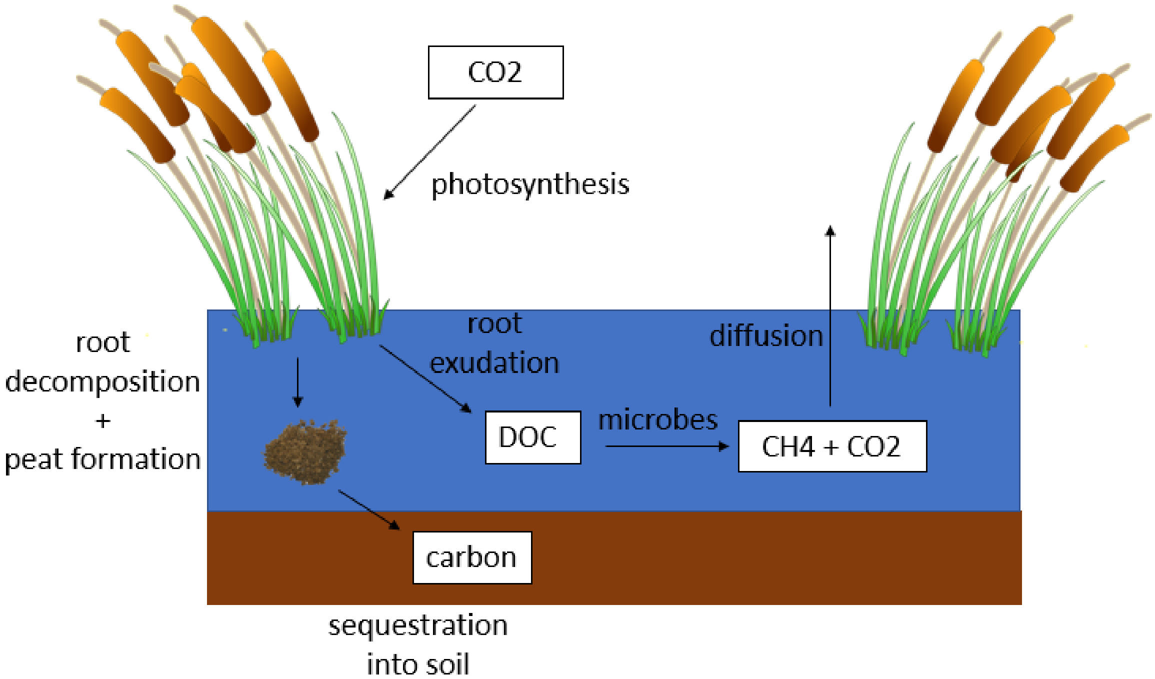

Figure 1: Simplified carbon cycle in wetlands. Macrophytes take in CO_2, release DOC through their roots and form peat when they decompose. The organic carbon forms a peat layer below the wetland and DOC is transformed by microbes into CO_2 (respiration) and CH_4 (methanogenesis) which can escape into the air through diffusion. Carbon sequestration is maximised in wetlands due to formation of peat under water-logged anoxic conditions.

To understand the mechanisms that affect carbon sequestration in wetlands, the following research questions were formulated:

1. Does carbon content increases with proximity to the inlet?
2. Do samples in the southward facing side of the wetland contain more carbon than ones facing the north?
3. What is the carbon density per unit volume and carbon storage per hectare of wetland per year?

Materials and methods

Constructed wetland facility

The experimental wetland facility studied is located in Halmstad in south-western Sweden. It consists of 18 open water flow wetlands which are equal in construction, dimensions and age. The wetlands were built in 2002 and have been functional since 2003. The three wetlands chosen for this study were all planted with the same emergent vegetation (*Pharagmites australis*, *Glyceria maxima and Phalaris arundinacea*). Each wetland is 4 x 10m at ground level and 1.6 x 7.6m at the base, with a 45-degree slope inwards at all sides and 1.2m depth, as can be seen in Figure 3. Over the years, the wetlands have shrunken a little due to sediment build up. The inlet is horizontal and about 10cm above water level and the outlet pipe is vertical at water level so that water flow can be controlled. A faucet at the inlet pipe can be used to adjust water flow. For the first two years the water depth was kept at 0.5m and the remaining years at 0.8m. Flow rates to have decreased since construction from about 5.8 to 3.6 m^3 d^{-1}. The water entering the wetlands is primarily from agricultural areas and is nitrogen-rich, with decreasing nitrogen concentration over time from about 12 to 8 g m^{-3}. The water is first collected in a tank and then is distributed into 3 tanks from which 6 wetlands each are fed, as per Figure 2. The area is dominated by heavy clay and the space between wetlands has been planted with grass. There is no vegetation in the area which provides shade or cover of any sort.

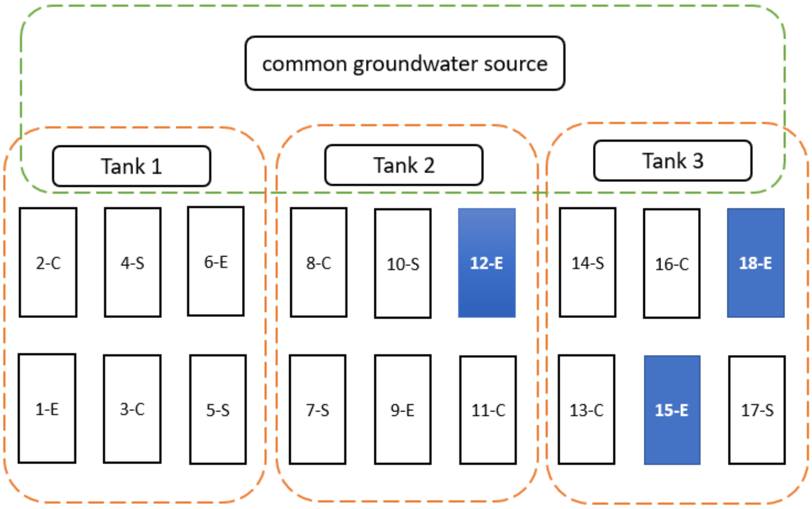

Figure 2: Schematic of wetland facility. C: unplanted control, S: submerged vegetation, E: emergent vegetation. Wetlands in blue were the ones sampled.

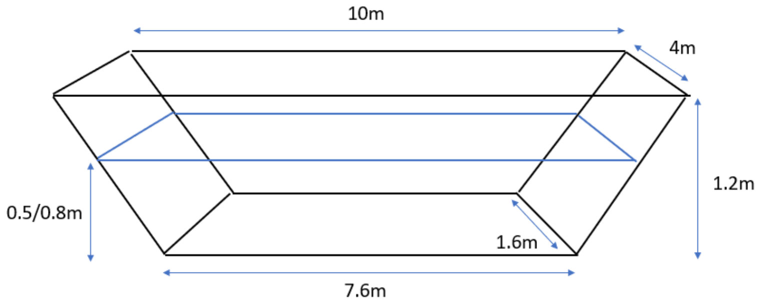

Figure 3: The wetlands were built to the above specifications.

Sampling

The sampling was carried out in mid to late 2020, when the wetlands were approx. 16 years old. Three of the eighteen wetlands were drained and vegetation protruding from the base of the wetland was cut down and removed. The wetlands were measured so that 9 systematic samples from each were taken; 3 at inflow, 3 in the centre and 3 at outflow. Blocks of the peat/soil/root mixture were cut out with dimensions of 20 x 20cm and variable at height due to different root and peat formation (range = 26 - 64, mean = 49cm). The samples were then stored in plastic bags in the freezer until it was time for analysis. For simplicity, the wetlands will be referred to as wetland A, B and C throughout the paper.

Sample preparation

Due to limited oven space only 4 samples at a time could be dried. The samples were first weighed wet and then placed in the oven at 60 degrees for approx. 7 days until consistent dry mass was achieved. A vertical sub-sample (about 100g) was sawed off from each, ground up using a coffee blender and consequently stored in closed plastic containers until analysis.

Sample analysis

Approx. 10g of each sample was placed into aluminium cupcake foils- and burned in a furnace at 550°C for 1 hour (in triplicate). The purpose of this was to burn off all organic material and determine the sample's organic content. Two samples could be done simultaneously due to limited furnace space. Carbon and nitrogen analyses were carried out simultaneously using CHN analyser (FlashEA 1112, Thermo Fisher Scientific, Waltham, US) with aspartic acid as a standard and bypass, and empty tinfoil as blank. Each sample was analysed in triplicate and consisted of 10mg of sample in a tinfoil holder.

Data analysis

The statistical tests used to test for differences between wetlands in terms of carbon and nitrogen was one-way ANOVA and Kruskal-Wallis depending on whether the data was parametric or not, respectively. In conjunction, a posthoc (Tukey HSD) test was used to see where the differences lie. The program used was IBM SPSS. The same tests were used to determine if there is a significant difference between south/north facing samples and inlet/outlet samples. Since only 9 soil core samples were taken from each of the 3 wetlands, the overall number of measurements was low: N = 27. This means there was only 9 samples per sample position altogether (inlet, centre and outlet). Each carbon, nitrogen and organic matter measurement was carried out in triplicate so that the average value for each given sample could be reliable, as things like sand content can alter the readings significantly.

Results

Table 1: Descriptive statistics for variables combined for the three wetlands (SOM = soil organic matter).

Variable	*Mean +/-std dev or median, range*
Carbon %	38.76 +/- 5.37
Nitrogen %	2.41 +/- 0.91
SOM % mass	78.85 +/- 0.91
Height (cm)	49, 26 – 64
Volume (cm3)	19600, 10400 - 25600

Table 2: Descriptive statistics for carbon, nitrogen and soil organic matter densities for the three wetlands combined (values calculated from 27 samples, 9 from each of the 3 wetlands). Soil organic matter densities are approximately twice the carbon densities.

	C (kg/m³)	*N (kg/m³)*	*SOM (kg/m³)*	*kg C/hec*	*kg N/hec*	*C:N ratio*	*Kg C/hec/yr**	*Kg N/hec/yr**
Min	6.540	0.280	13.60811	32701.059	1400.784	9.607	2043.816	87.549
Max	21.747	1.984	43.95761	108735.679	9920.163	30.019	6795.980	620.010
Mean	9.788	0.570	19.94872	**48941.525**	2848.536	**17.181**	**3058.845**	178.034
Median	9.688	0.527	19.63846	48438.884	2637.179	19.108	3027.430	164.824
St dev	3.191	0.377	6.36567	15955.725	1884.985	6.454	997.233	117.812

*assuming 0.5m thickness of peat

Carbon storage

The results for carbon are displayed in Figure 4. Carbon % from the wetlands combined gave a non-parametric distribution ($p = 0.004$), however, inlet, centre and outlet data values gave parametric distribution separately ($p = 0.068$, 0.200 and 0.200 for wetland A, B and C respectively). ANOVA showed no differences in % carbon between the three positions ($p = 0.484$).

Carbon density (kg m^{-3}) when combined gave parametric distribution ($p < 0.05$) however when separated by sample position, inlet and outlet were non-parametric ($p = 0.200$ and $p = 0.113$) and centre values were parametric ($p = 0.025$). Kruskal-Wallis showed no significant difference between the carbon density in different positions ($p = 0.564$).

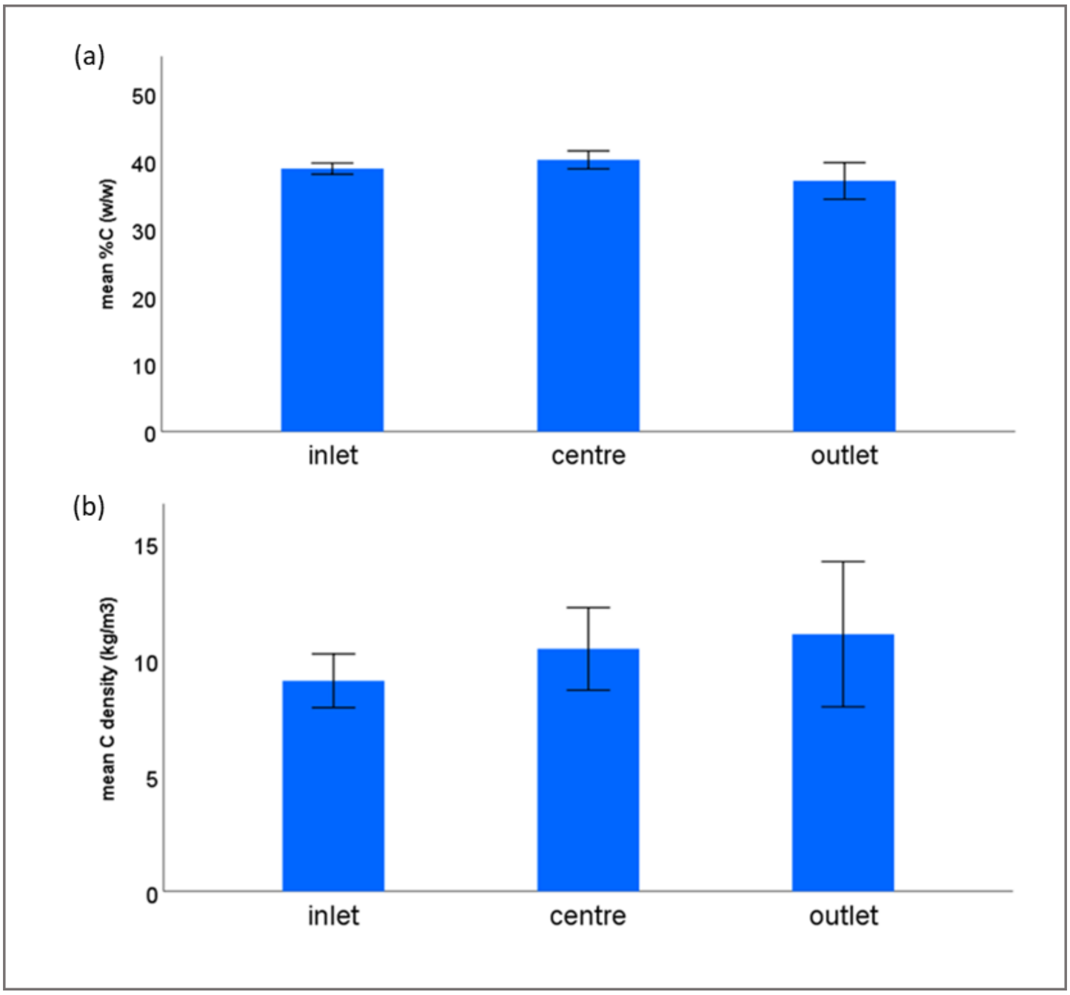

Figure 4: (a) Mean %C (w/w) per sampling position for the three wetlands with +/- 1 SE and (b) mean carbon density by sample position.

Extrapolating the carbon density to a hectare (100 x 100m) with 0.50m thick peat formation, the amount of carbon storage is 48,942 kg, which divided by the 16 years of the wetlands' functioning is 3,059 kg/year.

The below figure is a visual representation of carbon densities across all sample points in the three wetlands. Values in red are in the lowest quartile (up to 8.027kg/m^3) and values in green are in the highest quartile (above 10.3kg/m^3). It can be observed that no clear pattern emerges from this analysis.

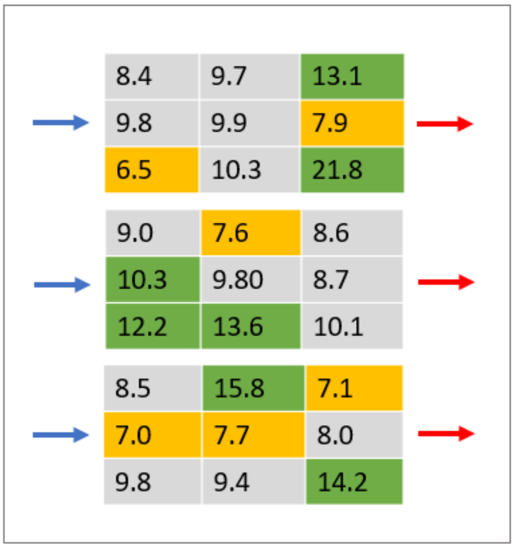

Figure 5: Carbon densities in kg/m^3 across wetland A, B and C, respectively. Values in yellow show the lowest quartile, values in green show the highest quartile.

Nitrogen storage

Nitrogen % from all three wetlands combined together gave a non-parametric distribution (p = 0.010), however, inlet, centre and outlet values separately were parametric (p = 0.200, 0.108 and 0.200 respectively). ANOVA test determined that there is a significant difference between nitrogen content between the three positions (p = 0.040), and specifically between inlet and centre.

Nitrogen density together was normally distributed (p = 0.048) however when divided by sample position, inlet, centre and outlet values were non-parametric (p = 0.200 and p =0.146, p =0.200, respectively). Kruskal-Wallis showed no significant difference between the positions (p = 0.232). The results for nitrogen can be seen in Figure 6 below.

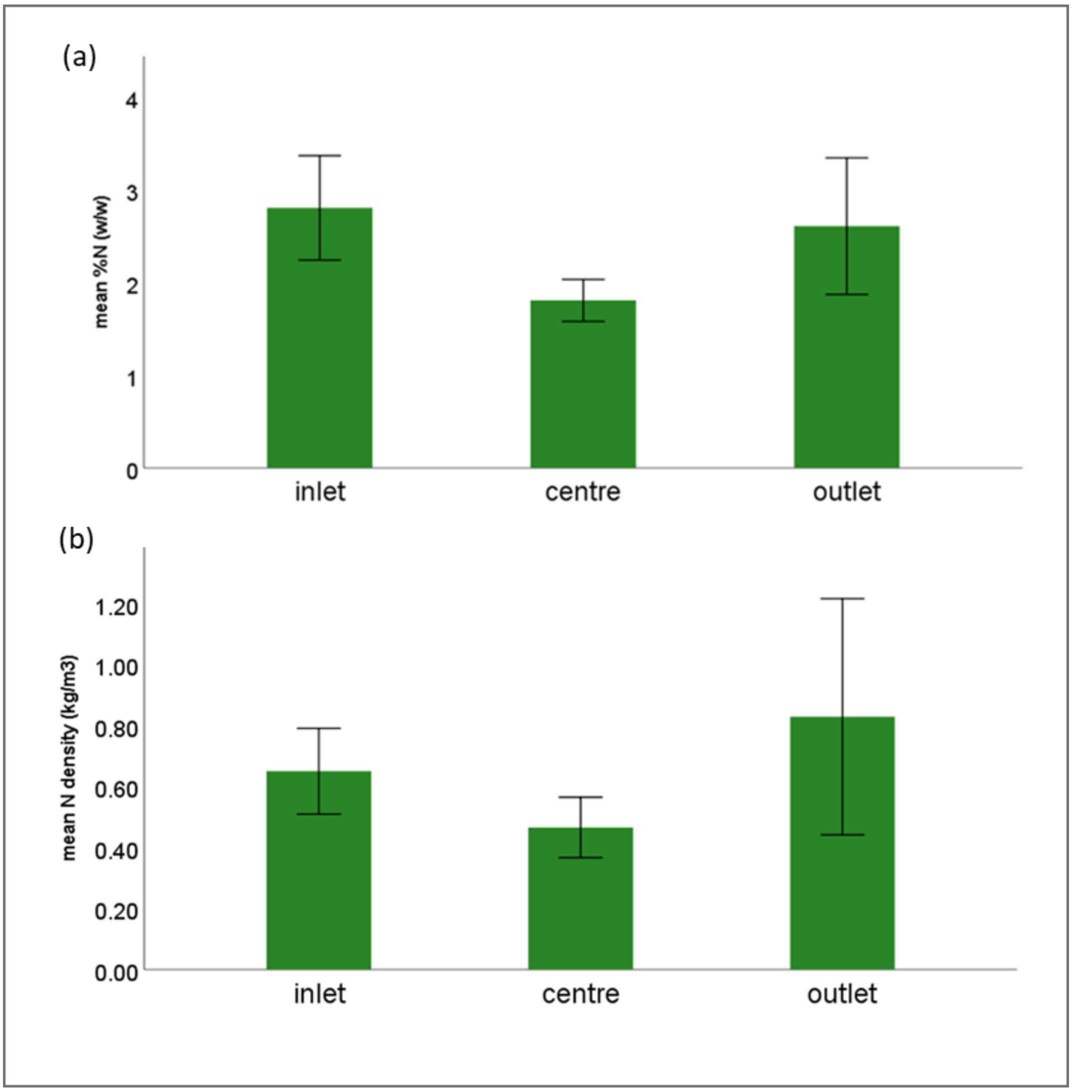

Figure 6: (a) Bar chart of mean %N by sample position and (b) mean %N (w/w) in the three wetlands combined with +/- 1SE.

Extrapolating the nitrogen density to a hectare (100 x 100m) with 0.50m thick peat formation, the amount of nitrogen storage is 2,849 kg, which divided by the 16 years of the wetlands' functioning is 178 kg/year.

Soil organic matter (SOM) content

Average organic % from all 3 wetlands combined gave normal distribution (p = 0.006). Average organic % in all inlet, centre and outlet values combined was not parametric (p = 0.200, 0.194 and 0.061 respectively). Kruskal-Wallis determined that average organic % did not vary between the three positions (p = 0.875).

Average organic matter density was normally distributed (p = 0.002) however inlet, centre and outlet values were all nonparametric (p = 0.200, p = 0.084, p = 0.71 respectively). Kruskal-Wallis determined that there was no significant difference between the sample positions (p = 0.552). The below figures display the findings for SOM content.

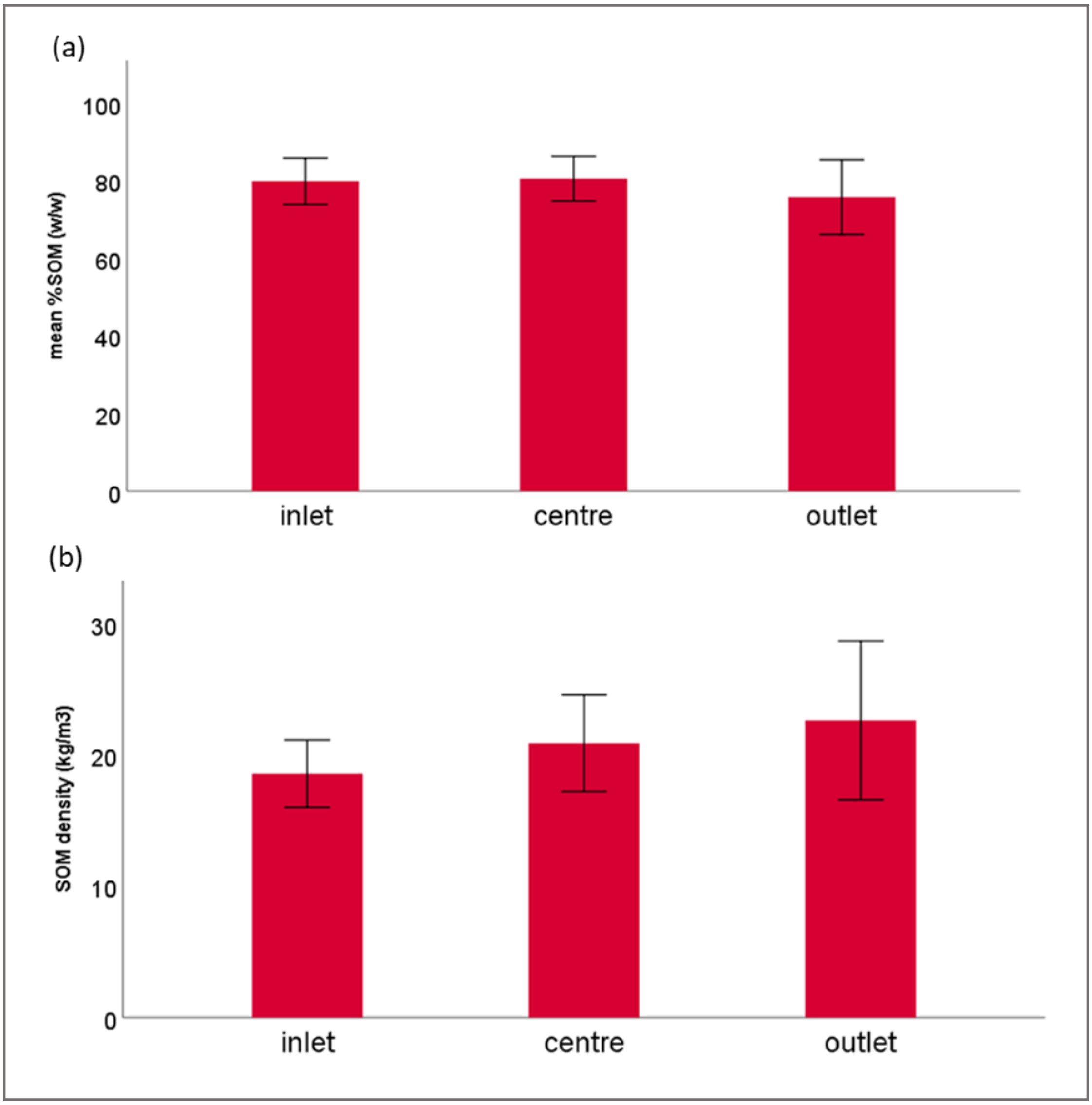

Figure 7: (a) Mean %SOM +/- 1 SE.and (b) SOM density by sample position.

The correlation between %SOM and %C was strong and positive ($r=0.901$, $p < 0.05$).

The correlation between SOM and C density was even stronger and also positive ($r=0.979$, $p < 0.05$). It is apparent from this graph that the carbon makes up roughly half of the mass of organic matter which is in line with the common conversion factor (Mazurczyk et al., 2018). These strong correlations can be visualised in Figure 8 below.

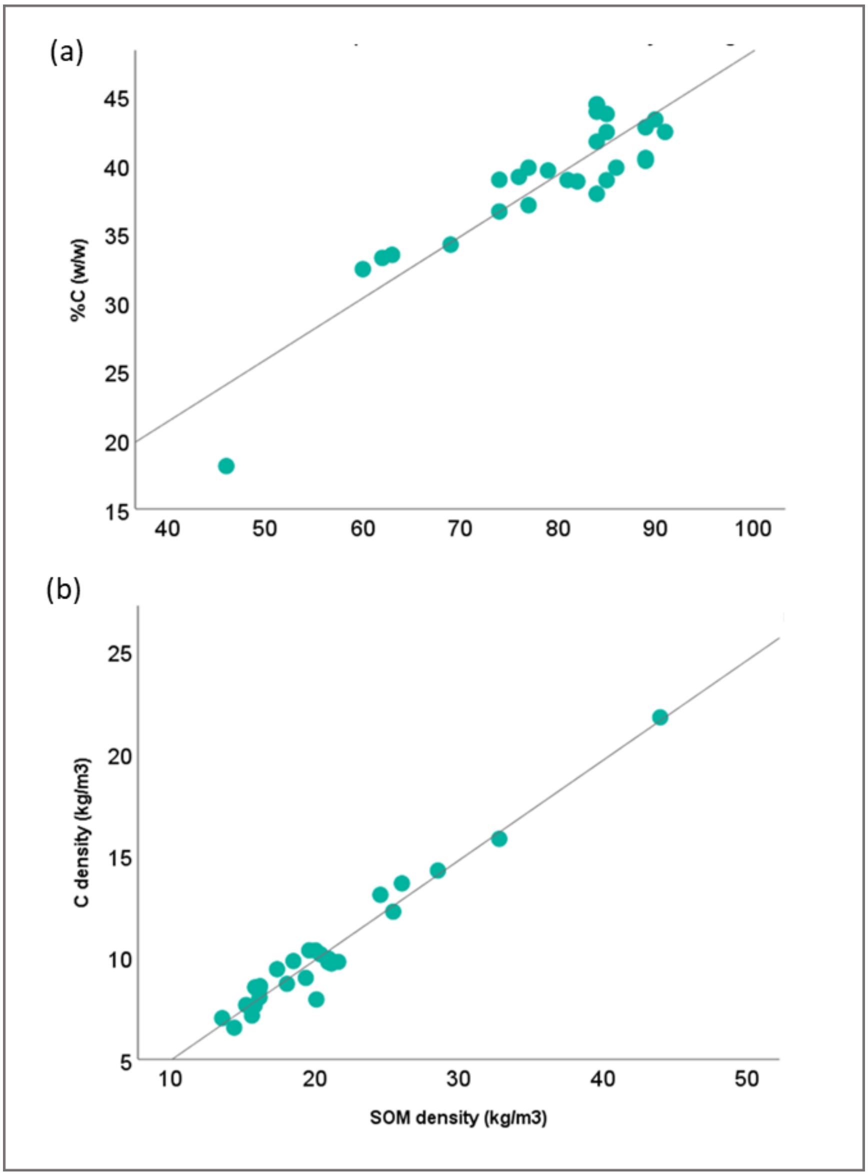

Figure 8: (a) Scatter plot of %SOM and %C and (b) of SOM and C density.

The below figure is a visual representation of nitrogen densities across all sample points in the three wetlands. Values in red are in the lowest quartile (up to 0.38 kg/m^3) and values in green are in the highest quartile (above 0.83 kg/m^3). It can be observed that no clear pattern emerges from this analysis.

0.86	0.37	1.29
0.40	0.48	0.28
0.32	0.45	1.98

0.51	0.38	0.29
0.89	0.44	0.77
0.62	0.53	0.54

0.89	0.83	0.35
0.63	0.42	0.67
0.74	0.31	1.30

Figure 9: Nitrogen densities in kg/m^3 across wetland A, B and C, respectively. Values in green show the lowest quartile, values in red show the highest quartile.

C:N ratio

C:N mass ratios were not parametric (p=0.058). Kruskal-Wallis found a significant difference between sample positions (p = 0.027, df = 2, KW-H= 7.199), specifically between inlet and centre.

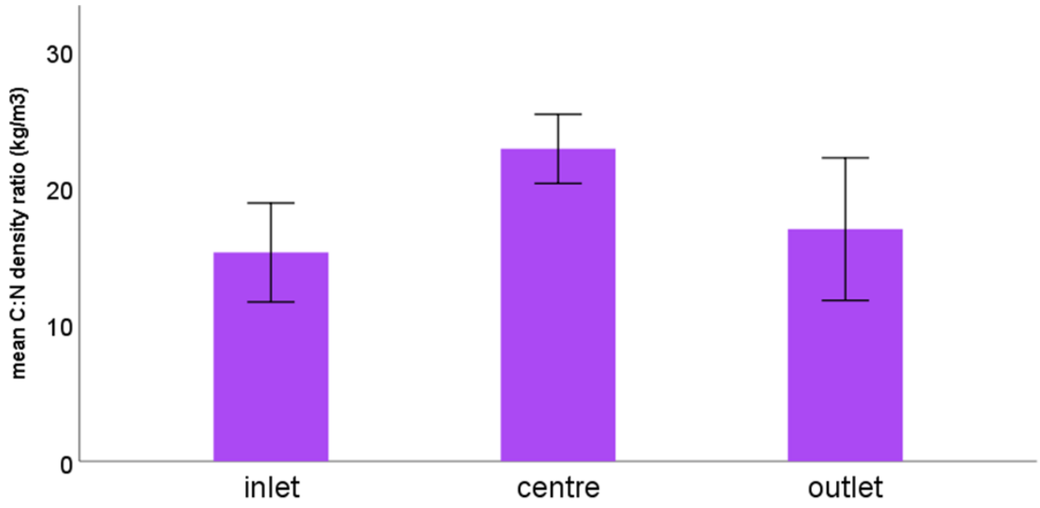

Figure 10: Bar chart of mean C:N density ratios by sample position.

C:N in terms of % w/w did not show a significant correlation (p = 0.346). C:N ratios in term of densities showed a strong positive correlation (r = 0.772, p < 0.05).

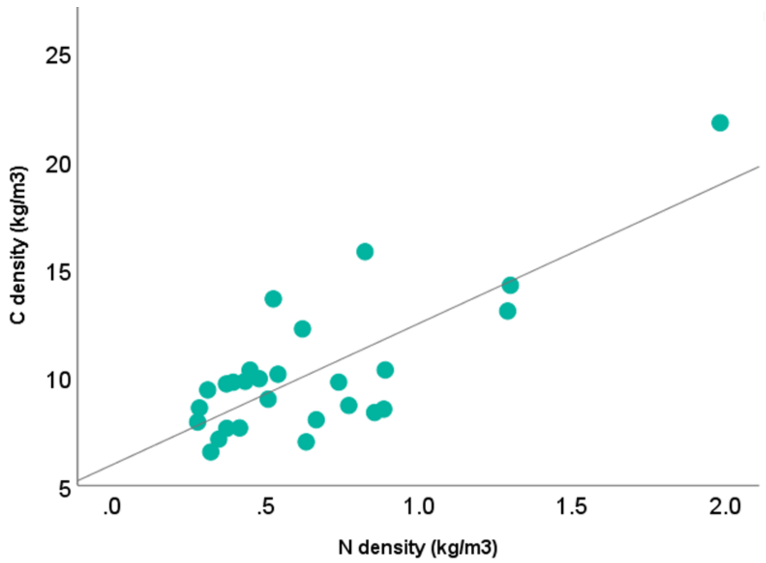

Figure 11: Scatter plot of carbon and nitrogen density.

Sample dimensions and density

Heights (and therefore volumes) were nonparametric (p = 0.200) and presented no patterns in terms of proximity to the inlet. C:N ratio was not correlated with sample density (p = 0.621).

South vs north

Upon examination of the wetland facility through satellite images it was observed that the inlet faces approximately north and the outlet faces approximately south. This meant that the results for this are the same as the ones that examined inlet versus outlet. No further statistical analysis was required.

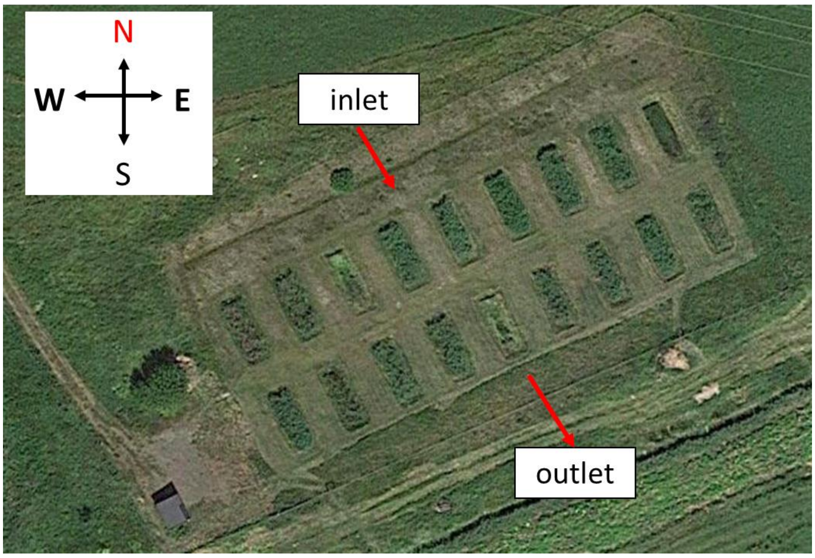

Figure 12: Satellite image of wetland experimental facility. The inlets are approximately at the north side of the wetlands and the outlets are at the south side.

Discussion

It was determined that carbon densities at the inlet and outlet are statistically similar and do not differ between the south and north facing side. There were no trends in nitrogen either, however, the C:N mass ratio was significantly lower at the inlet than at the centre. This means that there was proportionally more nitrogen at the inlet. This combination of results could be explained by the fact that wetlands sequester carbon mainly through plant respiration meaning it is approximately equal throughout the wetland (except for the middle where it may be less dense). Meanwhile, nitrogen concentration is relatively high in the incoming water and therefore the difference is noticeable between sample positions. Perhaps it could also be due to the 'edge effect' whereby more vegetation and soil surfaces at the edges of the wetland allow for more surface area for nitrogen to be stopped and adsorbed onto, rather than in the centre where there is free water. In order to determine whether this is actually the case, a bigger wetland should be examined with densely collected samples. Vegetation cover data was not analysed as part of this study, however, the data is available for future integration. However, it could be useful in future studies for correlation analysis of both carbon and nitrogen storage.

Table 3 below compares carbon densities found during literature research. It can be observed that the carbon densities found in this study are significantly lower than the majority of wetlands studied so far, however, not much lower than lacustrine human impounded wetlands examined by Mazurczyk et al. (2018). This makes sense as both wetlands have been affected by human activity and therefore neither contain as much aboveground biomass as natural wetlands. Yet it is worth noting that Mazurczyk et al. (2018) measured carbon in only the top 20cm of soil, meaning that the carbon storage extrapolated to 50cm could be twice as high. In terms of inland versus coastal, there does not appear to be a set pattern. For example, the studies by Gao et al., (2017) and Han et al., (2010) end up with a similar carbon density average, even though they examine two different types of wetlands. Wang et al. (2016) found drastically lower carbon densities in Changyi, China, than his counterparts in Hainan Island who also studied coastal wetlands. Subcategories of wetlands within coastal and inland also appear to have a large variety depending on their exact position on a water course. It is difficult to say with confidence that dividing wetlands by watercourse position is the best way of classification though. Perhaps other methods of classification could show a clearer pattern e.g. sand content of soil, distance from shore, latitude, etc. However, due to the vast expanse of land that wetlands cover it would be difficult to examine the soil types, geology and ecology of every wetland in order to find meaningful patterns.

Table 3: Summary of carbon densities found in the literature converted to tonnes of carbon per hectare.

Author, year	*Location*	*Wetland type*	*Depth measured*	*Carbon storage (t ha $^{-1}$)*
This study	Sweden	inland (constructed)	0.5m	**Average = 48.94**
Wang et al., 2016	Changyi, China	coastal	1m	**Average = 17.95** Total = 63,730 tonnes
Gao et al., 2017	Hainan Island, China	coastal	1.2m	210.73 estuaries 243.00 muddy beaches 167.41 saltwater lakes 426.57 mangroves 185.88 deltas 297.85 seagrass beds

				Average = 255.24 Total = 5,651,000 tonnes
Han et al., 2020	China	inland	1m	**Average = 271.70** Total = 9,945,000,000 tonnes
Mazurczyk et al., 2018	Pennsylvania, US	inland	0.2m	58.93 lacustrine human impounded 62.45 riverine beaver impounded 68.25 riverine upper perennial 70.11 riverine lower perennial 90.80 riverine headwater complex 150.64 perennial/seasonal depression 86.36 slope **Average = 97.46**
Nahlik et al., 2016	US	inland and coastal	1.2m	345.45 tidal saline 194.23 coastal plains 476.54 east mountains & upper midlands 193.55 interior plains 214.29 west **Average = 284.81** Total = 11,520,000,000,000 tonnes

In general, depth at which carbon is measured determines how much carbon one finds in the soil or peat. This is due to several reasons. First of all, the top layer of soil usually contains the majority of roots which exude carbon during respiration and break down into carbon when they decay. However, in areas where vegetation with longer roots grows, it may be possible that carbon densities are higher in deeper soil levels. Aboveground biomass, when decaying, falls onto the soil surface and also decomposes into the top layer. This means that carbon densities will be higher in the autumn than the summer as this is when most plant decomposition happens (Wang et al., 2016). Wang et al. (2016) noted that in the Changyi wetlands in China vegetation only contributed significantly to the top 20cm in terms of carbon density.

Secondly, in coastal wetlands, the constant deposition and erosion factor has led to contrary interpretations. Wang et al. (2016) suggest that the fast succession rate does not allow carbon to accumulate deeper in the soil before being washed away, and Nahlik et al. (2016) speculates that tidal action helps deposition and subsequent burial of organic matter by ongoing sand and soil influx. It must be remembered though that in order for carbon leeching to occur, water is required. While this may not be a problem for most wetlands, those which dry periodically may contain lower carbon densities than their ever-flooded counterparts, especially in deeper layers (Wang et al., 2016). All four papers from the table which measured carbon in at least 1m depth mentioned that carbon densities decreased either steadily or exponentially with depth. This study did not measure carbon at various depths, however, the samples have been left intact so further analysis is still possible.

Temperatures were another factor mentioned as influencing carbon accumulation. In the palustrine wetlands of China, Lu et al. (2020) noticed that while tropical parts had more vegetation cover, it also speeded up decomposition past the point of being able to withhold it in the soil and sequester it long term. It also speeds up respiration which means that a large portion of the carbon is used up to feed the plant and not much is left behind underground. Nahlik et al. (2016) found similar results in US wetlands, with colder regions storing significantly more carbon. In this context, the wetlands in this study would lean towards colder temperatures, however, one must consider also human disturbance as most likely the biggest factor as none of the wetlands in literature were constructed wetlands and therefore cannot be truly compared. It is doubtful that temperature would have a larger impact than anthropogenic disturbance.

Not only carbon densities should be used as the determining factor of whether to protect and restore wetlands, or whether to let anthropogenic activity take over. When debating conversion of wetlands to cropland, one must consider the bioavailability of the nutrients in wetland soils and whether it allows crops to succeed to a high enough standard to justify carbon storage loss. Mfundisi (2008) determined that although wetland soils had more nitrogen than agricultural land, organic matter and nitrogen does not mineralise as easily as in soils which have been drained for an extended period of time. While the root to shoot ratio increases in both types of soils with increasing nitrogen, it does so to a greater extent in agricultural soils. This suggests that wetland soils have a disadvantage when it comes to high quality crop growth due to smaller roots because the rhizosphere is the area which favours the growth of nutrient cycling bacteria required by plants (He et al., 2019). Therefore, one must remember that while hydrophytes thrive in waterlogged conditions, this may not be the case for crops commonly grown as a food source.

Conversion intro grassland has also been shown to drastically reduce soil organic carbon density by an astounding 68% and nitrogen by 50% in top soils (He et al., 2019). C:N ratios decrease approximately two-fold following loss of wetlands. This is mainly due to increased SOC release through increased soil respiration and means that wetland soils should not be regarded as very fertile as their nutrient storage advantage is either lost or unsuitable for agricultural crops. Also, water levels in current wetlands should be one of the priorities when protecting wetlands to avoid conversion to grassland. The acidic pH of wetland soils impedes the shoot growth of crops as well. Also, water levels in current wetlands should be one of the priorities when protecting wetlands to avoid encroachment of grassland (Mfundisi, 2008).

If conversion to agricultural land does occur, release of carbon can be minimised by using the no-till method (Euliss et al., 2005). Yet still even prairie wetlands have the potential to sequester twice the carbon as no-till agriculture (378 vs 152 Tg) despite making up only 17% of the total prairie area. Restored wetlands have the ability to sequester multiple times more carbon than restored grassland therefore the decision to convert wetlands into grassland should not be easily undertaken as even when reversed the original function cannot be restored to a similar efficiency.

In 2016 in China, analysis of carbon storage and release patterns of coastal wetlands has led to the assignment of a coastal redline beyond which human activity should be minimised (Li et al., 2018 This was because the top 20% of carbon loss was concentrated in 4.2% of the land studied and showed that beyond a certain proximity to the shore, carbon storage is maximised. This perhaps could serve as an example to other countries which have not yet implemented policies to protect their coastlines. In China, this action will most likely be quite significant as in the past over 380,000 ha of coastal wetlands have been disturbed resulting in the release of ca. 20.7 million tonnes of carbon. Determination of soil carbon is most likely a sufficient measure of carbon storage, most confidently in coastal areas, as it has been showed in the past that soil carbon accounts for between 83% (mangroves) and 96% (seagrass beds) of total wetland carbon. Carbon determination in above ground biomass may also prove more difficult due to varying plant height, density and species mixes.

Conclusions

The carbon storage per hectare in constructed wetlands has been found to be much lower than natural inland and coastal wetlands, however, similar to other human impounded wetlands. The low chance of restored wetlands returning to full functionality means that focus should be placed on protecting existing wetlands rather than restoration, especially in colder climates where slower plant respiration allows for longer term carbon sequestration. Future environmental protection policies need to acknowledge the vast amount of carbon storage happening in as little as 6% of the Earth's land which wetlands occupy. The establishment of anthropogenic activity-free zones needs to be backed by scientific data which identifies and prioritises crucial carbon storage areas such as coastal zones. In 2017, Sweden alone emitted 1.5 tonnes of carbon per capita. Even though this figure is among the lowest in the EU, it still takes 6 months for a hectare of wetland to sequester the same amount. Therefore, in order to regain the greenhouse gas balance and slow down its effects on climate change, we must act fast and start preserving and creating wetlands sooner than later, before we hit the point of no return.

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