Trollberget Experimental Area

Working report

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Background

Approximately one million km of ditches have been dug, mostly by hand, in peatlands and wet mineral soils over the last 100 years in Sweden, primarily to improve forest growth. Many ditches have resulted in new areas of productive forests, while others have only led to large-scale wetland degradation. The question now is what to do with this large number of aging forest ditches: restore them to more natural conditions, follow the forest industry's recommendation to increase ditch cleaning activities to maintain high biomass production, or leave them to develop freely? Before any informed decisions can be made, improved knowledge about the implications of the different management options for environmental and climate benefits is urgently needed.

The ditch-digging era in the first half of the 1900s resulted in one of the most widespread human-induced environmental disturbances in Sweden with largely unknown, but potentially large negative, legacy effects on soils and waters. Together with Finland, Sweden has the most drained forest landscapes in the world. When ditches age, ditch cleaning may be required to maintain forest productivity, especially during the regeneration phase in even-aged forestry to keep groundwater low and allow for aeration of seedling roots. However, there is currently limited empirical data about the consequences of this practice for hydrology, water quality and carbon dynamics under Swedish conditions, making this widespread activity questionable. Furthermore, studies from Finland suggest that ditch cleaning can be a large source of sediments, nutrients, and organic carbon to downstream waterbodies and also result in soil organic carbon degradation which has negative consequences for the greenhouse gas (GHG) balance. At the same time, enhanced tree growth following ditch cleaning results in increased uptake of CO_2, which is positive from a carbon balance perspective. Limited holistic knowledge about the overall effects on the environmental and carbon benefits cast doubt on the current strategy. Despite the risks, it has been suggested that Sweden should clean ditches on upwards of 400 000 hectares (out of ca. 2 million hectares of drained forest) to maintain forest production.

An alternative to ditch cleaning is restoration of historically drained peatlands to conditions believed to be more natural. Several governmental authorities, including the Swedish Environmental Protection Agency, the Swedish Geological Survey, and the Swedish Agency for Marine and Water Management argue that peatland restoration is a most effective way to reestablish biodiversity and reduce the likelihood of catastrophic flooding and drought stress in the future. In response to extreme weather-conditions that have occurred in recent years, most recently the exceptionally warm and dry summer of 2018, the Swedish government allocated 300 million SEK for peatland restoration. However, the science underpinning the desired outcomes of peatland restoration is lacking, and in fact, the limited empirical evidence from Sweden does not support that this approach necessarily is the best strategy to alleviate impacts on hydrology, nor that it is beneficial for water quality. Also, it is even more unclear what the climate consequences of such restoration strategies would be as it potentially could have harmful effects on the carbon balance and especially on the production of methane, which is a greenhouse gas with 34 times larger warming potential than CO_2 over a 100 year timeframe. In the worst case, peatland restoration to establish biodiversity could, therefore have many negative consequences on, for example, water quality and greenhouse gas production.

To overcome this lack of scientific knowledge and close the gap between science and management, the Swedish Forest Agency, The County Administration Board of Västerbotten, Holmen Skog, and SLU initiated the set up of the experimental ditch management infrastructure, called Trollberget Experimental Area (TEA) in Krycklan. TEA includes the first fully replicated and controlled experimental catchment system including restored and ditch-cleaned peatlands, as well as historical ditch networks 'left-alone' for free development. This experimental research infrastructure, initiated and funded by European Union LIFE Integrated project "GRIP on LIFE-IP" and later upgraded with funding from the Kempe Foundation and the Swedish Research Council Formas (see Appendix I) is one of the most well instrumented experiments world-wide for answering questions about the legacy and management aspect of historically ditched wetlands.

Trollberget Experimental Area

In the Trollberget Experimental Area –TEA- (64.17´N; 19.85´E) six experimental catchment have been established, with control sites in the adjacent Krycklan Catchment (www.slu.se/Krycklan). Of the six catchments, four have been harvested through clear-cut (CC) in July 2020, of which two were ditch cleaned (catchments DC1 and DC3) and two were left alone (no ditch cleaning, DC2 and DC4) during September 2021. Although we typically refer to the ditch cleaning treatment as "DC", there may be some cases that we use the term "ditch network maintenance" or "DNM". These do not refer to different treatments, but are used interchangeably. In addition, two of the catchments (WR1 and WR2) represent the outlets of a peatland that was restored in the fall of 2020. The restoration was conducted by filling in and blocking all ditches within the peatland.

Pretreatment measurements of all sites started in late November 2018 and have continued up to date. These measurements follow a flow adjusted sampling regime, meaning that during spring flood samples are collected as frequently as twice per week, during the growing season sampling occurs every two weeks, and during winter base-flow sampling occurs once per month. After ditch cleaning, an intensive sampling campaign was conducted in the ditch and no ditch cleaning catchments. Samples were taken twice a day for the first two weeks, every day for one week, three times a week for two weeks and once a week until snow fell (week 38 to week 45 2021).

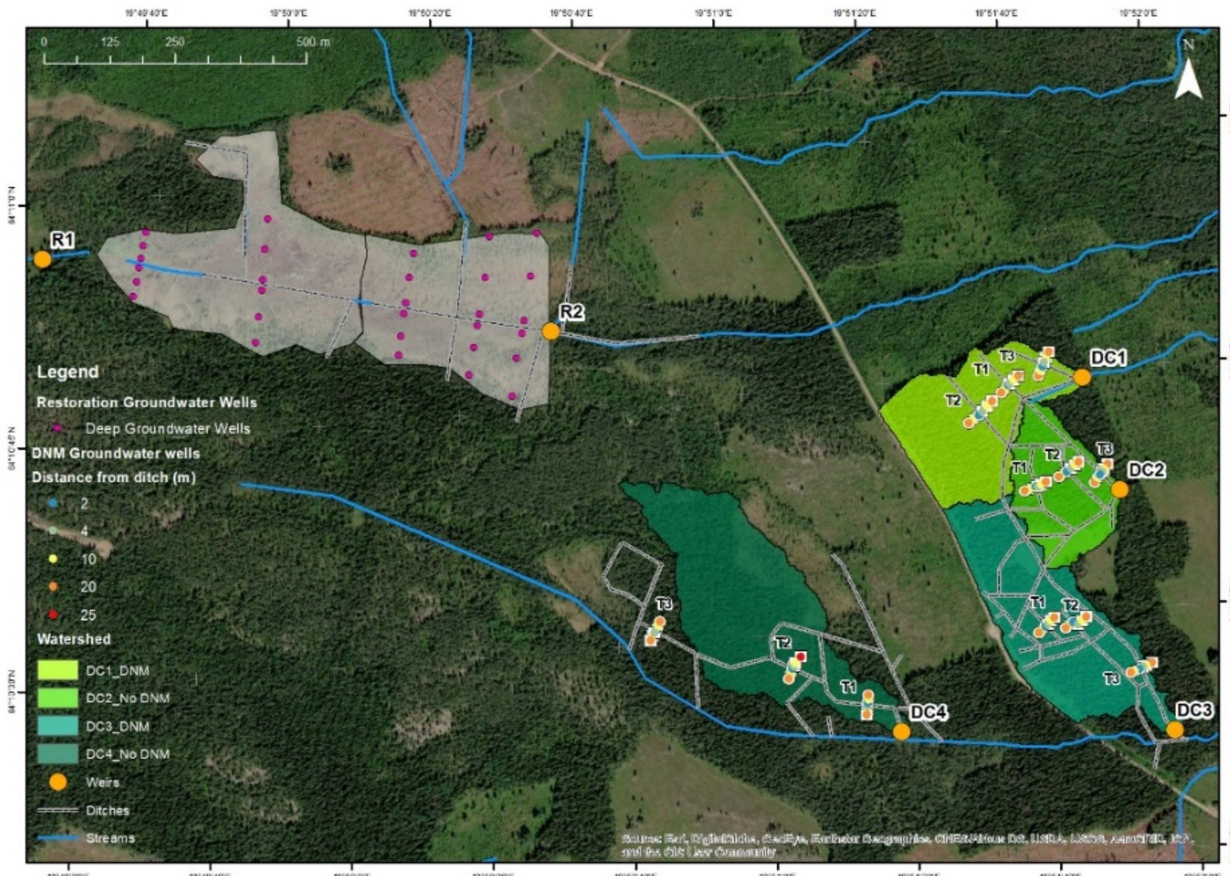

Figure 1. The Trollberget Experimental Area (TEA).

Water table level (WTL)

Water table level (WTL) measurements were set up within the Trollberget wetland restoration areas called WR1 and WR2, which drain into two different directions. There are two transects in WR1 and three transects in WR2 with 6 deep wells in each reaching 4-5 meters below the surface to the mineral soil below. Approximately half of the wells are equipped with Solinst Levellogger pressure transducers to record water levels automatically across the entire year. Water table level has been recorded at hourly intervals from November 2019. For the remaining wells without loggers and to calibrate the pressure transducer measurements to actual depth to water, manual measurements have been done from the top of the well casing to the water level every two weeks during growing seasons.

Stream discharge

Stream discharge has been monitored by recording water level at each gauging station immediately upstream of a V-notch weir with an automatic pressure transducer (hourly intervals). Moreover, manual water level observations have been done to calibrate the automatic water level data. Discharge rating curves have been derived using manual flow measurements. Daily specific discharge time-series (discharge per unit catchment area) were calculated for each catchment.

WTL and Discharge Results

Summary statistics of water level table are summarized in Table 1 and 2 for spring and summer respectively. The results from water table analysis indicated that restoration of peatlands increased storage of water in both wetland restoration sites, WR1 and WR2 and the storage was more pronounced during summer low flow (Figure 2). The drained peatlands experienced a drought in the summer 2020, with the water table dropping to 0.7 m below the ground surface. In spring, a significant increase of the water table occurred in WR1. In contrast, no significant change was observed in WR2, especially at 2m and 10m distances from the ditch after the restoration. It should be noted that the total precipitation during summer 2020 and 2021 were 150 mm and 231 mm, respectively.

Streamflow analysis results revealed significant differences between the hydrographs of two wetland catchments before and after restoration (Figure 3). Restoration practices altered the hydrology response of the two catchments and reduced downstream peakflow by an average 30 percent in the spring snowmelt period following the restoration

Table 1: Descriptive statistics for daily depth to water (m) for the spring water table.

Statistic	Minimum	Maximum	1st Quartile	Median	3rd Quartile	Mean	Variance (n-1)	Standard deviation (n-1)
Before restoration								
WR2-South-20m	-0.621	-0.375	-0.556	-0.544	-0.511	-0.532	0.002	0.042
WR1-South-20m	-0.565	-0.290	-0.540	-0.510	-0.461	-0.486	0.005	0.072
WR2-North-20m	-0.225	0.047	-0.154	-0.106	-0.027	-0.094	0.006	0.076
WR1-North-20m	-0.888	-0.146	-0.626	-0.608	-0.582	-0.599	0.006	0.081
WR2-North-10m	-0.163	0.046	-0.104	-0.065	-0.001	-0.058	0.003	0.057
WR2-South-2m	-0.221	0.100	-0.151	-0.053	0.039	-0.054	0.010	0.100
WR2-North-2m	-0.229	-0.045	-0.174	-0.123	-0.102	-0.135	0.002	0.043
WR1-South-2m	-0.170	0.057	-0.146	-0.069	0.014	-0.066	0.006	0.079
WR1-North-2m	-1.112	-0.064	-1.000	-0.797	-0.731	-0.739	0.118	0.344
After restoration								
WR2-South-20m	-0.108	-0.025	-0.077	-0.066	-0.053	-0.065	0.000	0.019
WR1-South-20m	-0.112	-0.054	-0.080	-0.076	-0.067	-0.075	0.000	0.012
WR2-North-20m	-0.124	-0.017	-0.088	-0.072	-0.058	-0.072	0.001	0.023
WR1-North-20m	-0.095	0.053	-0.001	0.012	0.024	0.008	0.001	0.028
WR2-North-10m	-0.139	-0.034	-0.095	-0.070	-0.061	-0.077	0.001	0.024
WR2-South-2m	-0.105	0.048	-0.040	-0.024	-0.002	-0.020	0.001	0.034
WR2-North-2m	-0.231	-0.092	-0.148	-0.136	-0.112	-0.134	0.001	0.029
WR1-South-2m	-0.155	0.013	-0.124	-0.101	-0.065	-0.095	0.002	0.040
WR1-North-2m	-0.025	0.297	0.037	0.112	0.201	0.120	0.009	0.093

Table 2: Descriptive statistics for daily depth to water (m) for the summer water table.

Statistic	Minimum	Maximum	1st Quartile	Median	3rd Quartile	Mean	Variance (n-1)	Standard deviation (n-1)
Before restoration								
WR2-South-20m	-0.708	-0.078	-0.615	-0.496	-0.141	-0.394	0.059	0.242
WR1-South-20m	-0.713	-0.064	-0.608	-0.559	-0.149	-0.397	0.058	0.241
WR2-North-20m	-0.365	-0.117	-0.232	-0.203	-0.171	-0.211	0.003	0.058
WR1-North-20m	-0.774	-0.005	-0.672	-0.603	-0.077	-0.401	0.095	0.308
WR2-North-10m	-0.497	-0.103	-0.302	-0.214	-0.149	-0.233	0.009	0.096
WR2-South-2m	-0.314	-0.121	-0.252	-0.219	-0.169	-0.216	0.003	0.055
WR2-North-2m	-0.397	-0.142	-0.306	-0.241	-0.189	-0.253	0.006	0.075
WR1-South-2m	-0.266	-0.109	-0.215	-0.183	-0.150	-0.186	0.002	0.044
WR1-North-2m	-0.342	-0.058	-0.277	-0.184	-0.102	-0.193	0.009	0.093
After restoration								
WR2-South-20m	-0.202	-0.049	-0.151	-0.125	-0.097	-0.123	0.001	0.037
WR1-South-20m	-0.321	-0.054	-0.178	-0.139	-0.094	-0.145	0.004	0.063
WR2-North-20m	-0.214	-0.056	-0.151	-0.131	-0.111	-0.132	0.001	0.035
WR1-North-20m	-0.236	0.027	-0.149	-0.093	-0.020	-0.090	0.005	0.070
WR2-North-10m	-0.361	-0.067	-0.240	-0.159	-0.124	-0.181	0.006	0.076
WR2-South-2m	-0.192	-0.018	-0.150	-0.111	-0.077	-0.112	0.002	0.042
WR2-North-2m	-0.345	-0.125	-0.300	-0.235	-0.180	-0.238	0.004	0.066
WR1-South-2m	-0.214	-0.067	-0.189	-0.159	-0.120	-0.153	0.002	0.039
WR1-North-2m	-0.147	0.089	-0.073	-0.033	0.010	-0.034	0.003	0.052

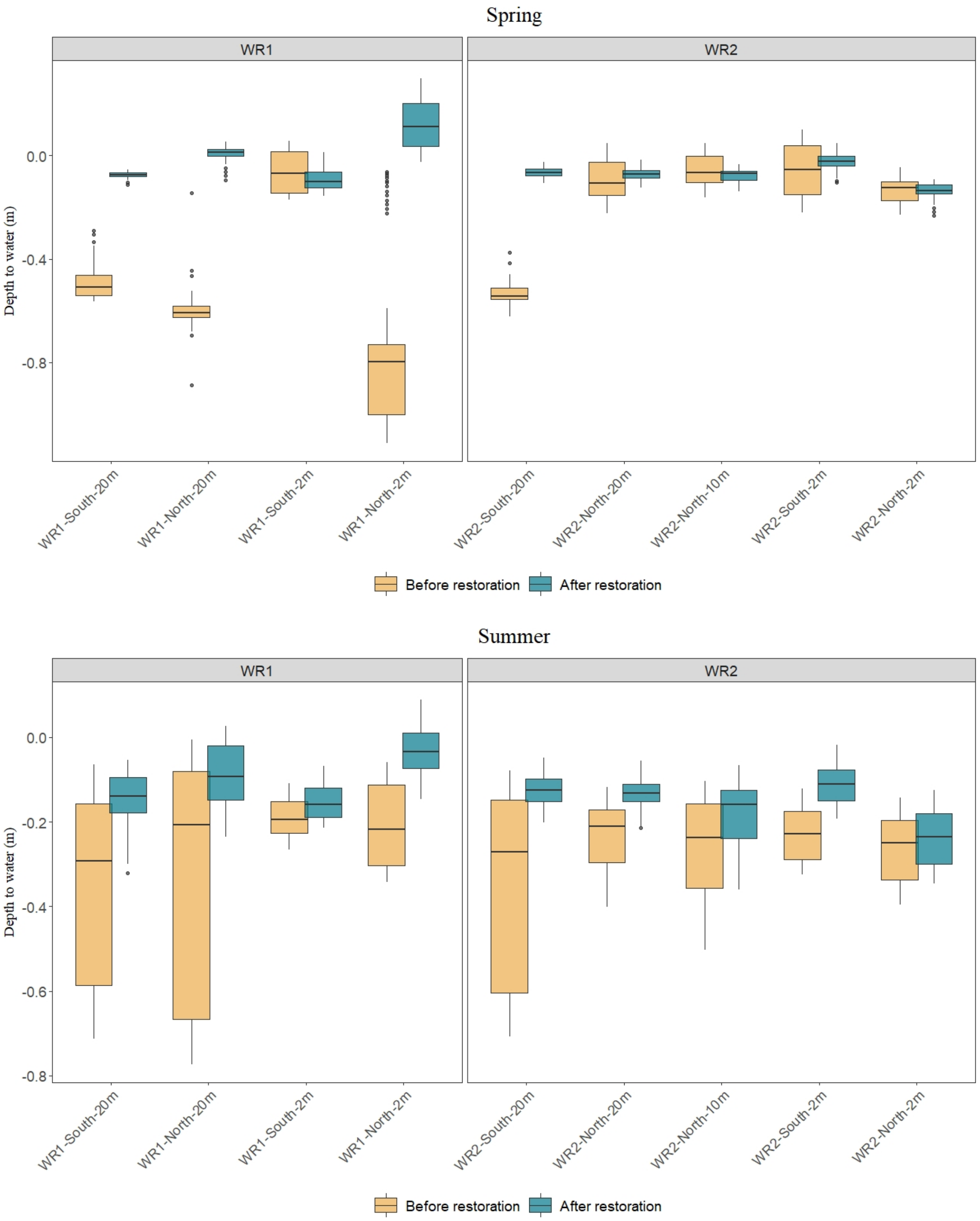

Figure 2. Box plots of the water table depths (meters below ground level or depth to water) for spring (upper two panels) and summer (lower two panels). The boundaries of the boxes represent the 25th and 75th percentiles, the solid line within the box marks the median. The whiskers represent the 10th and 90th percentiles. Note that variation in water table is smaller after restoration.

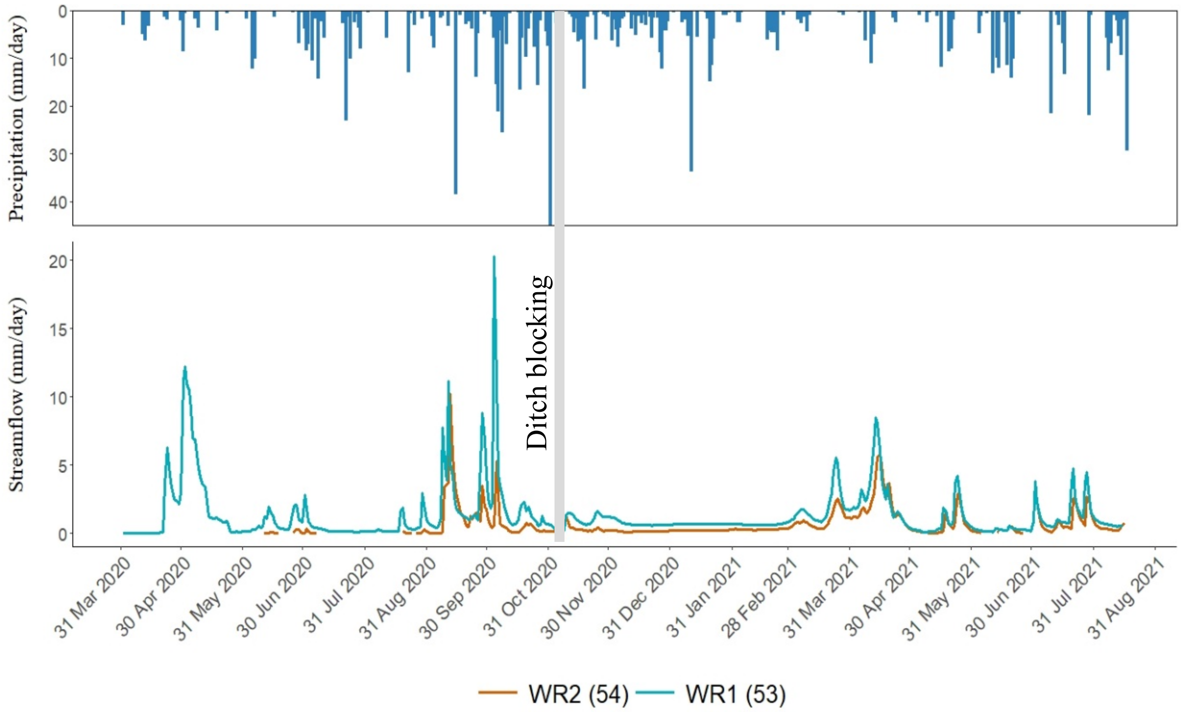

Figure 3. Daily specific discharge measured at two wetland restoration sites (WR2 = red solid line and WR1=blue dotted line). The vertical grey bar indicates the period when the wetland was restored by blocking ditches. Blue bars at top show the precipitation during this time period.

Nutrients

Sampling and Analysis

Runoff water is being collected at the outlet of each catchment and analyzed for dissolved organic carbon (DOC), total dissolved nitrogen (TDN), nitrate (NO_3-) ammonium (NH_4), dissolved inorganic nitrogen (DIN = NO_3- + NH_4), dissolved organic nitrogen (DON = TDN-DIN), and phosphate or soluble reactive phosphorus (PO_4), among many others at the frequency described above. In addition, groundwater water quality was sampled in fall 2020, summer and fall 2021, before and after each treatment. The groundwater well network setup is made up of transects with three wells at three different distances from the ditch (2 m, 10 m, 20 m) on both sides and three transects at each catchment. All infrastructure in TEA can be found in Figure 1.

Statistical differences in nutrient concentrations and depth of groundwater for catchments with and without DNM and treatment timing (before any treatments, after CC, but before DNM, and after CC and DNM) were tested using a two-way ANOVA. A TukeyHSD test ($p = 0.05$) was used in posthoc tests.

Results

All four experimental catchments have responded to both forest harvest and ditch network maintenance (DNM), with an increase in inorganic and organic nutrients in surface water across all catchments (Figure 4). The effects of CC seem to have been larger than that of DNM, and although all four catchments had an additional increase in nutrient leaching to streams after one year, the catchments with DNM had relatively less nutrient leaching than those that did not (the percent change was lower; Table 3). After the CC, the average concentration of PO_4, DIN, and DON was high (7.1 ± 1 µg l^{-1} for PO_4, 108 ± 9.7 µg l^{-1} for DIN and 725 ± 60.8 mg l^{-1} for DON). One year after the CC and just after DNM, all sites had almost doubled their averages for PO_4, DIN, and DON (19.6 ± 1.2 µg l^{-1} for PO_4, 521 ±29.7 µg l^{-1} for DIN and 1 112.0 ± 43.4 mg l^{-1} for DON). While both DIN and PO_4 concentrations showed a similar increase after clear-cut for all four experimental catchments, regardless of DNM treatment, the catchments with DNM seemed to have lower concentrations (16 ± 0.9 µg l^{-1} for PO_4 and 405 ± 38.6 µg l^{-1} for DIN) than those catchments that were left alone (24 ± 2.3 µg l^{-1} for PO_4 and 665.2 ± 39.5 µg l^{-1} for DIN). DON concentrations were also lower in the catchments that had DNM (835 ± 46.7 mg l^{-1}) compared to those left alone (1,456 ± 51.1 mg l^{-1}). However, the catchments that were left alone also showed higher concentrations before clear-cut and before ditch cleaning for DON, thus future analyses should take into account different starting conditions.

Table 3: Average percent change in nutrient concentrations of surface water after clear-cut (CC), and clear-cut + ditch cleaning (DNM).

	Treatment combinations	**PO4**	**NO3**	**NH4**	**DON**	**DIN**	**Average % change of all nutrients**
DC2+DC4	After CC	403,82	59,60	359,98	21,93	202,28	209,52
	After CC, No DNM	375,04	153,17	1106,89	116,54	909,01	532,13
DC1+DC3	After CC	472,33	273,46	416,50	38,06	256,31	291,33
	After CC + DNM	195,58	87,77	432,32	62,82	275,29	210,75

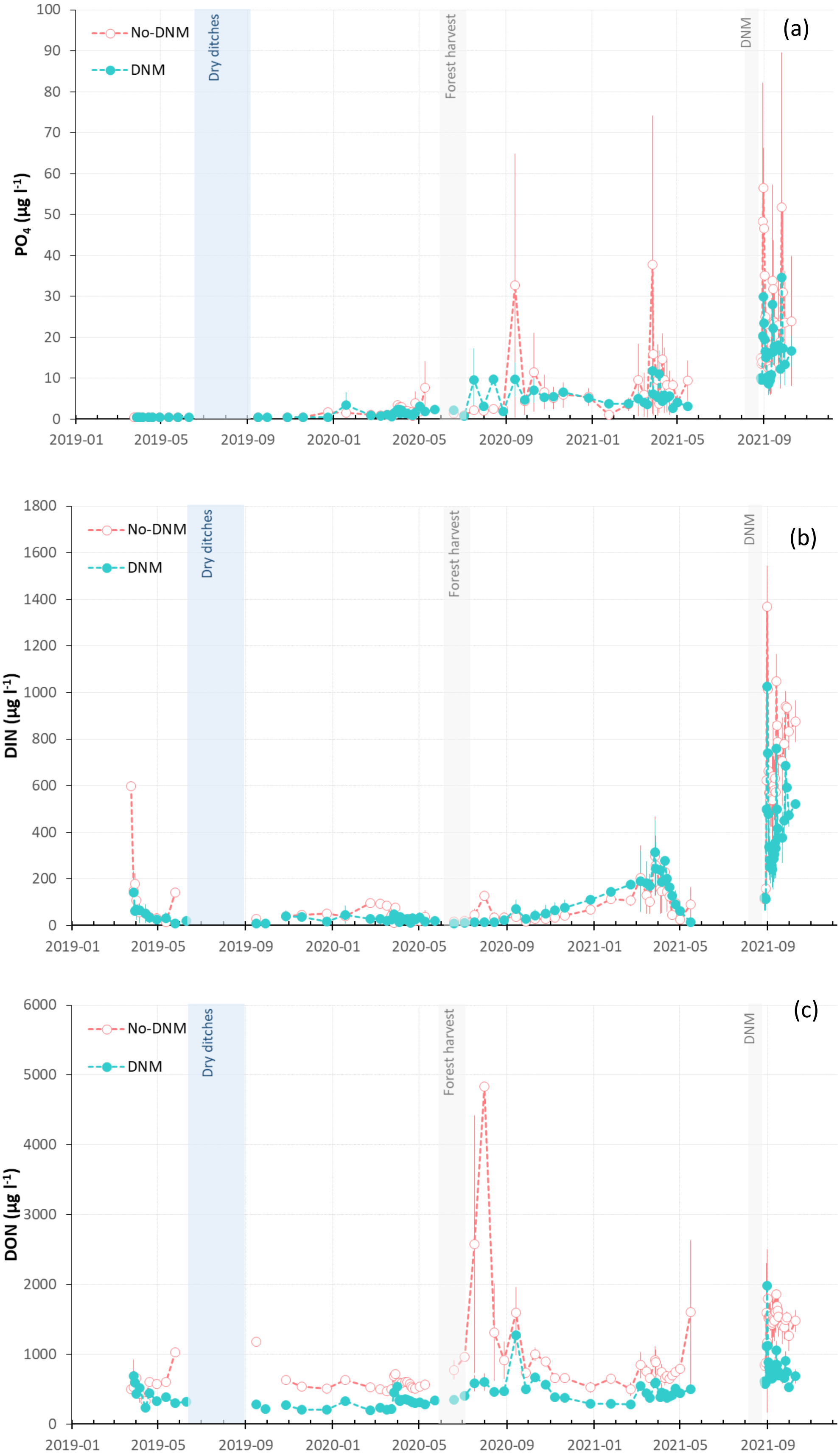

Figure 4 Time series of organic and inorganic nutrients for the period 2019-2021. (a) PO_4, (b) DIN and (c) DON concentration for the four experimental catchments at TEA. Catchment DC1 and DC3 are averaged as the ditch cleaning (DNM) and catchments; DC2 and DC4 are averaged as no ditch cleaning (No-DNM) with ± 1SE. Different shaded vertical bars represent the timing of events (drought) or treatments.

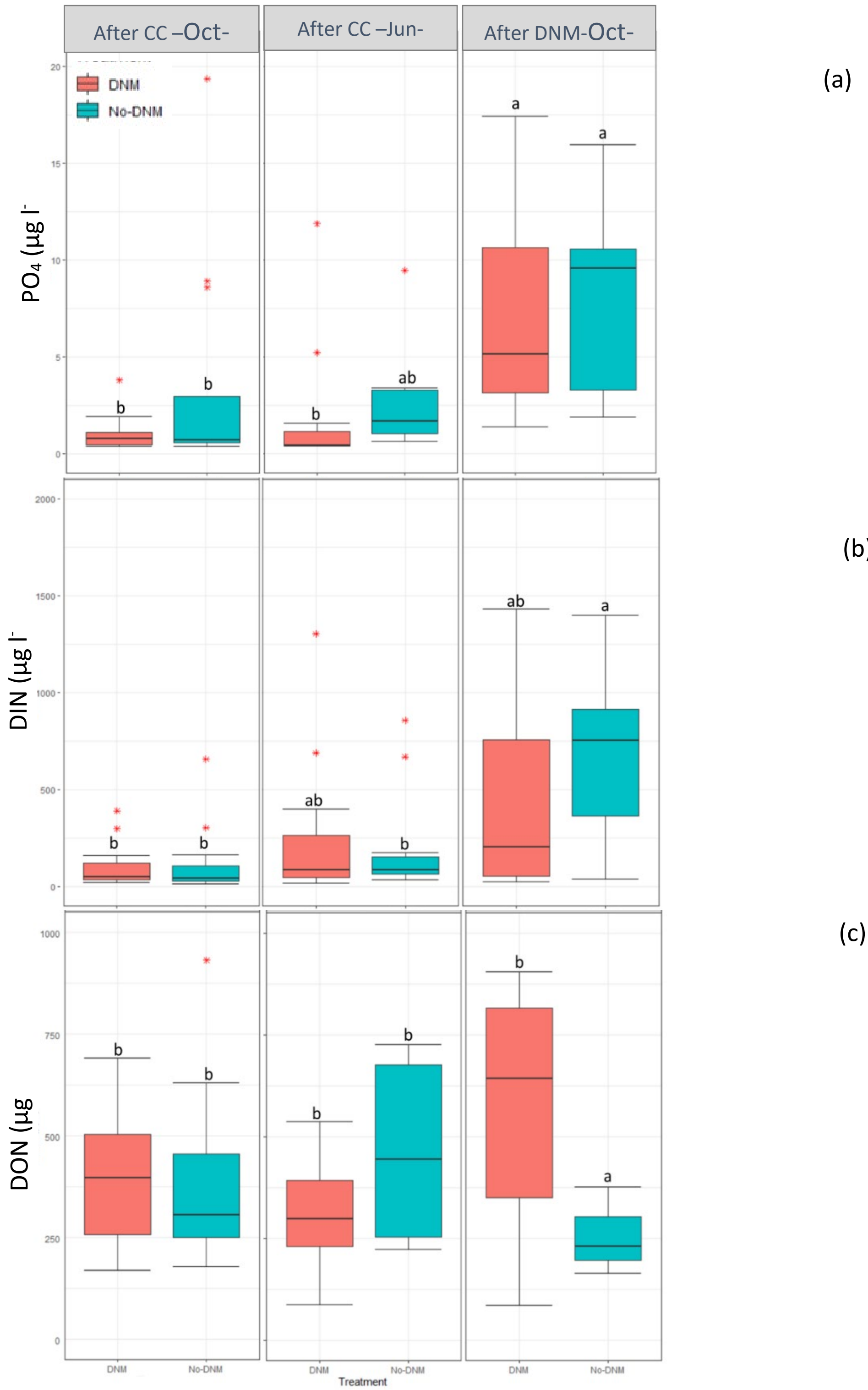

Figure 5. Groundwater concentration differences of organic and inorganic nutrients for three sampling times after different treatments at TEA: (a) PO_4, (b) DIN and (c) DON. DNM shows data combined from six wells placed along three transects in two catchments (DC1 and DC3); No-DNM shows data combined from six wells placed along three transects in two adjacent catchments ((DC2 and DC4). **PLEASE NOTE** that DNM actually only occurred in the panel on the far right called "after DNM;" all other panels show the pre-treatment time period. Different letters indicate significant differences between all treatments (DNM) and treatment timing (Before any treatments, after CC, but before DNM, and after CC and DNM; $p<0.05$). The boundaries of the boxes represent the 25th and 75th percentiles, the solid line within the box marks the median. The whiskers represent the 10th and 90th percentiles.

Groundwater nutrient concentration increased significantly after ditch cleaning for PO_4, but did not show a difference between the catchments that where cleaned and those that were left alone. DIN groundwater concentration also increased significantly after cleaning and showed higher concentrations for those catchments that were left alone compared to those that have had been cleaned. Lastly, DON only showed lower concentrations for the catchments that were left alone (Figure 5). Groundwater levels increased significantly after CC and after ditch cleaning, but showed no difference between the catchments that had been cleaned and those that were left alone (Figure 6).

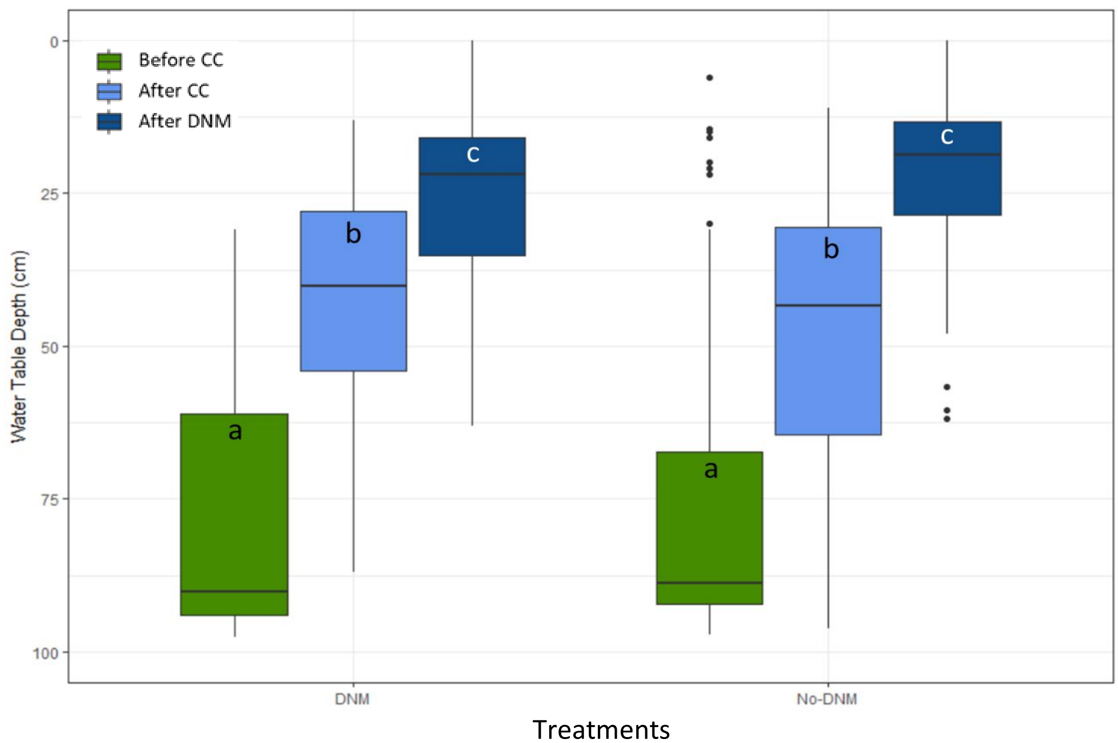

Figure 6. Groundwater level differences between DNM and No-DNM after different treatments in TEA. DNM shows data from six wells (three different distances from ditch), within three transects in two catchments (DC1 and DC3); No-DNM shows data from six wells (three different distances from ditch), within three transects in two catchments (DC2 and DC4). Separate small letters indicate significant differences between all treatments and campaign time ($p<0.05$). Notice groundwater table depth is shown in cm and with inverse y-axis. The boundaries of the boxes represent the 25th and 75th percentiles, the solid line within the box marks the median. The whiskers represent the 10th and 90th percentiles.

Wetland restoration

There were significant differences between WR1 and WR2 for PO_4 ($p < 0.01$), DIN ($p<0.001$) and DON ($p<0.05$). For PO_4 and DIN, the median concentration was higher for WR1 (0.9µg l^{-1} and 23.5µg l^{-1}, respectively) than for WR2 (1.76 µg l^{-1} and 64.99 µg l^{-1}, respectively). For DON the pattern was opposite, being WR2 (493.3 µg l^{-1}) higher than WR1 (428.9 µg l^{-1}) (Figure 5).

Preliminary results do not show significant effect ($p<0.05$) from the wetland restoration (i.e. comparing pre-and post- restoration) for PO_4 and DON, however for WR2 there was a significant decrease ($p<0.05$) in NH_4 before restoration (28 µg l^{-1}) than after restoration (19.9 µg l^{-1}). Although not significant, the median concentration of PO_4 and DIN is higher before restoration than after.

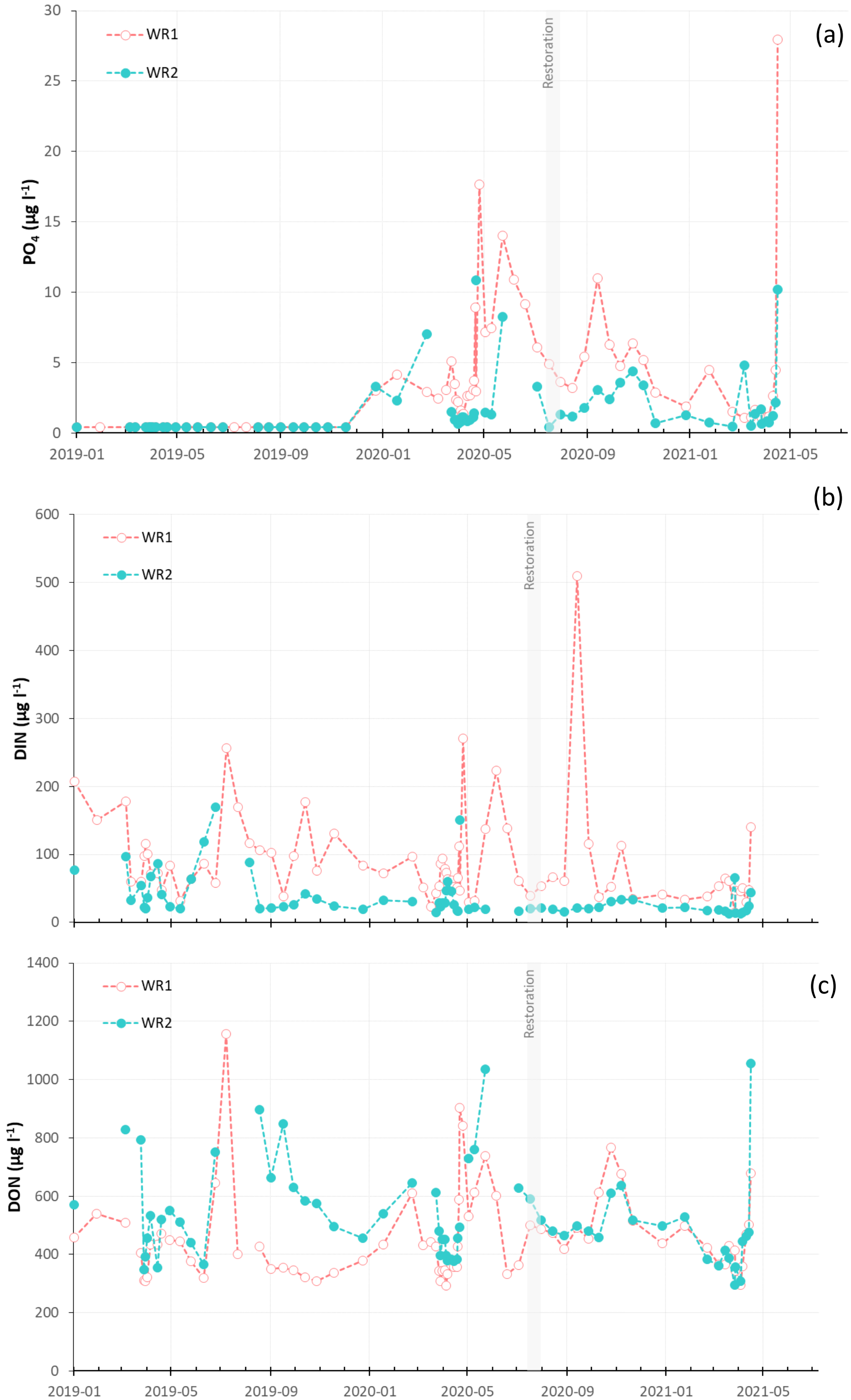

Figure 1. Time series of organic and inorganic nutrients for the period 2019-2021. (a) PO4, (b) DIN and (c) DON concentration for the two outlets (WR1 and WR2) of the restored wetland at TEA. Grey vertical bar marks the time that restoration was completed.

CARBON

Sampling and analysis

Sampling for concentrations of dissolved organic carbon (DOC), dissolved inorganic carbon (DIC) and methane (CH_4) were conducted in the six TEA catchments following the general sampling protocol. DOC samples were collected in 250 mL polyethylene bottles and transported dark and cold to the lab. DOC analysis was performed using a Shimadzu TOC-CPCH (Laudon et al., 2011). Samples for DIC and CH_4 were taken by using a 10 mL syringe and injecting 5 mL of ditch water into a sealed 22.5 mL glass vial. The vials were prior to sampling evacuated and filled with N_2 at atmospheric pressure and prefilled with 0.1 ml 85 % H_3PO_4 to shift the carbonate equilibrium toward CO_2. Headspace CO_2 and CH_4 concentrations were analyzed on a gas chromatograph equipped with a methanizer and flame ionization detector (GC-FID). In-situ ditch concentrations of DIC and CH_4 were calculated from headspace concentrations considering water and headspace volumes and temperature-dependent equations. For further details concerning DIC and CH_4 sampling and analysis see Wallin et al. (2010; 2014). Statistics are based on used Dunn´s test, a non-parametric test for non-normally distributed data that tests for differences among median values.

Results

Wetland restoration

There were clear differences in aquatic carbon chemistry between the two wetland restoration sites, WR1 and WR2 (Figure 7). For DOC, the median concentration was higher ($p<0.001$) in WR2 (31.7 mg L^{-1}) than in WR1 (24.6 mg L^{-1}) during the full study period. For DIC and CH_4 the pattern was the opposite, with higher median concentrations observed in WR1 (6.4 mg L^{-1} and 103.7 µg C L^{-1}, respectively) than in WR2 (3.3 mg L^{-1} and 7.5 µg C L^{-1}, respectively) ($p<0.001$). Notable is the much higher (about ten times higher) median CH_4 concentrations observed in WR1 than in WR2.

Initial and preliminary effects of the restoration (i.e., comparing pre- and post- restoration) were identified among the different C components. Median DOC and CH_4 concentrations at WR1 increased (29% and 86%, respectively; p=0.002) during the period after the restoration. In contrast, no change in DOC occurred after the restoration at WR2, whereas both median DIC and CH_4 concentrations decreased (-24% and -56%, $p<0.05$). On a seasonal scale, the median seasonal concentrations post-restoration were compared with median seasonal concentrations pre-restoration. At WR1, an increase in the median DOC concentrations post-restoration was observed during summer (28%, p=0.048), autumn (61%, p=0.01) and winter (40%, p=0.04). Median CH_4 concentration underwent a significant increase after the restoration during spring (180%, p=0.01) and especially during summer (356%, p=0.02), when it peaked from 272.6 to 1243.2 µg L^{-1}. No significant change in median pre- and post-WR DIC concentrations was observed at WR1. On the other hand, post-restoration DIC concentrations decreased (-44%, p=0.02) during summer at WR2. Finally, CH_4 median concentrations decreased significantly (-73%, p=0.045) in the autumn following the restoration.

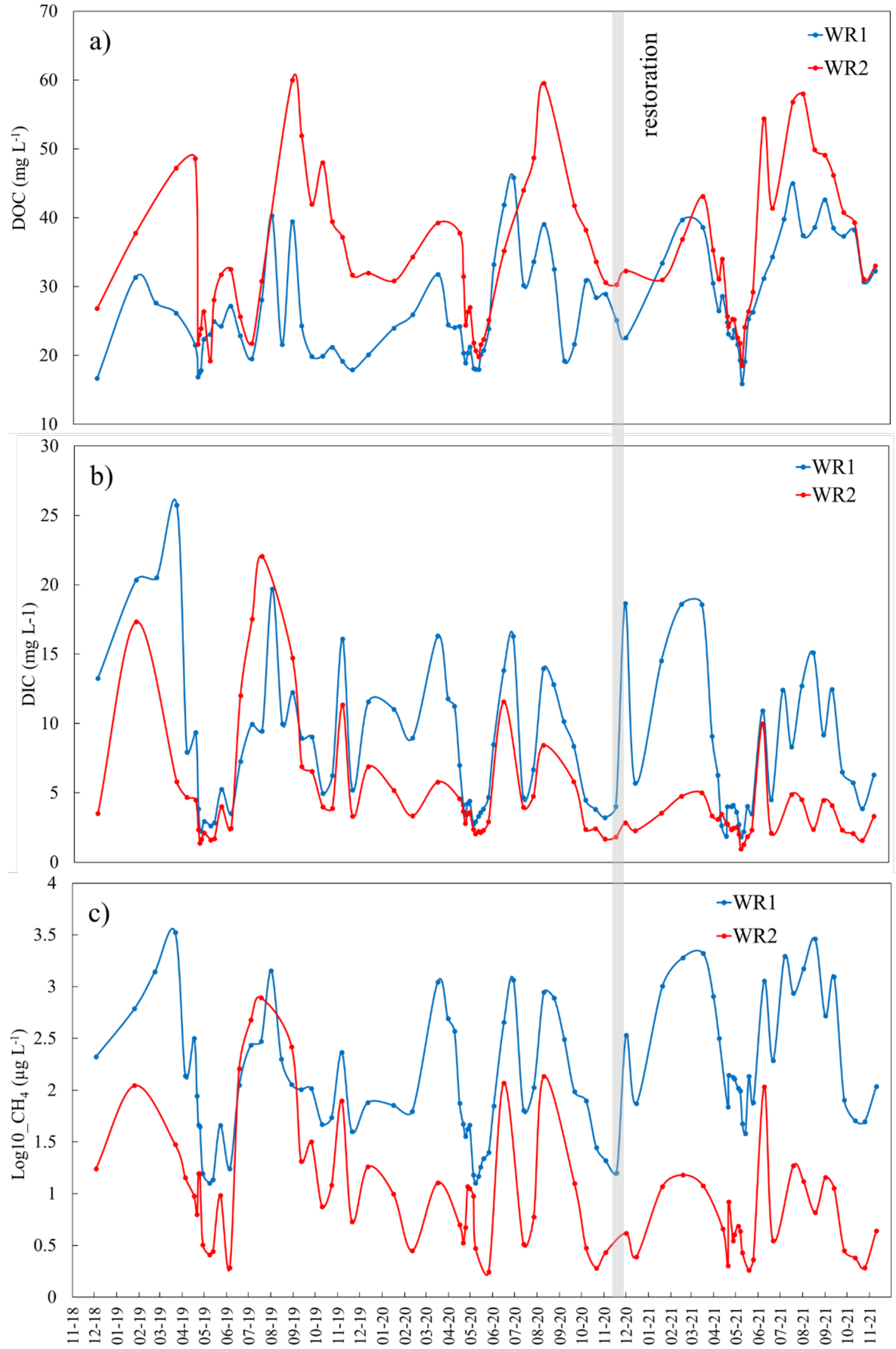

Figure 7. Time series of a) DOC, b) DIC and c) CH_4 before/after restoration for the WR sites of the TEA. The grey bar indicates the period when the wetland was restored by filling all ditches upstream of the sampling point (reference date: November 27th, 2020, when the restoration was concluded).

Ditch cleaning effects on Carbon

For the ditch cleaning part of the study, two different operations were conducted, first a clear-cut forest harvest that was conducted in July 2020 and secondly, the ditch cleaning that was made in September 2021. For DOC, it was evident that concentrations increased in response to the clear-cut harvest (Figure 8). Median DOC concentrations increased at all four sites of the clear-cut (DC1, 48%, DC2, 53%, DC3, 75% and DC4, 44%) ($p<0.0001$). Median spring DOC concentrations increased after the clear-cut in DC2 (44%), DC3 (45%) and DC4 (18%) ($p<0.0001$) compared to pre-harvesting conditions but not in DC1. At DC3, the median DOC concentrations also increased during the fall (160%, $p=0.01$) and summer (96%, $p=0.03$). Extremely high DOC concentrations were measured after the clear-cut in DC4, which peaked at 292 mg L^{-1} directly after the harvest. For DIC, post-harvest median concentrations increased at DC1 (30%, $p=0.004$), DC2 and DC3 (26% and 54%, respectively, $p<0.0001$). Median DIC concentrations increased during the spring following the clear-cut at DC2 (20%) and DC3 (23%) ($p<0.05$) but decreased at DC4 (-24%) ($p<0.05$). In addition, after the clear-cut, median autumn DIC concentrations increased (67%) at DC3 and decreased (-24%) at DC4 ($p<0.05$). Very high concentrations of DIC were observed in DC4 during the summer over the whole study period (14.8, 19.5 and 21.5 mg L^{-1} in the summer of 2019, 2020 and 2021, respectively).

Following the ditch cleaning, an immediate response in DOC concentrations was observed with increased DOC at all sites (Figure 8), including the control sites that were not cleaned (i.e., DC2 and DC4). In DC1 and DC3, where the ditches were cleaned, post-ditch cleaning DOC median concentrations increased by 29% and 48% ($p<0.0001$) with respect to the period before ditch cleaning but after the clear-cut. This relative increase in DOC was lower compared to the increase in median DOC concentrations observed in the ditched that were not cleaned, DC2 (55%, $p<0.0001$) and DC4 (109%, $p=0.0013$). During the days immediately after DC was conducted, DOC concentrations peaked at 103.5 mg C L^{-1} in DC1, 98.6 mg C L^{-1} in DC2 and 76.2 mg C L^{-1} in DC3. No clear and significant effects in median DIC concentrations were detected at the sites that were ditch cleaned.

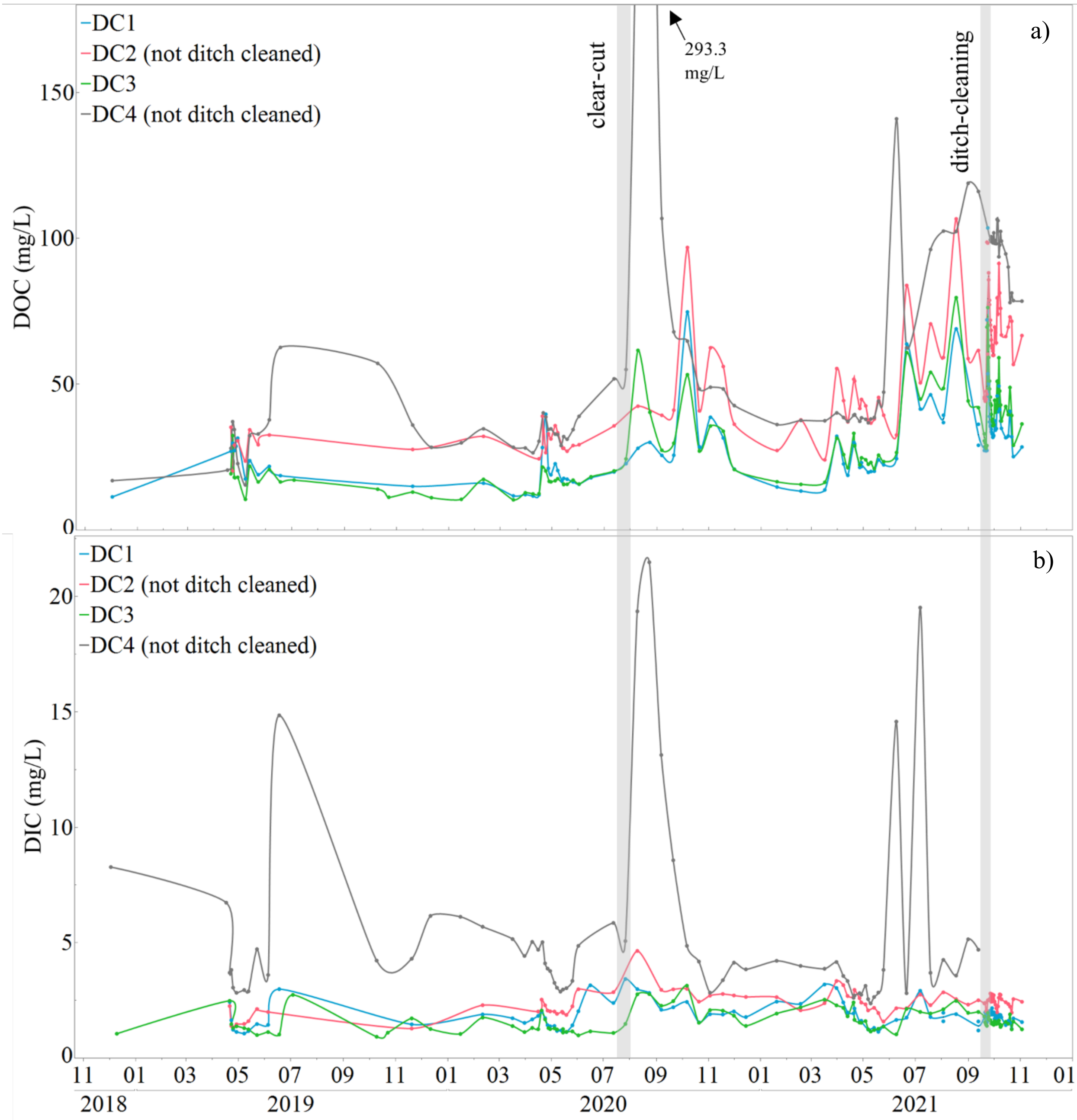

Figure 8. Time series of a) DOC and b) DIC concentrations before/after clear-cutting and ditch cleaning for the DC sites of the TEA: DC1-4. The grey bars indicate the period when the clear-cutting (July/August 2020) and the ditch cleaning (September 2021) were conducted.

Mercury

Sampling and analysis

The sampling of total mercury (THg) and methyl-mercury (MeHg) included the six TEA catchments followed largely the other sampling with two wetland restoration were conducted in autumn 2020 (WR1 and WR2), two that were harvested in summer 2020 and ditch cleaned in autumn 2021 (DC1 and DC3), and two sites that were only harvested in summer 2020 (DC2 and DC4). Concentrations of THg and MeHg in these six catchments were also compared to concentrations in untreated reference forest catchments in Svartberget/Degerö (Ref). Sampling of THg and MeHg in ditches, were conducted at around 15 occasions each year.

As THg and MeHg are highly sensitive for contamination, we used trace clean methods in field and laboratory. Single use gloves were used when collecting water for THg and MeHg analysis. Ditch water were collected in Teflon (THg) and high-density polyethylene (MeHg) bottles, after rinsing in ditch water three times. Samples were stored dark and cool during transport to laboratory. Samples for THg analyses were preserved with concentrated suprapur HNO3, and samples for MeHg analyses were directly delivered to Umeå University. THg concentrations were analyses at IVL and MeHg concentrations were analysed by the chemistry department at Umeå University.

Results

Preliminary results indicate that concentrations of both THg and MeHg were elevated, at least during some periods, in some of the harvested areas after harvest, while concentrations in reference catchments were staying at a base line level (Figure 9 and 10). Concentrations of MeHg were rather high (up to 6 ng/L) in some of the harvested areas during late summer of 2020 and 2021. The ditch cleaning (autumn 2021) may potentially worsen the situation by increasing the mobilization of THg and MeHg into the ditch channel. Further sampling will evaluate the effect of ditch cleaning on THg and MeHg concentrations and exports.

Wetland restoration were conducted in the R1 and R2 catchments in late autumn 2020, just before the first snow. The wetlands filled up with water during the spring flood in 2021. No clear wetland restoration effect could be detected from the preliminary data so far (Figure 11 and 12). However, there is a tendency towards increasing concentrations of THg in the restored catchments. Our hypothesis is that MeHg, rather than THg, will increase after wetland restoration, due to elevated MeHg formation in flooded soils. However, also THg mobilization may increase if more Hg is mobilized from soils during flooding.

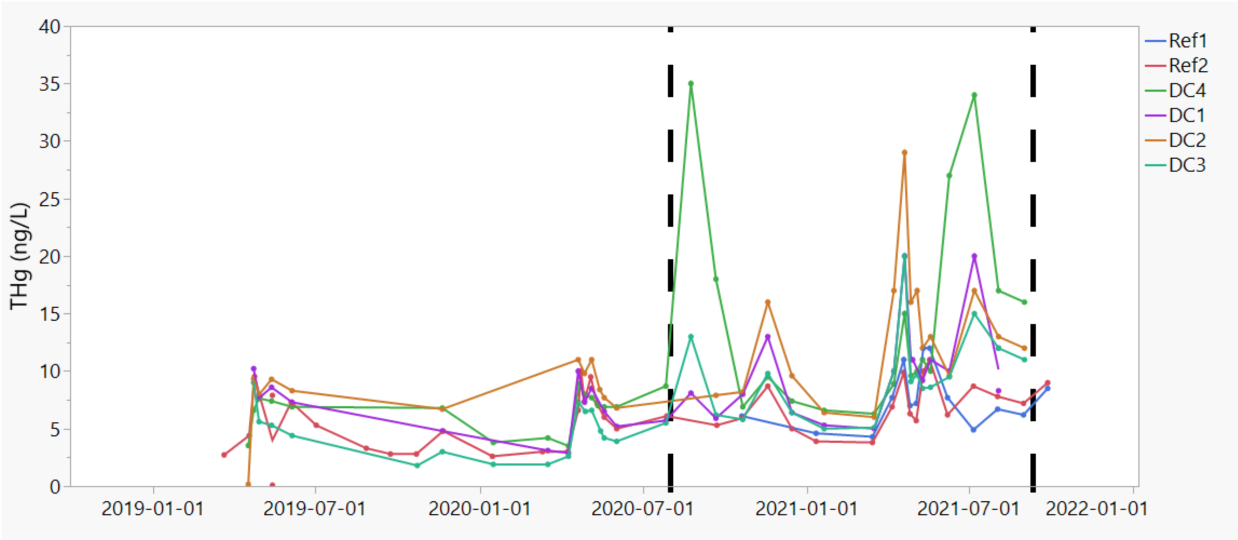

Figure 9. Concentrations of THg in the harvested and ditch cleaned catchments (DC1 and DC3), the harvested only catchments (DC2 and DC4), and the reference catchment with growing forest (Ref1 and Ref2). The earlier line shows the timing of the forest harvested and the later line show the timing of the ditch cleaning.

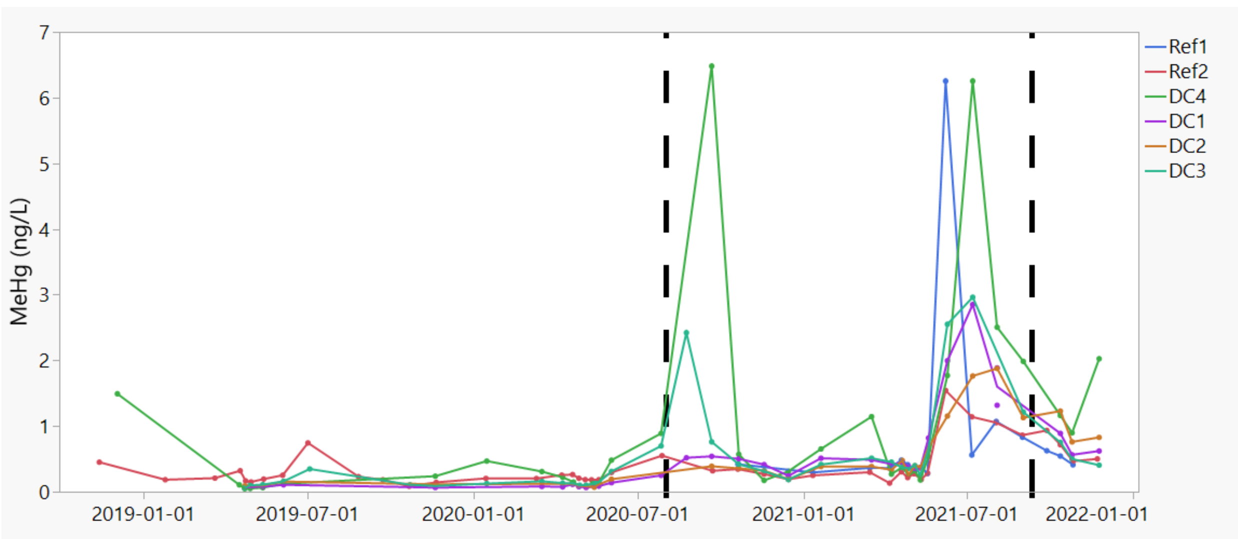

Figure 10. Concentrations of MeHg in the harvested and ditch cleaned catchments (DC1 and DC3), the harvested only catchments (DC2 and DC4), and the reference catchment with growing forest (Ref1 and Ref2). The earlier line shows the timing of the forest harvested and the later line show the timing of the ditch cleaning.

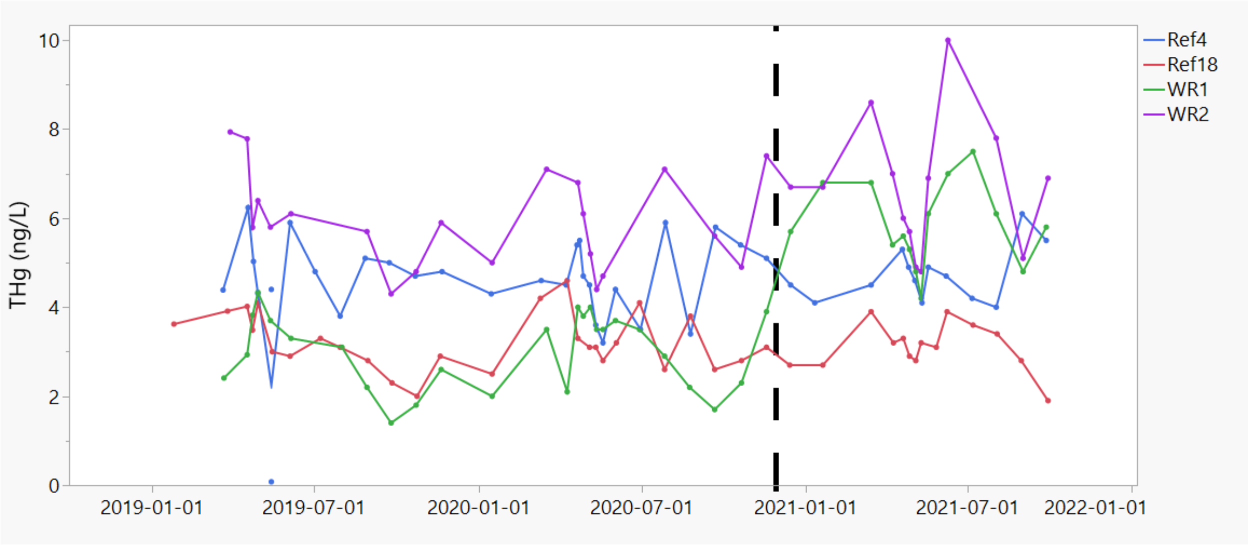

Figure 11. Concentrations of THg in the catchments were wetlands were restored (R1 and R2), and the reference catchment with none restored wetlands (Ref4 and Ref18). The stretched line shows the timing of the wetland restoration.

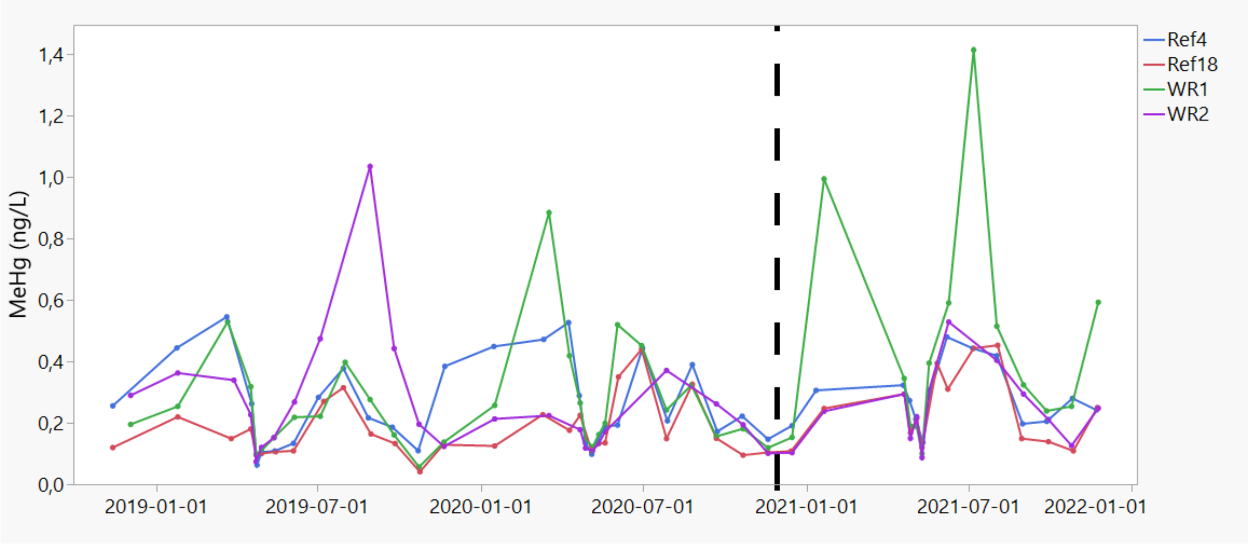

Figure 12. Concentrations of MeHg in the catchments were wetlands were restored (R1 and R2), and the reference catchment with none restored wetlands (Ref4 and Ref18). The stretched line shows the timing of the wetland restoration.

Appendix 1. Other external funding for TEA

Funding	Project title, description (short)	Amount (SEK)	Amount (Euro)	Duration
International (Water JPI)	SOSTPRO - SOurce STream (headwater) PROtection from forest practices: what are the costs and benefits, and how best to do it?	336 000	31 584	Ongoing
Water JPI 2018 Joint Call on "Closing the Water Cycle Gap – Sustainable Management of Water Resources" - Via FORMAS	Reducing the Effects of FORest Management to inland WATERS: REFORM WATERS	3 00 000	280 352	Ongoing
FORMAS	Evaluate drainage impacts on C and GHG balances of forested peatlands in boreal Sweden, 2017-2019	2 800 000	263 200	Ongoing
FORMAS	Optimizing digital tools for balancing forest productivity and water quality when managing drained boreal forests	2 982 471	280 352	Ongoing
FORMAS	Using wetland restoration as a tool to mitigate runoff extremes	3 000 000	282 000	Ongoing
FORMAS	How does rewetting affect the greenhouse gas balance of drained peatland forests in boreal Sweden?	2 966 001	278 804	Ongoing
FORMAS	Impact of forestry on greenhouse gas release from streams	2 996 001	281 624	Ongoing
Skogssällskapet	A field test of the "DitchFlowTracker" to prioritize forest drainage ditch maintenance for sustainable forest management"	426 000	40 044	Finished
Kempe foundation	Development of an experimental platform for studies of ditch cleaning, wetland restoration and riperian zone protection along streams.	3 000 000	282 000	Ongoing
Skogssällskapet	Reducing forestry related greenhouse gas emissions from stream ecosystems by smarter riparian buffer zones	1 996 902	187 709	Ongoing
Skogssällskapet	Towards climate-responsible forestry: Assessing the greenhouse gas balances of drained and restored peatland forests in boreal Sweden	1 952 944	183 577	Ongoing
FORMAS	Forest ditch cleaning and its effect on mobilization of an old soil carbon store	2 998 647	275 529	Ongoing
Stiftelsen Oskar och Lili Lamm	Wetland restoration and its effect on brownification of surface waters	2 400 000	220 522	Ongoing

Kempe foundation	Four post-doc funding for ditch-cleaning and restoration studies in TEA (stipends)	2 400 000	220 522	Ongoing
Formas	Barriers and Opportunities to Managing forest ditches for climate – Research, Up-scaling, & Legislation (BOM)	16 000 000	1 470 147	Ongoing
Naturvårdsverket	Ditch cleaning versus wetland restoration – Effects on mercury in water	4 989 609	458 466	Ongoing
Skogssällskapet	BIO-REACT: Biochar reactors to purify forest runoff water in managed peatland forests - efficiency of novel biochar feedstocks	1 019 628	98 093	Ongoing
Total external funding		**54 244 575**	**5 036 432**	

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