Norwegian University
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**Master's Thesis 2021 60 ECTS**

# Effect of macrophyte removal on CO2 emissions in the river Otra, Norway

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# Abstract

The main goal of this study is to examine how macrophyte removal affects $CO_2$ emissions in rivers with a secondary aim of quantifying $CO_2$ concentrations and emissions in the river over the course of 24 hours. The study was performed in river Otra in Norway which flows through the valley of Setesdalen. $CO_2$ emissions were measured by floating chambers with infrared gas analyzers (IRGA) with logging abilities. The study uses before and after control impact (BACI) design. Large amounts of macrophytes (submerged growth of *Juncus bulbosus*) were removed between the 15th and 22nd of June 2020 from the impact site, but not from the control site. $CO_2$ emissions and other measurements were done in both the control and the impact site before, during and after macrophyte removal. There were no significant differences in $CO_2$ emissions between the Control and Impact site. Neither before, during nor after macrophyte removal. Even though there was a slight $CO_2$ emission increase after removal it was probably due to factors like water-level, -velocity, and -temperature fluctuations. As secondary studies we also 1) measured $CO_2$ emissions in the river every 2 hours for 24 hours, 2) measured the gas transfer velocity in the river. These studies helped us better understand the fluxes in the river.

**Keywords**: macrophyte, carbon dioxide ($CO_2$), before after control impact (BACI), gas transfer velocity.

# 1 Introduction

Rivers and lakes are significant sources of carbon dioxide ($CO_2$) emissions. It´s crucial for us to accurately estimate the fluxes between freshwater surfaces and the atmosphere so that we can understand the global carbon budget and calculate climate change variation in the future.

Almost all inland waters (96%) are $CO_2$-oversaturated relatively to the concentration in the atmosphere. Most (82%) have at least twice the concentration of the atmosphere. There is generally a lack of direct $CO_2$ flux measurements. Even though there is a decent number of measurements for some regions of the planet, such as Scandinavia and the United States of America, there are many freshwater ecosystems significantly contributing to the aquatic carbon (C) flux that remain poorly surveyed in terms of $CO_2$ partial pressure ($pCO_2$). Some of the issues stopping us from collecting robust $CO_2$ flux estimates are; 1) incomplete spatial coverage

of $pCO_2$ sampling locations 2) difficulties in estimating the surface area of inland waters and 3) calculating gas-transfer velocities (Regnier et al., 2013). $CO_2$ emissions from inland waters have been estimated to be 2.1 Pg yr-1. As a comparison, the estimated land carbon sink is 2.6 Pg yr-1 (Bastviken et al., 2015).

This study focuses on $CO_2$ emissions from rivers, and more specifically, how removal of the species *Juncus bulbosus* affects $CO_2$ emissions. *J. bulbosus* is a macrophytic cyperid native to Europe and North Africa (Moe et al., 2013) that can grow very dense stands and its expansion has been linked to elevated free $CO_2$ levels in the water (Svedang, 1990). It belongs to the family *Juncaceae* that grows mostly in freshwater but also on land. The last 4 years, it has spread across big parts of Northern Europe and the populations are becoming denser. Because of this, many big areas in rivers and lakes are covered in *J. bulbosus*. That can be a serious problem since this macrophyte can hinder human activities like fishing, transport with boat and even clogged water system tubes. The plant can also change the currents in the river causing sand and mud to accumulate, destroying the quality and quantity of potential spawns for fish (Lakseelver, 2019).

*J. bulbosus* is very effective at $CO_2$ uptake. It is capable of absorbing $CO_2$ from the water as well as sediments. An enzyme called PEP-Carboxylase helps the plant with $CO_2$ fixing. Because of this strategy the species is well adapted to environments with low $CO_2$ concentrations (Schneider & Demars, 2020). Most natural rivers are highly $CO_2$-supersaturated with large fluxes between the water and the atmosphere. Soil and terrestrial organic matter that end up in the river are substantial $CO_2$ inputs in many rivers (Guerin et al., 2006). Flowing water systems emit more $CO_2$ than lakes. Lakes store a lot of $CO_2$ in their sediment and reservoirs create large wetlands in their upstream tails that store a lot of $CO_2$ as well (Regnier et al., 2013)

It seems that *J. bulbosus* grows mostly in springtime, with a growth decline in the summer, which is an unusual trend. That is possibly due to more available $CO_2$ in the water early in the spring compared to in the summer and the strategy of *J. bulbosus* is to avoid competition with other primary producers. Though no conclusion can be made it is also possible that through photosynthesis and utilizing $CO_2$, *J. bulbosus* increases pH in the water which in turn suppresses its growth by shifting the inorganic carbon pool towards $HCO_3$-, which the plant can´t utilize (Svedang, 1990).

The goal of this study is to examine; 1) whether and if so how macrophyte removal in rivers affects $CO_2$ emissions; 2) as a secondary study, how $CO_2$ concentrations and emissions change in the Otra river over the course of 24 hours.

I expected that; 1) macrophyte removal would cause slightly higher $CO_2$ emissions since the plants use $CO_2$ in the water for photosynthesis 2) higher $CO_2$ concentrations during the night due to little to no photosynthesis and lower $CO_2$ concentrations during the day due to more photosynthesis.

# 2 Materials and methods

## 2.1 Study area

The study was performed at different locations in river Otra which flows through the valley of Setesdalen and is in Rysstad kommune (Fig. 1). It is the largest river in the southern region of Norway. It is quite acidic, with twelve hydroelectric power plants, as well as many large lakes along the river. Brokke is the largest power station of Otra. It started operating in 1963 and has to this day an average annual output of 1,5 TWh. The powerplants change the Otra Rivers hydrology in various ways. In the winter, a higher human demand for electrical energy results in increased water flows. That causes water-level fluctuations and lack of ice cover. One of the ecological consequences of significant flow regime alterations in this case, is mass development of *J. bulbosus*. The altered flow regimes also create non-natural habitats where an opportunistic species like *J. bulbosus* will manage to grow (Rørslett, 1988).

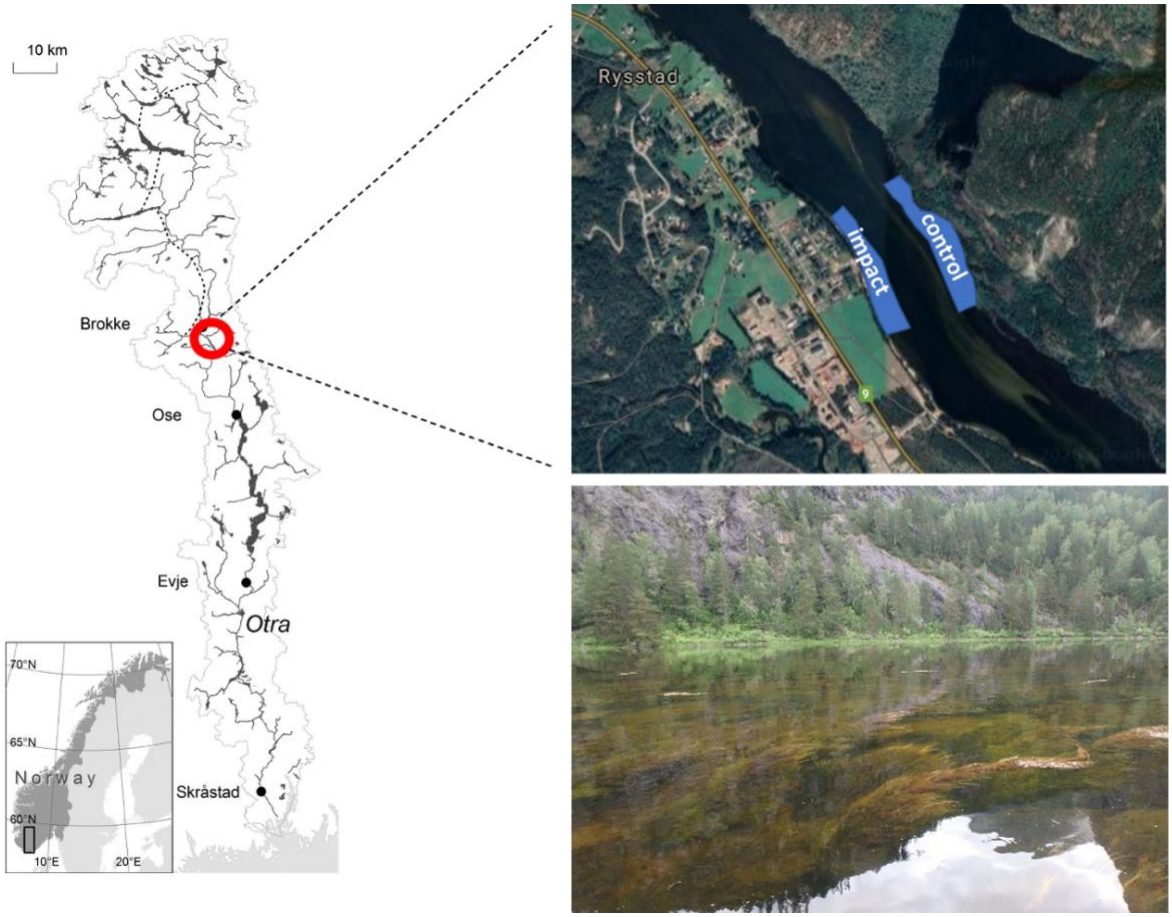



**Figure 1:** Map of the Otra River, southernmost Norway, showing the location of the study area in Rysstad, Norway. The pictures are showing the control and impact sites and the study species *Juncus bulbosus.* (Source 1: Susanne Claudia Schneider), (Source 2: **https://www.niva.no/en/projectweb/madmacs/results/macrophyte-removal-in-the-otra-river).**

## 2.2 Study design

### 2.2.1 Chamber study

The study has an experimental approach using before and after control impact (BACI) design. Large amounts of macrophytes (submerged growth of *J. bulbosus*) were removed between the 15th and 22nd of June 2020 from the impact site, but not from the control site. $CO_2$ emissions and other measurements were done in both the control and the impact site before, during and after macrophyte removal. 28 chamber runs were completed on 10 different dates. Even though

the measurements were repeated 10 times, due to only one control and one impact site, the experiment is un-replicated.

Floating chambers with infrared gas analyzers (IRGA) with logging abilities installed on the inside (Fig. 2) were used to measure $CO_2$ fluxes between the river water and the atmosphere, which is a convenient and affordable way to collect such data compared to many other methods that are typically labor intensive and require costly equipment (Bastviken et al., 2015).
For this experiment we used a boat. We drove it out to the impact and control sites to do the data collection. After arriving, before starting the data collection, we anchored the boat and waited for 10 minutes. That way, any potential $CO_2$ from the motor that had entered the chambers and could distort the results, could get out. 3 chambers were tied from the boat and placed on the water surface. We let the boat drift down the river for about 30 minutes. While the boat drifted, every 30 seconds, the chamber headspace collected data on the change in $CO_2$ over time. The data from the infrared gas analyzers were transferred over to a computer with a USB cable and analyzed on UIP5 software. The data were then analyzed on excel and used to calculate the $CO_2$ flux between the water and the atmosphere (Fig. 3). We used 3 chambers to make sure the collected data was of good quality. Water samples were taken before and after each chamber run. During sampling, the water bottles were filled to the rim without bubbling, sealed underwater with gas-tight butyl rubber stoppers and then crimped. 0.2% $HgCl_2$ was added with a syringe through the rubber, to eliminate biological processes. The samples were kept cool (+4°C) in the dark until the day of gas analyses. The samples provided data for the calculation of $CO_2$ saturation deficit (supersaturation), which together with the flux measurements recorded by the infrared gas analyzers allowed for the determination of the gas exchange rate. The chamber runs were done on both the control site and the impact site, on 3 different time periods. 1) Before macrophytes were removed, 2) While they were getting removed and 3) After they were removed. That way we could find out if macrophyte removal has any effect on $CO_2$ emissions, which is what I will attempt to give an answer to with this thesis.


**Figure 2.** Pictures of the floating chambers with Infrared Gas Analyser (IRGA) with $CO_2$ logging abilities. Used to measured $CO_2$ emissions.

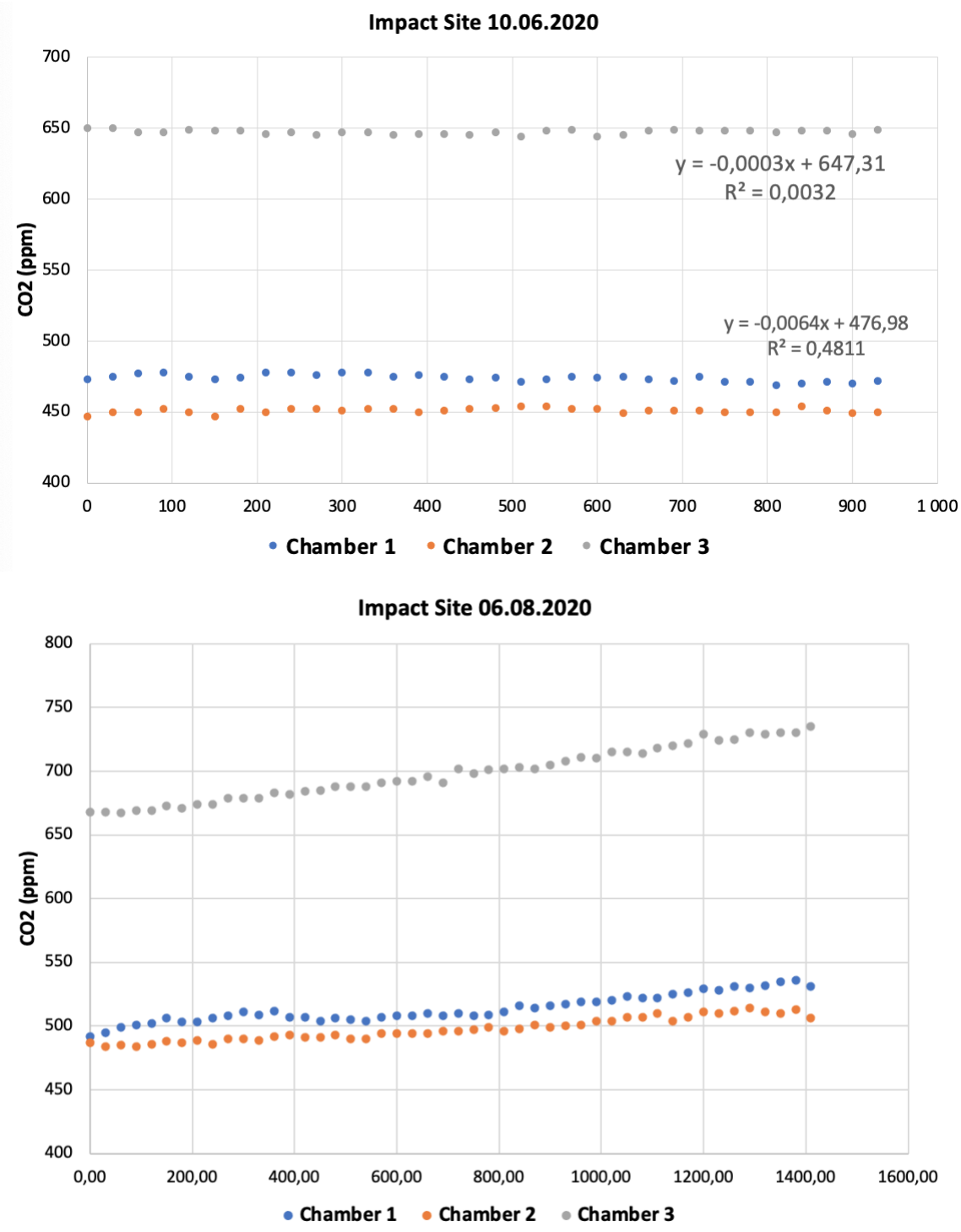



**Figure 3.** Data from the gas chamber study. $CO_2$ concentration levels in the chambers over the course of 1 chamber run. On 10.06.2020 the slope is negative, meaning that $CO_2$ was moving from the inside of the chamber and into the water (influx). On 06.08.2020 the slope is positive which means that $CO_2$ is moving from the water and into the chamber/atmosphere (efflux).

### 2.2.2 Diel change study and gas analyses

Water samples were collected at two different locations on two different dates. The first diel change study started on 12th of June and ended on 13th of June. The second was from 25th of June to 26th of June. The two locations were Rysstad Øy (59.097909, 7.528174) and Straume bridge (59.068323, 7.573630), thereafter Øy and Straume. Measurements were taken at Øy every two hours starting at 12:00 and ending 12:00 the next day and in Straume every two hours starting at 12:30 and ending 12:30 the next day.

One water sample was collected on each location every 2 hours, in 120 mL glass bottles. During sampling, water bottles were filled to the rim without bubbling, sealed underwater with gas-tight butyl rubber stoppers and then crimped. 0.2% $HgCl_2$ was added with a syringe through the rubber, to eliminate biological processes. The samples were kept cool (+4°C) in the dark until the day of gas analyses. The gas analyses were done in Ås, Norway at the Climate Gas Laboratory, at the university of NMBU. The samples were warmed at room temperature and weighed before they were filled with 20-30 mL Helium (He) to create a helium headspace. Under the headspace technique, the Helium replaced a corresponding volume of water which was removed from the bottle samples through a tube. The bottles were weighed again to determine the volume of water removed from the bottle and shaken gently horizontally at 150 rpm for at least an hour, prior to gas analysis of the headspace. The samples were then analyzed for $CO_2$ by gas chromatography following the same method as in (Yang et al., 2015).

The gas chromatography provided the concentration of dissolved gases (in ppm) in the headspace that is in equilibrium with the water. The concentrations of dissolved gases in the water at equilibrium with the headspace were calculated from the solubility of gases in water using (Carroll et al., 1991) and Henry´s law, to find the $CO_2$ concentration.

## 2.3 Statistical analysis

All the statistical analyses were conducted using the software Microsoft Excel. I used regression analysis as the statistical test, with $CO_2$ concentration in the chamber (in ppm) being the Y-range dependent variable and time (in seconds) being the independent X-range variable. The relationship between the change of $CO_2$ concentration in the chamber (Y-variable) and time (X-variable) for every chamber run was represented by a coefficient that was found from

the regression analysis. All 3 chambers on each run had a coefficient. The average of the coefficients of every run were then used as a variable for the calculation of the $CO_2$ flux (F).

The $CO_2$ flux (F), reported as mmol $CO_2$ $m^{-2}$ $h^{-1}$, was calculated as (Martinsen et al., 2018) $F = \frac{dCO2}{dt}\frac{V}{RTA}$, where the first term is the rate of change of $CO_2$ partial pressure over time in the floating chamber, V is the chamber volume (0.008 $m^3$), R is the universal gas constant ($m^3$ atm $K^{-1}$ $mol^{-1}$), T is the ambient temperature (K) and A is the chamber area in contact with water (0.075 $m^2$). Gas exchange velocity (kz, m $h^{-1}$) was calculated by dividing the $CO_2$ flux (F) of each chamber run with the corresponding saturation deficit.

# 3 Results

## 3.1 $CO_2$ emissions

The differences in $CO_2$ emissions between the Control and Impact were not statistically different before and after macrophyte removal (anova, p=0.0634, Fig. 4). Even though the error bars of the control and impact site before macrophyte removal don´t overlap, the anova-test indicates that the difference is not statistically significant. This means that removal of *J. bulbosus* had no significant effects on $CO_2$ emissions.

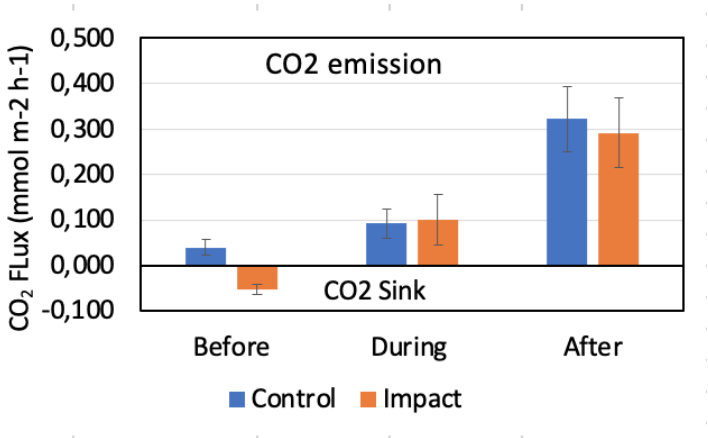



**Figure 4.** $CO_2$ flux in control and impact site before, during and after *J. bulbosus* removal.

## 3.2 Gas transfer velocity

The differences in gas transfer velocity between the Control and Impact were not statistically different before and after macrophyte removal (anova, p=0.187, Fig. 5). This means that removal of *J. bulbosus* had no significant effect on the velocity which $CO_2$ is exchanged between the water and the atmosphere.

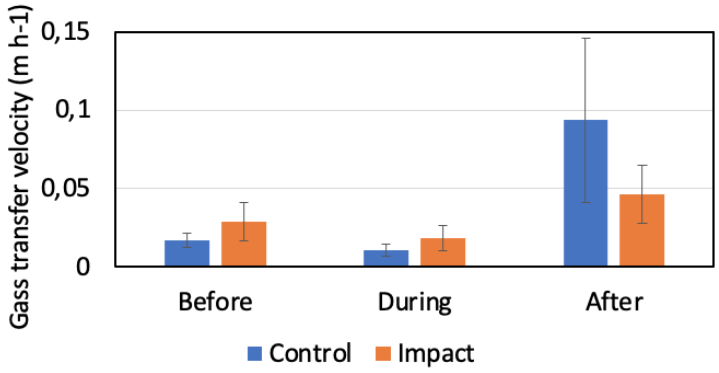



**Figure 5.** Average gas transfer velocity before, during and after *J. bulbosus* removal.

## 3.3 Diel change study

The largest diel changes in $CO_2$ supersaturation were observed at Straume, downstream end of Rysstad basin, hosting large stands of *J. bulbosus*, with diel changes of up to 0.75 mmol $m^{-2}$ $h^{-1}$. $CO_2$ emissions were as expected lower during the day due to photosynthesis and higher at night due to less photosynthesis and probably higher ecosystem respiration (Fig. 6).

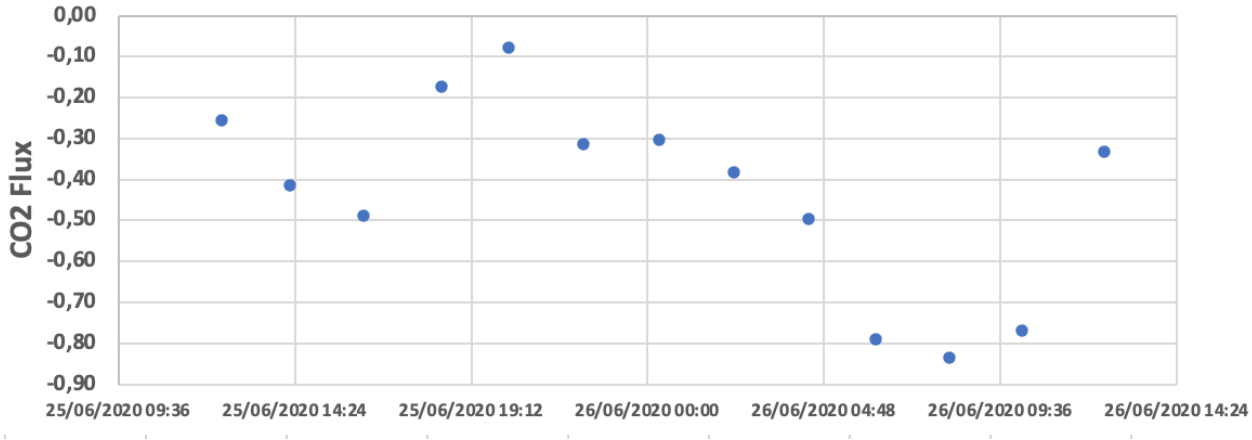



**Figure 6.** Diel change in $CO_2$ flux across a 24-hour time span. Negative fluxes represent $CO_2$ emissions in *mmol* $m^{-2}$ $h^{-1}$.

# 4 Discussion

In this study I aimed at demonstrating 1) the effects that macrophyte removal in freshwater, specifically rivers, has on $CO_{2a}$ emissions and 2) how the $CO_2$ flux changes in a river over the course of 24 hours.

## 4.1 Gas chamber study

A potential explanation for why we saw an increase in $CO_2$ emissions after cutting compared to before and during cutting, could be factors like water-level, -velocity, and -temperature fluctuations. The water level of Otra river was significantly lower after *J. bulbosus* removal. This could have affected water velocity and temperature which in turn could influence $CO_2$ saturation. BACI is a good design for this study. Without a proper control site, we could've reached the wrong conclusion. Things can change over time so it's important to control for change over time.

I have found no other studies comparing $CO_2$ emissions before and after macrophyte removal. However, there are studies that have taken a closer look at the relationship between *J. bulbosus* and $CO_2$ concentrations in the water. (Svedang, 1990) saw that when $CO_2$ concentrations in

freshwater increase, especially in acidifying freshwater, *J. bulbosus* growth rates increase. They also saw a decline in *Juncus* biomass paired with a fall in $CO_2$ concentrations. This supports the findings of several other studies, being that *J. bulbosus* expansion has been linked to elevated free $CO_2$ levels in the water.

A study done by (Bristow, 1969), found that plants that lack the ability to assimilate $HCO_3^-$ (like *J. bulbosus*) require high concentrations of $CO_2$ in the water to be able to grow. Note that even though it needs somewhat high $CO_2$ concentrations to grow, it is still well adapted to environments with low $CO_2$ concentrations as mentioned before (Schneider & Demars, 2020).

The average $CO_2$ emissions in Otra river in this study were 0.132 mmol $m^{-2}$ $h^{-1}$. That is quite low compared to other studies like (Guerin et al., 2006), that measured an average of 35.8 ± 16.7 mmol $m^{-2}$ $h^{-1}$. On that study though, the river water was significantly enriched in $CO_2$ from reservoir hypolimnions further upstream, which Otra, the river of this study is not. Altogether these results show that the conditions upstream of the river have a significant influence on the water further downstream.

## 4.2 Diel change study

This study was a secondary study, done to give us a clearer picture of the $CO_2$ emissions in the river in 24 hours. The reason we found that there are $CO_2$ emissions even during the day when photosynthesis levels are high is probably due to either 1) $CO_2$-supersaturated water originating from the powerplant or 2) ecosystem respiration is higher than photosynthesis which is the case in most rivers. Even though most of the $CO_2$ from the powerplant should theoretically leave the water right after it enters the river, some $CO_2$ could certainly travel far enough to affect the results.

## 4.3 Gas transfer velocity

This study was a secondary study, done to help us understand $CO_2$ emissions better. There is a strong correlation between how fast the gas flux is and how much $CO_2$ is being emitted. A potential explanation for higher rates of gas transfer velocity after macrophyte removal compared to before and during, could be water level variation. Since the water level was lower at that period, the macrophytes would be closer to the water surface, producing more turbulence

and potentially increasing gas exchange. With that said, there are 2 clear outliers in the dataset of the "after" period that are responsible for the relatively higher gas transfer velocity after macrophyte removal.

# Acknowledgements

I want to thank my supervisors Susanne Claudia Schneider and Benoit Demars for their valuable support, statistical advice, helpful discussions and comments during the entire process of data collection and writing of this thesis. Thanks to Peter Dörsch for helping with the gas analyses in the lab. I would also like to thank NIVA and NMBU for taking part in funding this project.

# References

Bastviken, D., Sundgren, I., Natchimuthu, S., Reyier, H. & Galfalk, M. (2015). Technical Note: Cost-efficient approaches to measure carbon dioxide (CO2) fluxes and concentrations in terrestrial and aquatic environments using mini loggers. *Biogeosciences*, 12 (12): 3849-3859.

Bristow, J. M. (1969). Effects of Carbon Dioxide on Growth and Development of Amphibious Plants. *Canadian Journal of Botany*, 47 (11): 1803-&.

Carroll, J. J., Slupsky, J. D. & Mather, A. E. (1991). The Solubility of Carbon-Dioxide in Water at Low-Pressure. *Journal of Physical and Chemical Reference Data*, 20 (6): 1201-1209.

Guerin, F., Abril, G., Richard, S., Burban, B., Reynouard, C., Seyler, P. & Delmas, R. (2006). Methane and carbon dioxide emissions from tropical reservoirs: Significance of downstream rivers. *Geophysical Research Letters*, 33 (21).

Lakseelver, N. (2019). Fjerning av krypsiv – behov og effekter.

Martinsen, K. T., Kragh, T. & Sand-Jensen, K. (2018). Technical note: A simple and cost-efficient automated floating chamber for continuous measurements of carbon dioxide gas flux on lakes. *Biogeosciences*, 15 (18): 5565-5573.

Moe, T. F., Brysting, A. K., Andersen, T., Schneider, S. C., Kaste, O. & Hessen, D. O. (2013). Nuisance growth of Juncus bulbosus: the roles of genetics and environmental drivers tested in a large-scale survey. *Freshwater Biology*, 58 (1): 114-127.

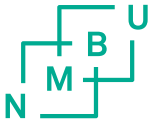
Regnier, P., Friedlingstein, P., Ciais, P., Mackenzie, F. T., Gruber, N., Janssens, I. A., Laruelle, G. G., Lauerwald, R., Luyssaert, S., Andersson, A. J., et al. (2013). Anthropogenic perturbation of the carbon fluxes from land to ocean. *Nature Geoscience*, 6 (8): 597-607.

Rørslett, B. (1988). Aquatic weed problems in a hydroelectric river: The R. Otra, Norway.

Schneider, S. C. & Benoit, D. (2020). *Vannplanter i Otra oppstrøms Brokke før og nå, og hva det betyr for problemvekst av krypsiv*

Svedang, M. U. (1990). The Growth Dynamics of Juncus-Bulbosus L - a Strategy to Avoid Competition. *Aquatic Botany*, 37 (2): 123-138.

Yang, H., Andersen, T., Dorsch, P., Tominaga, K., Thrane, J. E. & Hessen, D. O. (2015). Greenhouse gas metabolism in Nordic boreal lakes. *Biogeochemistry*, 126 (1-2): 211-225.

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