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The impact of spawning pink salmon (*Onchorhynchus gorbuscha*) on the water quality of northern Norwegian rivers

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Eline Helen Hansen

Abstract

Since the 2017 invasion of pink salmon in northern Norwegian rivers, increasing populations of the odd-year stock have continued to return and are further expanding their range southwestwards. A relatively short time from its first invasion and the pink salmon's strictly 2-year life cycle, gives a unique opportunity to compare the pink salmon's effect on the riverine system, during a season with its presence, compared to a season without.

The aim of this thesis is to elucidate the impacts of pink salmon on nutrient dynamics and bacterial communities in four Norwegian rivers, by comparing data from a peak year (2023), with high pink salmon abundance, to a non-peak year (2022). Decompositon of a large number of salmon carcasses after spawning, during a peak year will lead to significant increase of nutrients, potentially stimulating growth of bacterial communities. By analyzing water samples collected through both seasons, from river stations which of different degrees are affected by mitigation measurements, makes it possible to compare pink salmon abundance, expected timing of migration, spawning and senescence death, in contrast to fluctuating variables of water chemistry and bacterial water quality, in relation to the rivers normal seasonal pattern.

With pink salmon presence, variables of water chemistry and bacterial water quality were generally increasing from middle of July, including one or several peaks of varying range, until late September. In general, there were few significant differences of variables when comparing a season of pink salmon present, to a season without, but some significant differences when comparing between stations during its presence.

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1 Introduction

Species dispersal is constrained by physical features and climatic conditions, creating boundaries for movement (Lockwood et al., 2005; Roughgarden & Diamond, 1986). Under human influence, species have been transferred faster and further than ever before (Ricciardi et al., 2013). Organisms introduced beyond their natural range, invasive species (Ojaveer et al., 2014), could cause enormous changes for the recipient ecosystems (Simberloff, 2011), and through predation, competition, and habitat alteration cause extinction of already vulnerable species (Mack et al., 2000). Additionally, introduced diseases and parasites can devastate native ecosystems that lack immunity (Dunn, 2009), and interbreeding with local species, can cause loss of genetic diversity (Meilink et al., 2015). Previous studies have indicated that terrestrial and freshwater systems could be more affected by non-native species, already suffering from other anthropogenic pressures such as habitat degradation and nutrient pollution (Gurevitch & Padilla, 2004; Wetzel, 2001). Invasive species are often fast-growing species with a high nutrient uptake, offering nutrient rich litter that decomposes faster than that from native species increasing the rate of nutrient cycling (Hickman et al., 2013). Moreover, invasive species are degrading human health and wealth (Vitousek et al., 1996), and could beside the ecological impacts, negatively influence socio-economical values (Ojaveer et al., 2014).

As an additional food source and for recreational fishing, pink salmon were introduced to rivers at Kola Peninsula in northwestern part of Russia (Sandlund et al., 2019). Between 1956 and 1979, eggs of pink salmon *Onchorhynchus gorbuscha* (Walbum 1972), were collected from rivers at the Sakhalin Island, in the northern Pacific Ocean, transported and released in rivers draining into the White and Barents Sea (Gordeeva & Salmenkova, 2011). This release of millions of fry resulted in observations and catches of pink salmon in rivers along the Norwegian coast during the 1960s and 1970s, but no observations of self-reproducing populations (Mo et al., 2018). In 1985, the donor-river were changed to the more northern located Ola-river, which resulted in self-reproductive populations, but large fluctuations in numbers of adult spawning individuals in odd-numbered years, correlating with average annual water temperature (Gordeeva et al., 2005). An attempt to establish an even-year broadline was not successful, although some individuals still enter the rivers in even-numbered years (Gordeeva et al., 2015). In recent years, between a few and hundreds of individuals of pink salmon has been observed in rivers along the Norwegian coast (Sandlund et al., 2019). This changed in 2017, when the species was observed in 263 rivers with 6390 individuals caught (Berntsen et al., 2018). Observations also extended to Ireland, Scotland, Greenland, and further southwards in Europe (Armstrong et al., 2018; Millane et al., 2019; Nielsen et al., 2020). By 2023, the recorded number of pink salmon caught in Norwegian rivers exceeded 240 000 individuals and it was observed in rivers along the entire Norwegian coast (Miljødirektoratet, 2024). Pink salmon now occurs in extremely high numbers in northern Norway, primarily centered in rivers located in north-eastern part of Finnmark County and spread and establishment to new locations is expected (Maduna et al., 2024).

The anadromous, migratory pink salmon has a strictly two-year life cycle (Groot & Margolis, 1991), resulting in separate odd- and even-year populations, driving biennial population cycles (Heard, 1991). The pink salmon in the Atlantic Ocean is observed migrating up the river where it spawns in July, August, and September (Lennox et al., 2023). Eggs are laid in the gravel, with embryos developing through the following autumn and winter (Groot & Margolis, 1991). After hatching, the larvae remain hidden in the gravel, minimizing their use of the yolk-sack, while waiting for the spring migration (Lennox et al., 2023). Both timing of spawning and hatching are seen as critical variables deciding the species invasiveness (Erkinaro et al., 2022). Once the yolk-sack is absorbed, the smolt follows the stream directly towards the ocean (Quinn, 2007), unlike the native salmonid species that usually spend some years in their respective rivers. Arriving at the ocean, the smolt joins shoals of fish, and could be feeding in the fjords and estuaries (Willette, 2001), before they follow the stream towards the Barents Sea (Diaz Pauli et al., 2023). The pink salmon feeds and overwinters at sea, gaining up to 95% of its bodyweight, before it returns to the coast after 12-14 months (Heard, 1991). As the pink salmon stops feeding when migrating up the river for spawning, stored energy is allocated gametogenesis, behavioral changes, and development of sexual characteristics, traits that maximize its reproductive success (Hendry & Berg, 1999), increases the oxidative stress, and further suppressing their immune defense (Morbey et al., 2005).

In its native range, the pink salmon’s spawning migration acts as a major link between ocean, freshwater, and terrestrial ecosystems, and is characterized as “a unique way to move nutrients upward” (Cederholm et al., 1999). Were, for instance the black bear is an important predator at the pink salmon spawning grounds, where it feeds on, and transports carcasses into the surrounding riparian sites (Gende et al., 2001). After pink salmon senescence and death, the carcasses can be stranded on gravel bars, detained by woody debris, settle in deep pools, or get washed into the estuaries. Whether moved by bears or settled along the river, these carcasses act as an important food source for both vertebrate and invertebrate scavenger communities (Cederholm et al., 1999), and influences recipient ecosystems population dynamics through feeding, movement, and reproductive success (Willson et al., 1998). In northern Norway, Eurasian magpie (*Pica pica*), hooded crow (*Corvus cornix*), common raven (*Corvus corax*), goosander (*Mergus merganser*), red fox (*Vulpes vulpes*), and white-tailed eagle (*Haliaeetus albicilla*) are observed scavenging on carcasses and thereby transferring energy and nutrients from the aquatic to the terrestrial ecosystem (Bonde, 2023; Dunlop. et al., 2021). Among birds in pink salmons native range, several types of Gulls (*Larus spp.*) scavenge major parts of the decomposing carcasses (Christie & Reimchen, 2005), which was also observed at our study site (pers. obs).

Pink salmon is through its presence, spawning, and senescence death, increasing the nutrient level of its recipient river, a level that increases with growing number of individuals (Gende et al., 2002; Pinay et al., 2009). The specific composition of each individual depends on sex and stage of maturity, but was in a study by Gende et al. (2004) estimated to consist of 5.3 kJ energy/g, 3.3% N and 0.48% P. This means that 15 000 individuals entering a river contributes with about 11.3 GJ energy, 630 kg N and 100.8 kg P, assuming respective weights of 1.8kg for males and 1.0 kg for females. During the migration, the morphological- and behavioral changes lead to considerable excretion, whereas the decomposing carcasses releases nutrients during breakdown (Naiman et al., 2002). Also, eggs supply significant amounts (Cederholm et al., 1999). Even if many of the carcasses are flushed out of the rivers again (Gende et al., 2004), the contribution of the limiting nutrients nitrogen and phosphorus could enrich the primary productivity. This, in turn, could lead to shifts from the base of the food-web, as the oligotrophic aquatic systems are dominated by prokaryote autotrophs and more heterotrophic systems by phytoplankton and phagotrophic heterotrophs (Cotner & Biddanda, 2002). How greatly the pink salmon affects the nutrient level of a certain river depends on multiple factors. These include pink salmon density, and earlier years (history) of spawning (Gende et al., 2002), the river's nutrient level without pink salmon presence, the rivers discharge and morphology, anthropogenic pressures and the ecosystems connected to the river system (Hindar et al., 2020).

The level of ammonium seems to increase drastically as soon as the salmon enters the river (Pinay et al., 2009), from excretion and protein metabolism (Groot & Margolis, 1991), elevating as the salmon "stays" in river before further increasing as the pink salmon dies (Pinay et al., 2009). Carcasses left in the river from the pink salmon spawning also contribute substantial amounts of decomposing organic matter. When organic matter is broken down and mineralized through the ammonification process by aerobe and anaerobic bacteria, it results in increased level of NH_4^+ (Kalff, 2002). *Nitrosomonas*, the nitrifying bacteria oxidizes NH_4^+ to NO_2^-, before *Nitrobacter* oxidizes NO_2^-, to NO_3^- during oxidized conditions (Wetzel, 2001). Under more alkaline conditions, ammonium is converted to free ammonia (Liu et al., 2019), as the primary source of NH_3 is decomposition of dead material (Effler et al., 1990). During a pH above 9.0, half of the ammonium appears as gas, compared to one tenth below 8.0 (Dodds & Whiles, 2010). Elevated level of total ammonia, including both free and ammonium, could be toxic during more alkaline conditions, with a threshold at 250 µg NL^{-1} and pH at 9.0 (Ip et al., 2001). Nitrobacter is sensitive to levels between 0.1 and 1.0 mg NL^{-1} that could cause nitrite build up (Villaverde et al., 1997) which converts hemoglobin to methemoglobin for aquatic organisms and being toxic for both salmonid fish and people.

The organic matter and nutrient input associated with the abundance of pink salmon could influence and initiate growth of bacterial communities, including potentially harmful ones. Traditionally, fecal indicator bacterium, FIB has been used as an indicator for determining the bacterial water quality (Jang et al., 2017), determining the abundance of *Escherichia coli*, *Clostridium perfirigens*, the *Enterococci*-genus and Coliform ones (Lovdata, 2024). These bacteria are primarily found in the intestine of warm-blooded animals, but can survive and reproduce in the environment, during optimum temperatures, with varying needs for sources of carbon and nutrients (Craun et al., 1997; Dubin & Pamer, 2017; Hogan & Larry Smith, 2003; Ishii & Sadowsky, 2008; Jang et al., 2017; Rood & Cole, 1991). This bacterial growth represents changes in the ecosystem that could affect the water quality and pose a risk for aquatic organisms and human health.

The aim of this thesis is to elucidate the impacts of pink salmon on nutrient dynamics and bacterial communities in four Norwegian rivers, by comparing data from a peak year, with high pink salmon abundance, to a non-peak year. We hypothesize that the decomposition of a large number of salmon carcasses during a peak year will lead to a significant increase of nutrients, potentially stimulating growth of bacterial community. This research is needed to understand the broader ecological and public health implications of an increasing pink salmon population in Norwegian rivers. Findings from the study contribute to a growing knowledgebase of pink salmon's impact on both freshwater and connected ecosystems outside its native range. Moreover, it informs management strategies that need to balance economic priorities, preserve ecosystem diversity, and public health safeguarding.

2 Methods

2.1 Study site

This study includes four rivers in northeastern Norway (Sør-Varanger municipality, Finnmark County), that drain into the Barents Sea (*Figure 1*). In Sør-Varanger, the Siberian taiga meets the Artic tundra and other more typical southern types of nature (Systad et al., 2004). The municipality has a unique geology, where gneiss, micaceous gneiss, monzonite and granite dominate in the eastern part of the municipality, and banded gneiss, granite, and granodiorite in the western part of it (Norges Geologiske Undersøkelse, 2024).

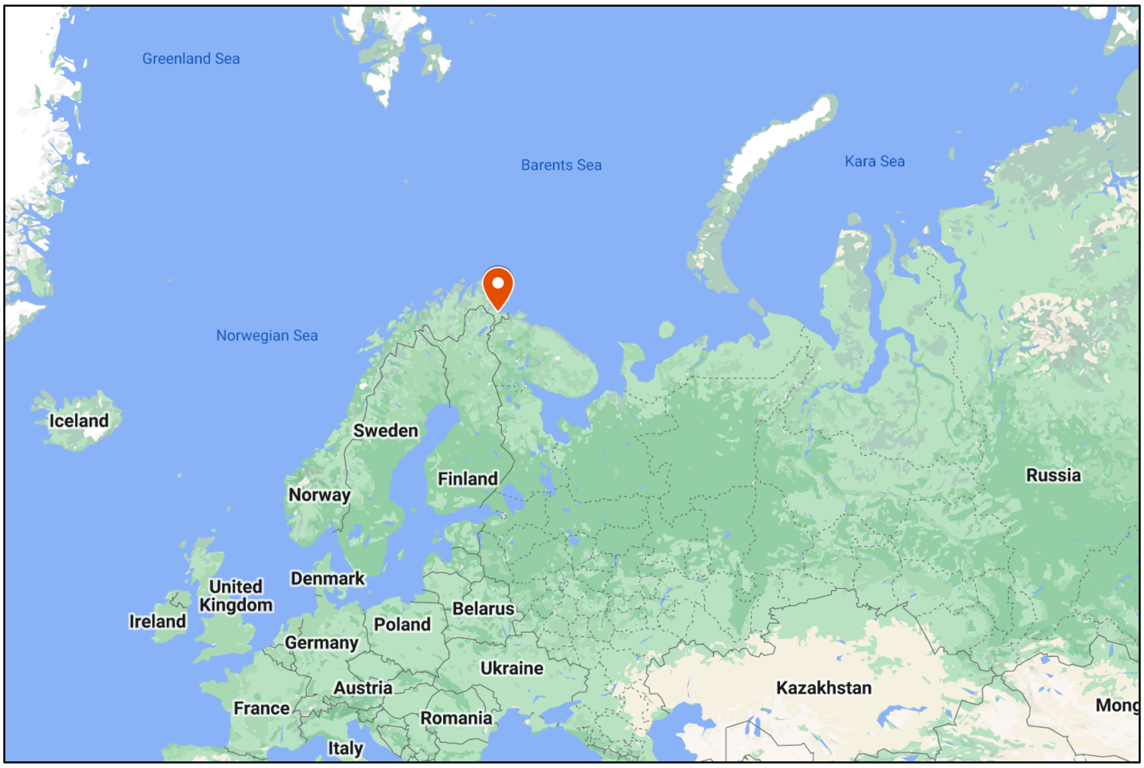


Figure 1 Study location. *The municipality Sør-Varanger located in the northwestern part of Norway. Map is created with Google My Maps (2024).*

The easternmost river, Grense Jakobselv (*Figure 2, Tabell 1*), is a border-river between Norway and Russia and could to some degree be affected by pollution from the now declined industrial activity in Nickel and Zapolyarny, as well as military exercises on the Russian side. The river also experiences activity from border guards on both sides throughout the year, and from tourists, salmon fishermen and the local community staying in their cabins during the summer months on the Norwegian side. Since Grense Jakobselv is a border river, there is no trap in the river (Hindar et al., 2020), which results in the river being affected by pink salmon without any significant mitigation measures. The river has been greatly affected since the pink salmon invasion in 2017, with some of the pink salmon migrating as far up as the water flows in the watershed. Water was collected from five sites in the river (*Figure 3*).

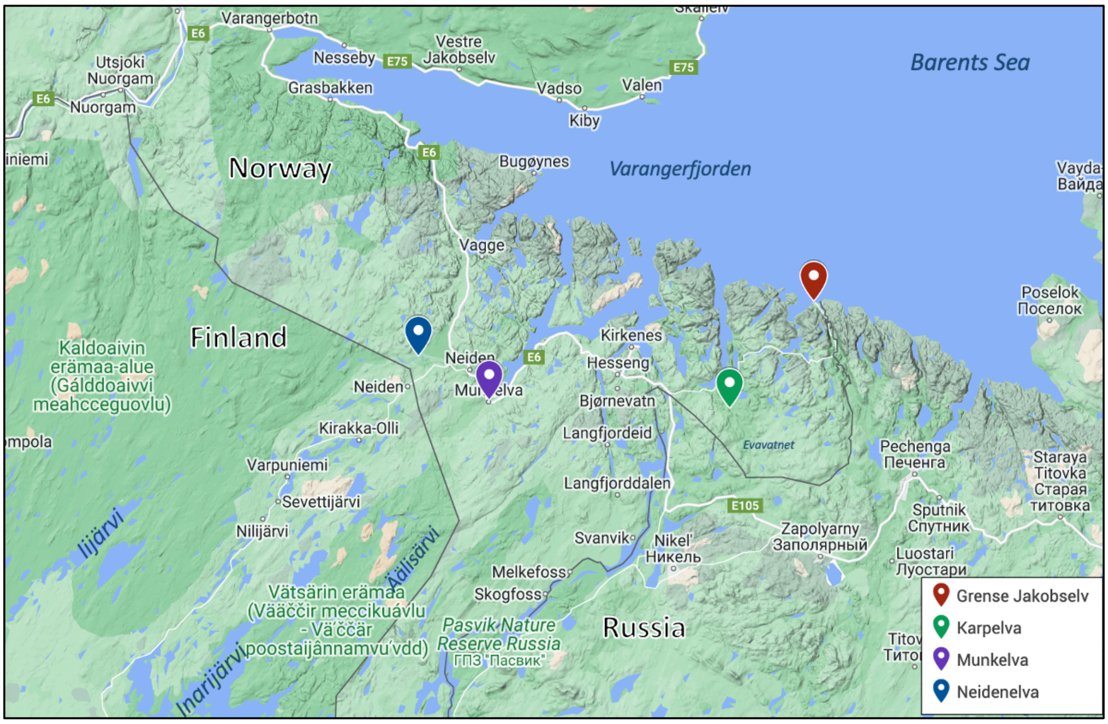
The watershed in Karpelva (*Figure 2, Tabell 1*) experiences some level of human influence throughout the year. This includes visits by the local community to cabins or through recreational activities, as well as activity from the border guard. However, the river is probably most affected by a few small farms located downstream along the river. Karpelva had one station for water sampling, located about 50 m beneath the salmon trap (*Figure 3*). The potential spawning area between the trap and the outflow to the fjord is approximately 2500 m2.

Munkelva (*Figure 2, Tabell 1*) is also to some degree affected by the local community visiting their cabins throughout the year, but probably more during the summer months, including salmon fishermen and hunters during the fall. The sampling station was about 10 m below the trap (*Figure 4*), where the possible spawning area between the trap and outflow to the fjord is about 1200m2.

The westernmost river, Neiden (*Figure 2, Tabell 1*), starts in Iijärvi, where the watershed includes the more densely populated areas; of Näätämö in Finland and Neiden on the Norvegian site of the border. The river runs through pinewood and different types of wetlands (Systad et al., 2004). Local communities visit their cabins along both the Finish and Norwegian river sections but is probably most affected by agricultural activities in the most downstream areas. Neiden has two stations for water sampling; one located about 1,5 km downstream from the salmon stairs (*Figure 4*), and one located about 10 km upstream relative to the stairs, thought to be relatively unaffected by the pink salmon. The most downstream station is affected by pink salmon, which has a relatively large area available for spawning, as the distance between the salmon stairs and the outflow in the fjord is about 4-5 km.

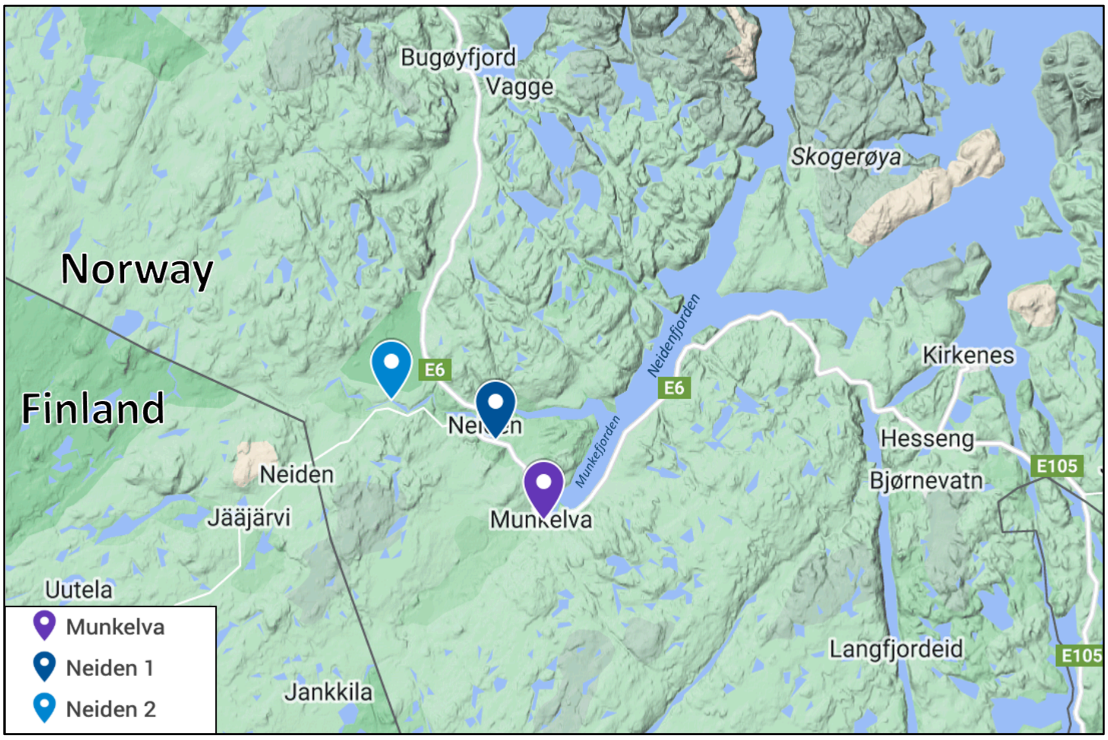
Tabell 1 River characteristic. *Overview of location, length, catchment size and annual discharge of rivers.*

River	**Location**	**Length** (km)	**Catchment** (km^2)	**Annual discharge** ($*10^6/m^3$)
Grense Jakobselv	69°45N, 30°51E	49.0	240.1	147.1
Karpelva	69°39N, 30°23E	25.9	125.8	68.0
Munkelva	69°42N, 29°27E	51.8	468.9	156.4
Neiden	69°42M, 29°10E	149.2	3008.3	1093.5



Figur 2 Location of rivers. *Neidenelva, Munkelva, Karpelva and Grense Jakobselv, relative to Finland, Norway, Russia, Varangerfjorden and the Barents Sea. Map is created with Google My Maps (2024).*

Figur 3 Eastern located stations. *Karpelva with one station located beneath the salmon trap and Grense Jakobselv station 1, 2, 4, 5, 6 relative to Norway, Russia and Kirkenes. Map is created with Google My Maps (2024).*



Figur 4 Western located stations. *Neiden station 1 and 2 and Munkelva, were Neiden 1 and Munkelva are located beneath the salmon trap or stairs. Relative to Finland, Norway and Kirkenes. Map is created using Google My Maps (2024).*

2.2 Water sampling

In the control year (without pink salmon), river water samples were collected monthly between 29th of April and 31st of October. In 2023 (pink salmon year), samples were collected monthly between April 26th and early July, then weekly from mid-July to mid-October. Because of registration of higher levels of some bacteria in autumn 2023, a final sample was collected on November 5th.

Water samples were collected using sealed and sterilized 500 mL HDPE plastic bottles. To prevent contamination by ourselves and release of algae and sediments from the riverbed, a long stick was used for filling the bottle. Bottles and lids were flushed three times with water from a visible flow of water of the river, before filling it. All the flushing was done a bit downstream of where the sample was taken, to prevent disturbance of the water and potential release of nutrients. When the sample itself was taken, the bottle was placed in the middle of the stream, with the opening placed directly upstream, to prevent sampling surface water or water closest to the riverbed. The bottle was placed in a smooth flow, not a rifle or a backwater. Once filled, the bottle opening was turned upright, to minimize contamination when removing it from the water and returning it to land, where the lid was then secured. All samples were taken at the exact same locations in the rivers, at each station, on each date of sampling. Temperature was measured with a thermometer placed in the water. After collection, all samples were placed in isolated boxes of Styrofoam, kept dark, until they were brought back to NIBIO at Svanhovd in the Pasvik Valley. Samples were stored in a refrigerator at 4-5 °C, before being transported by mail with a couple of freezer packs to the lab in Alta.

2.3 Analysis of water samples

The water samples were analyzed using either standard NS-EN ISO or internal and accredited methods by Eurofins Food and Feed Testing Norway in Alta for bacteria, and Eurofins Environment Testing Norway in Moss for nutrients. Some nutrient data and all bacteria data were reported as unaccredited by the analytical laboratory due to the extended storage time prior to analysis, >24h for all bacteria, ammonium, nitrate and phosphate > 48h for pH and chemical oxygen demand, and >7 days for dissolved organic carbon. Some of the variables have a certain quantification uncertainty, and a lower and upper detection limit. For some variables, different methods are used between the seasons (*Appendix 1-2).*

2.4 Data analysis

Data for pink salmon abundance are daily catches from or in connection to salmon traps or stairs in Karpelva, Munkelva, and Neiden for the 2023 season (*Appendix 3)* and derived from Miljødirektoratet (2024) and estimates for Grense Jakobselv provided by Rune Muladal (2024).

Level of river discharge in Karpelva (id: 247.3.0) and Neiden (id: 244.2.0), (*Appendix 4*) are visualized using data from Sildre (2024) with datapoints taken 'as measured'. River discharge from Neiden is used for both Neiden and Munkelva, as Munkelva is without a measuring station. Since the rivers are located relatively close, they should have quite similar discharge pattern. Discharge in Karpelva is used both for Karpelva and Grense Jakobselv, as Grense Jakobselv also lacks a water measuring station. These easternmost rivers are further apart with a mountainous area between them (*Figure 3*) and could have some differences, but the data are still useful for visualizing the seasonal pattern.

Data files containing results for water chemistry, bacterial water quality, catches from pink salmon traps, and river discharge were imported and treated in R-studio (Posit team, 2024).

Values below deteciton limit was replaced with a random number between 0.5 * detection limit and detection limit. This was done to facilitate data processing for calculating means and statistics (*Appendix 5-7*). In plots, values below the detection limit was replaced with 0, and vaules above the detection limit replaced with the value of the upper range. Respective graphs to which this applies include a line for the lower and upper detection limit. The set.seed() function in RStudio was used to generate random values for recordings below the detection limit. The seed values used were '6' for nutrient nutrient data 2022 and '5' for 2023, for bacteria '22' for 2022 and '23' for 2023.

However, results for sampling of ammonia free on October 12, 2023, include detection limits at '<0.005' and '<0.0005', while the rest of 2022 and 2023 samples are refered to with levels ranging down to zero (0.00). These are treated the same way as other data below the detecion limit (*Appendix 1*). Some values of coliforme bacteria at the last sampling on November 11, 2023, exceeded the detection limit of 100 cfu/mL at several stations, which could be a result of a different type of method for analysing the sample or analysed by a different laboratorie.

2.4.1 Comparing water chemistry and microbial water quality

For graphical comparison of water chemistry and microbial water quality between the seasons, graphs were made using RStudio (Posit team, 2024) and visualized with the GG-plot2 package (Wickham, 2016). For statistical comparisons, data were first checked for normal distribution with the shapiro.test() (Shapiro & Wilk, 1965). In general, the 2022 data were normally distributed, while the 2023 data were not. The wilcox.test() (Bauer, 1972; Hollander & Wolfie, 1973) was used to compare between seasons for a particular variable, with all data from below trap pooled to get more samples for comparison. The dunnTest (Dunn, 1964) was used as a post hoc procedure following a rejection of a Kruskal-Wallis test, to identify the actual significant differences between stations below traps in 2023, or for comparing between stations in Grense Jakobselv. By including data from 10th of July (as the previous sample were taken in middle of June both years) to the end of the season, the comparison was more directly coupled to the timing of pink salmon river entrance. For both graphs and statistics, the sampling stations were divided into three groups (*Table 2*): all stations from Grense Jakobselv (the only river without larger mitigation measures), all stations below traps, including Grense Jakobselv 1, and Neiden's stations located below and above the salmon stair.

Tabell 2 Groups of stations for comparison. *Grense Jakobselv including all its stations, stations located below trap including Grense Jakobselv station 1 and stations in Neiden below and above the stair.*

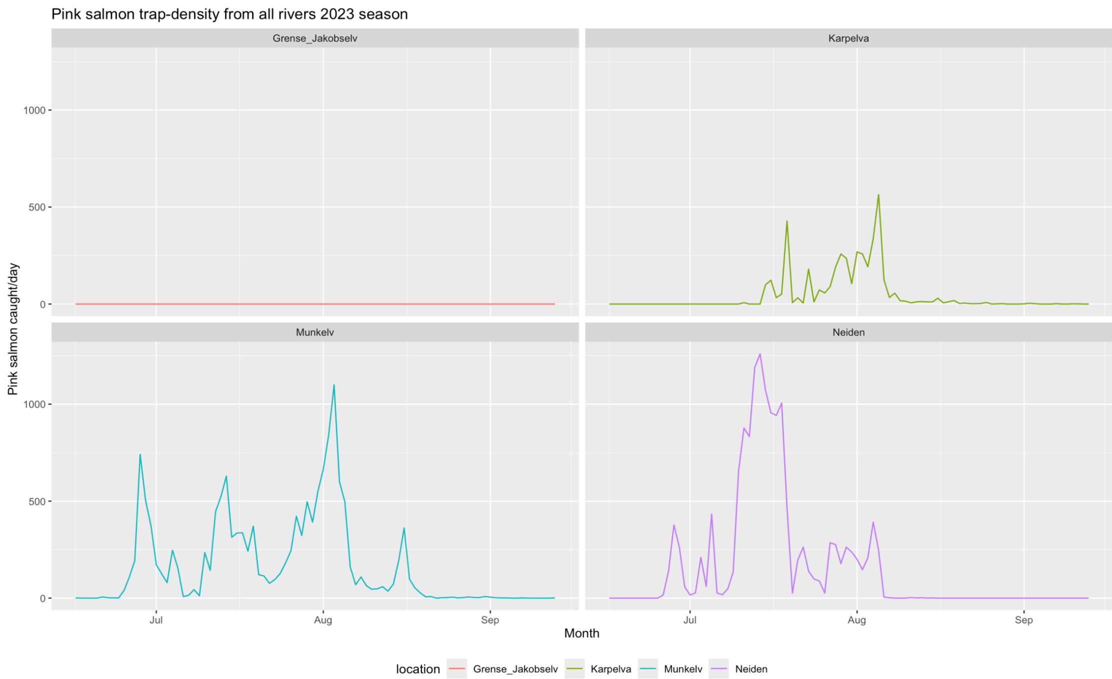
Grense Jakobselv	**Below trap**	**Neiden**
Grense Jakobselv 1	Grense Jakobselv 1	Neiden 1
Grense Jakobselv 2	Karpelva	Neiden 2
Grense Jakobselv 5	Munkelva	
Grense Jakobselv 4	Neiden	
Grense Jakobselv 6		

3 Results

3.1 Pink salmon abundance

Grense Jakobselv had an estimated maximum of 100 individual pink salmon in 2022, and between 10 – 20 000 individuals in 2023. The first individuals were observed migrating up the river in late June, with observed spawning from late July to mid-August, and the majority had finished spawning during the first week of August (Muladal, 2024). The length of river migration for some individuals was as far upstream in the river and watershed as they could reach.

The first peak of catches from the traps and stairs occurred in late June for the most western rivers Neiden and Munkelva (*Figure 5*). This was followed by two major peaks for Munkelva, compared to one for Neiden. Most pink salmon had entered the rivers during the first part of, or middle of August. Karpelva had a shorter, more compressed season, lasting just over two weeks with 4 005 cathces, while Neiden and Munkelva had totals of 14 564 and 14 754 catches respectively over the entire season. Pink salmon has not been observed above the traps in large numbers, but they could migrate through the stairs in Neiden during elevated discharge. Both Neiden and Munkelva are relatively long rivers, which makes registration challenging (Muladal, 2024) and as the traps are installed in rivers after the main spring flood, some early migrators could reach entering the rivers.

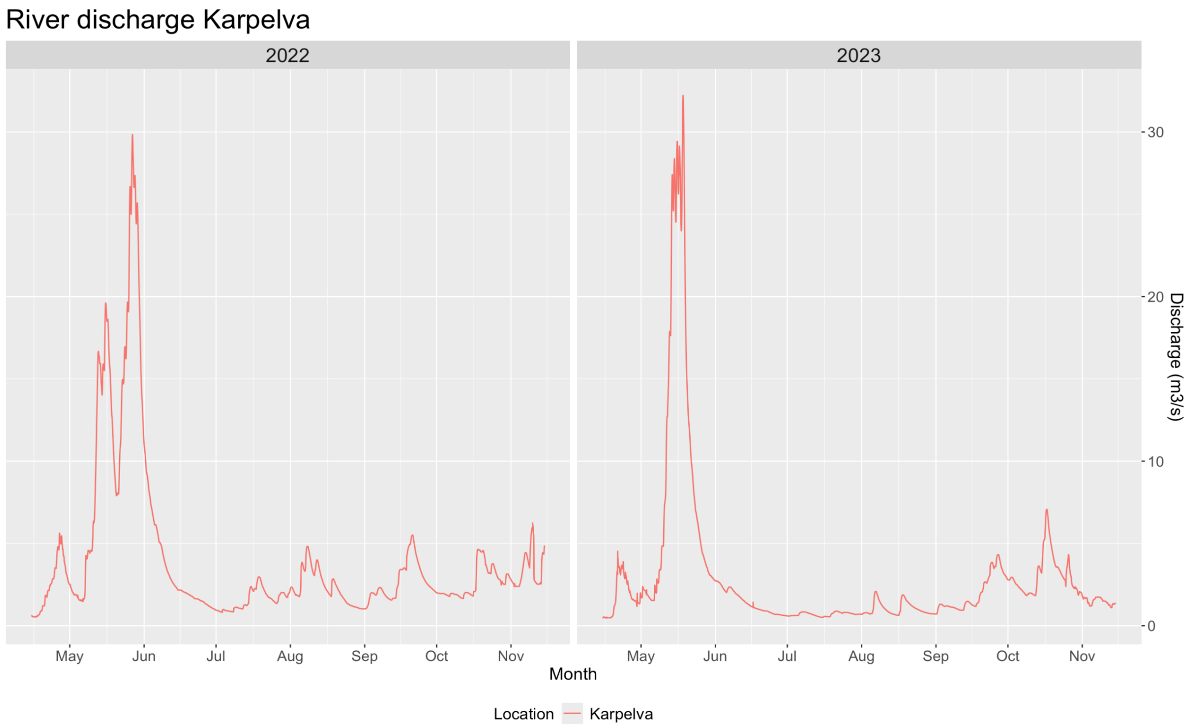


Figur 5 Number of pink salmon caught in traps each day. *From traps located in Karpelva, Munkelva, and Neiden. Locations are colored, with number of individuals caught on the left. Grense Jakobselv does not have a trap, therefore zero catches per day through the*

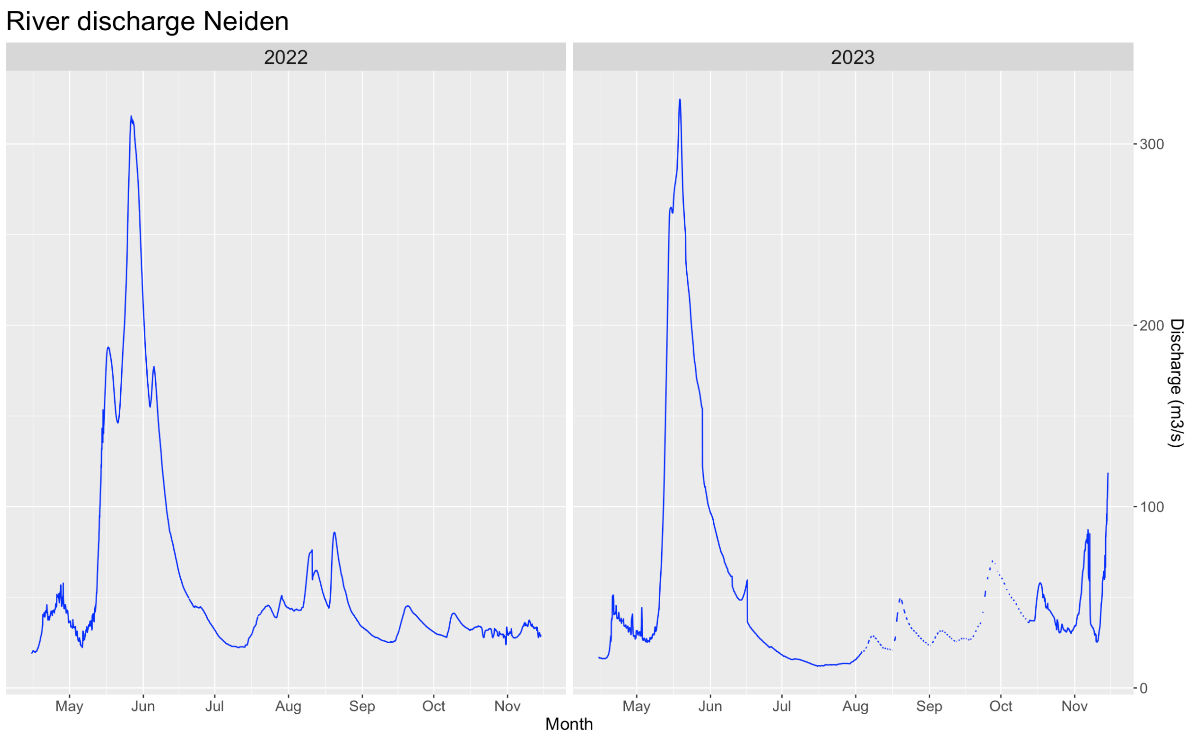
3.2 River discharge- and temperature

Karpelva and Neiden started the 2022 season with a spring flood, and a discharge reaching up to 29.8 and 315.4 m3/s in last part of May (*Figure 6-7*). The water level decreased until the start of July, reaching lows of 0.54 and 19.3 m3/s, followed by fluctuating levels with several peaks through the rest of the season. The final months in Neiden showed more stable levels than in Karpelva. The mean discharge was 4.0 for Karpelva and 59.0 m3/ for Neiden.

In 2023, the spring flood in both rivers came a week earlier and was more compressed, occurring in the middle of May with levels reaching up to 32.2 m3/s in Karpelva and 324.6 m3/s in Neiden. The water level decreased until the middle of July, reaching a minimum level at 0.46 and 12.01 m3/s, and continued the following months with more stable and lower levels with fewer peaks than the season before. Neiden ended the season with drastically increasing levels compared to 2022, while Karpelva ended with more decreasing levels than the season before. The mean discharge was 2.8 m3/s for Karpelva and 53.8 m3/s for Neiden, meaning both rivers had a relatively lower mean in 2023 compared to 2022.



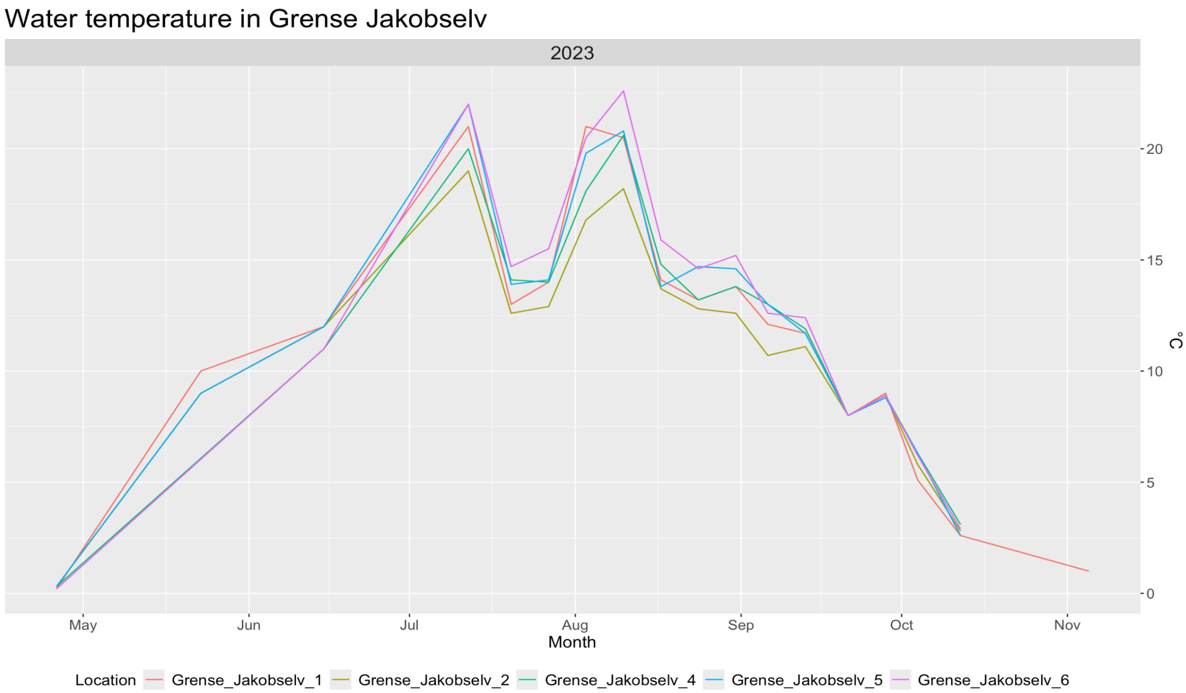
Figur 6 River discharge Karpelva. *Level of water "as measured" through 2022 and 2023 season, from a station located in the river. Level of water (m3/s), in right of figure. Data from Sildre (2024).*



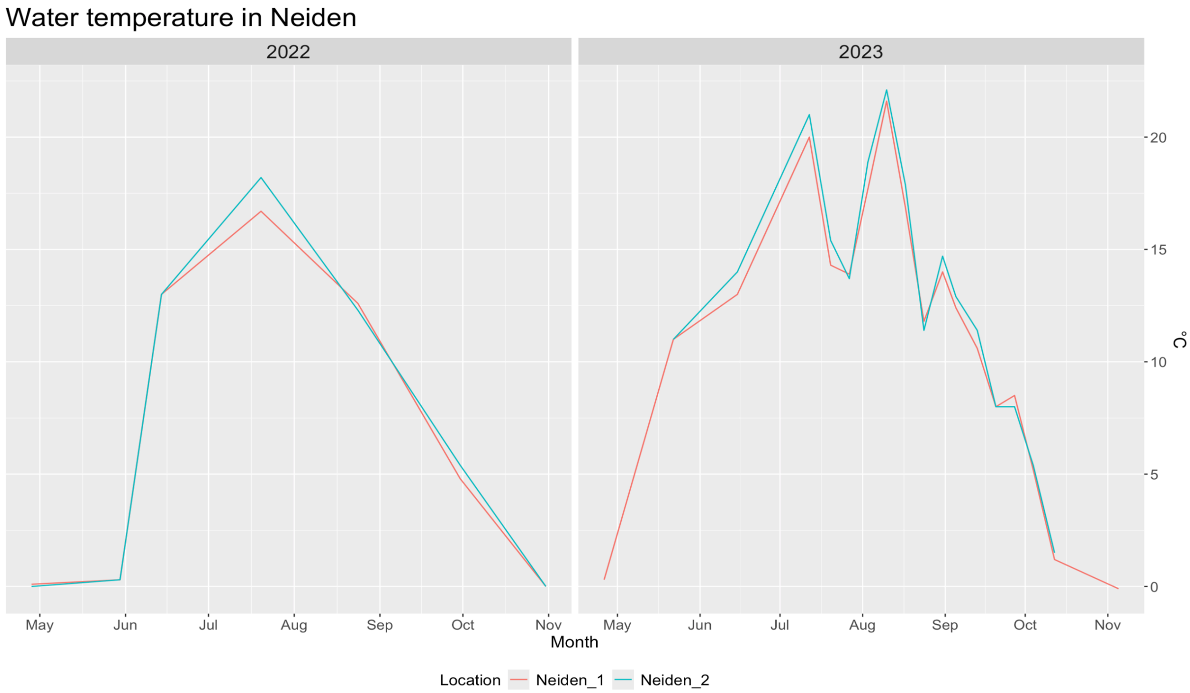
Figur 7 River discharge Neiden. *Level of water "as measured" through 2022 and 2023 season, from a station located in the river. Level of water (m3/s), in right of figure. Data from Sildre (2024).*

In 2022, the water temperature in Neiden, Karpelva, and Munkelva slightly increased from 0ºC at first sampling in late April 2022 (*Figure 9-10),* reaching the upper range in mid-July between 16.7 and 21.1 ºC. The temperature then gradually decreased, ending at 0ºC in late October. Mean was 6.8-7.0ºC for Neiden and Munkelva, and 9.2ºC for Karpelva.

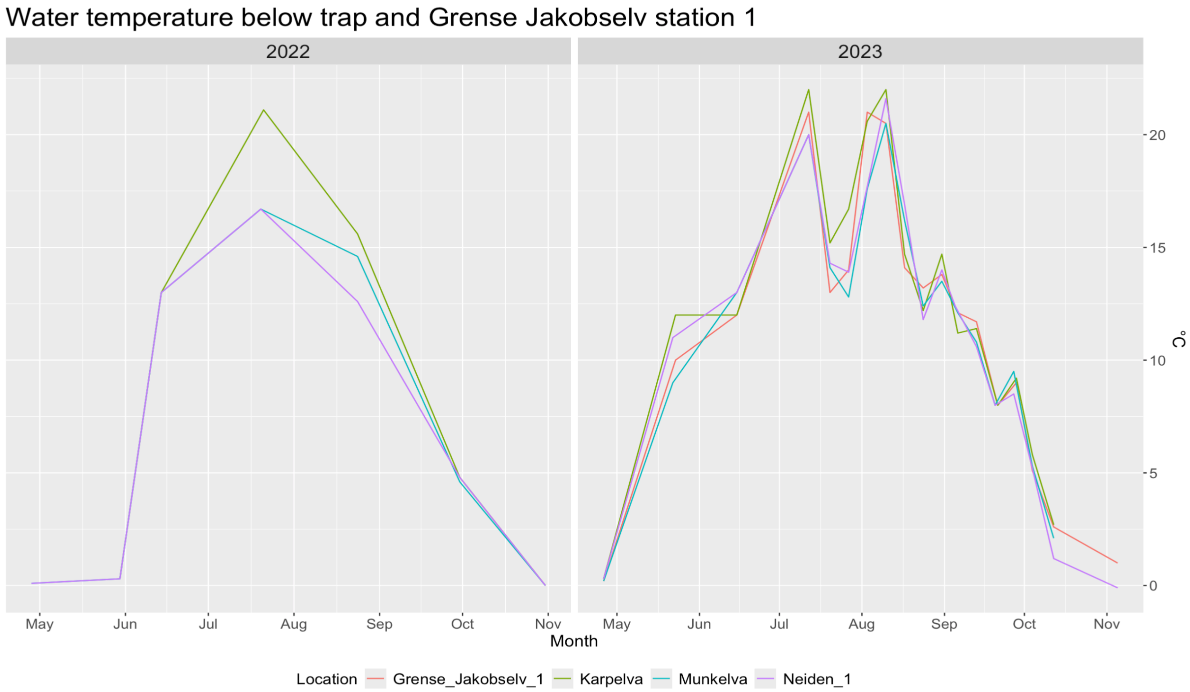
In 2023, measured water temperatures were about the same as in 2022 at the start and end of the season (*Figure 8-10*). Temperatures increased to 20 ºC just before the middle of July, followed by a decrease to 15 ºC about two weeks later, a few degrees lower than the same time the previous year. In early August, the temperature reached the upper range between 20.5-22.6 ºC, before gradually decreasing, with smaller peaks, until the final sampling in early November. The mean water temperature was between 11.0-13.0 ºC for all rivers, which was relatively higher than in 2022.



***Figur 8 Water temperature in Grense Jakobselv**. From samples collected through 2023 season. Each station/location is colored, with measured level on the right side.*



Figur 9 Water temperature in Neiden. *From samples collected through 2022 and 2023 season. Each station/location is colored, with measured level on the right side.*



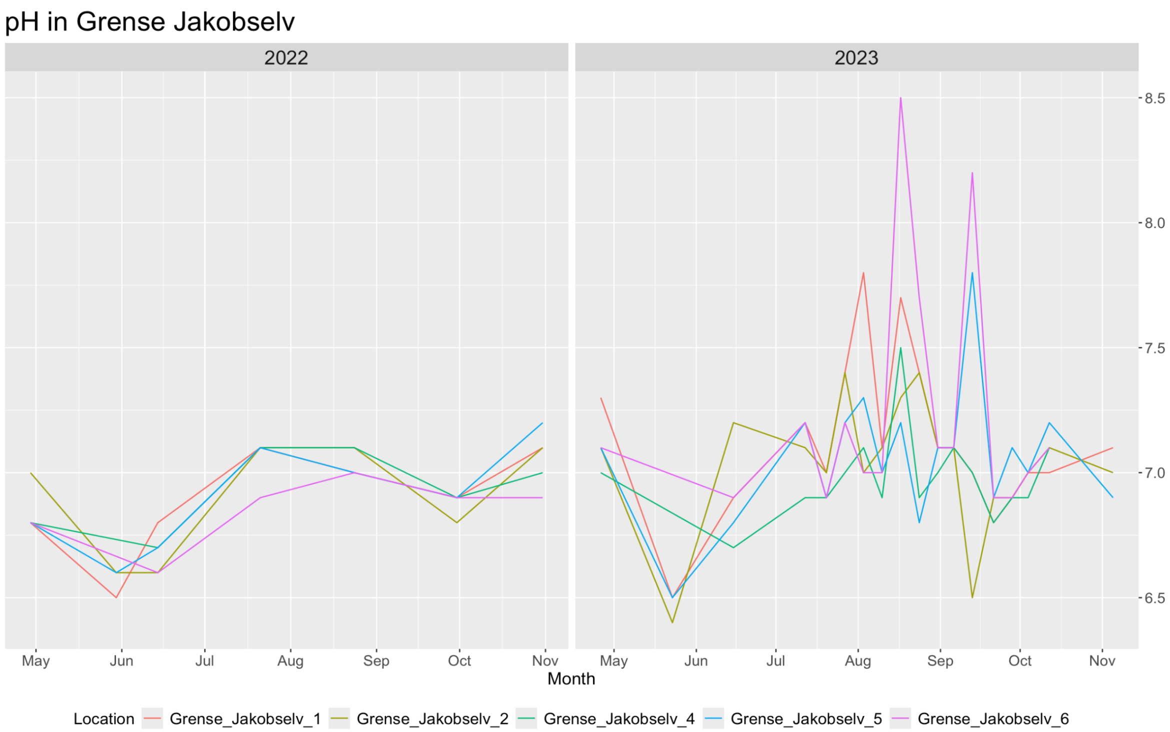
Figur 10 Water temperature below traps and Grense Jakobselv station 1. *From samples collected through 2022 and 2023 season. Each station/location is colored, with measured level on the right side.*

3.3 Water chemistry

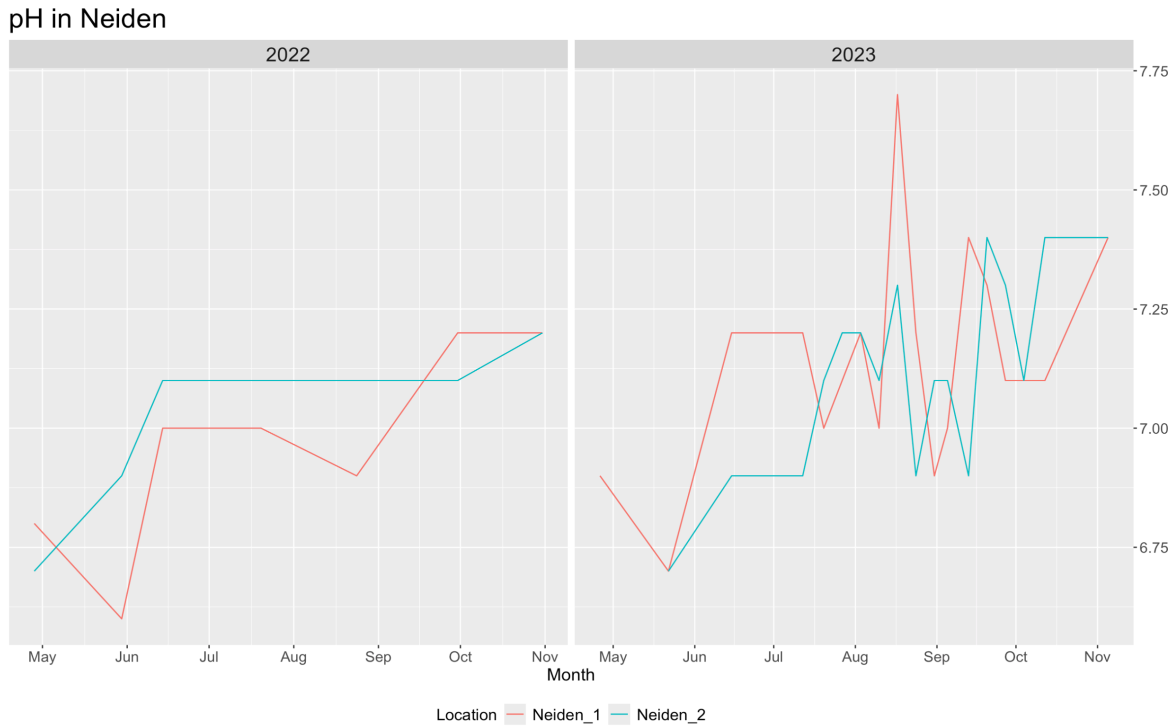
3.3.1 pH

In 2022, pH was measured between 6.95 and 7.49 in the Pasvik and Tana rivers from early June to late October (Norsk institutt for vannforskning, 2023). This study's rivers had measured level of pH between 6.5-6.7 in late May (*Figure 11-13*), before increasing to around 7.0 in June and July, with slightly fluctuating levels until the final sampling in late October, between 6.8 and 7.2. The mean was between 6.9 and 7.1 for all stations in all rivers.

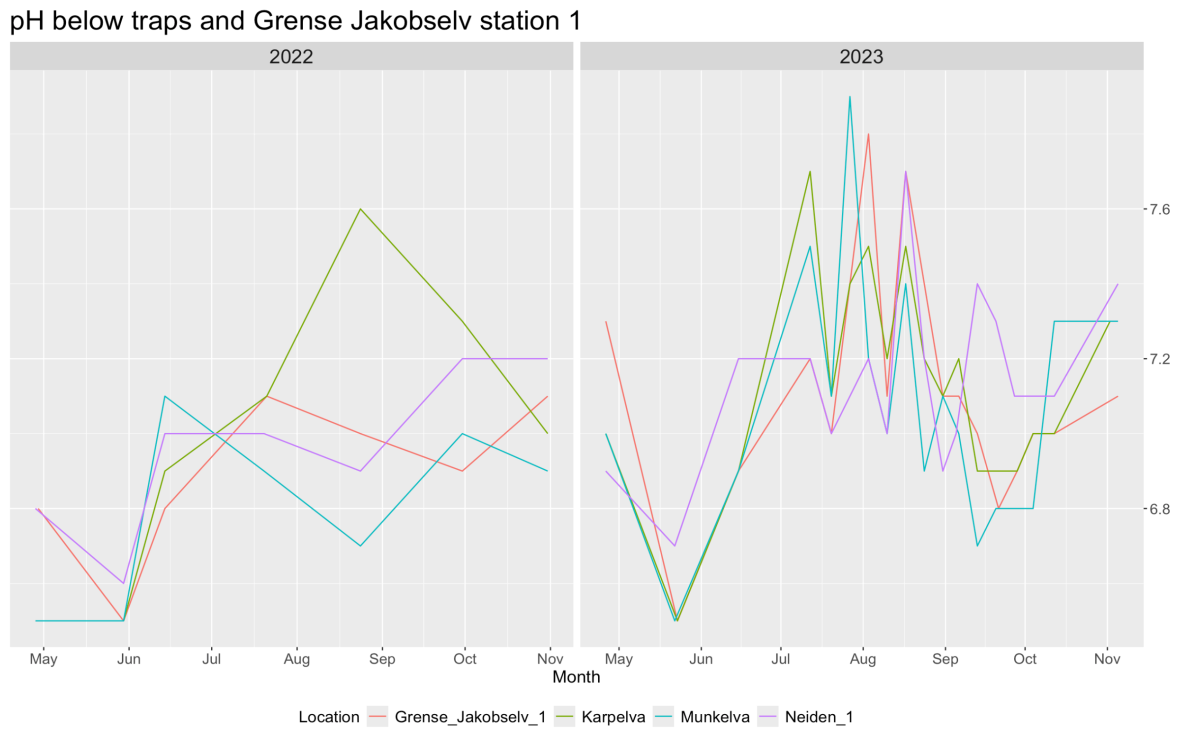
The 2023 season began with pH levels like the previous year, although slightly lower levels were observed from mid-June. From mid-July pH levels started fluctuating, with the highest measured values for stations below traps being between 7.7 and 7.9. Noteworthy was the level at Grense Jakobselv 6 ranging up to 8.2 and 8.6. Mean was between 7.0 and 7.14 for all rivers stations through 2023. There was no significant difference between the seasons at stations below traps, between those stations in 2023, or between stations in Grense Jakobselv in 2023.



Figur 11 Measured level of pH in Grense Jakobselv. *From samples collected through 2022 and 2023 season. Each station/location is colored, with measured level on the right side.*



Figur 12 Measured level of pH in Neiden. *From samples collected through 2022 and 2023 season. Each station/location is colored, with measured level on the right side.*

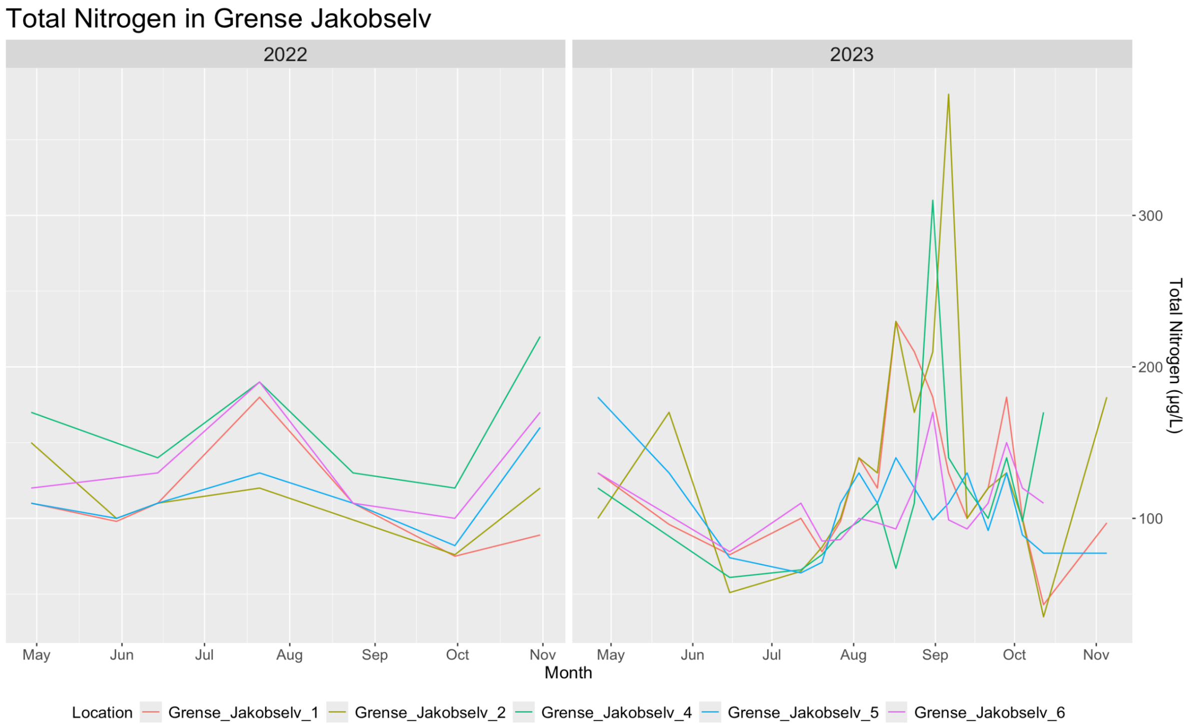


Figur 13 Measured level of pH below traps and Grense Jakobselv station 1. *From samples collected through 2022 and 2023 season. Each station/location is colored, with measured level on the right side.*

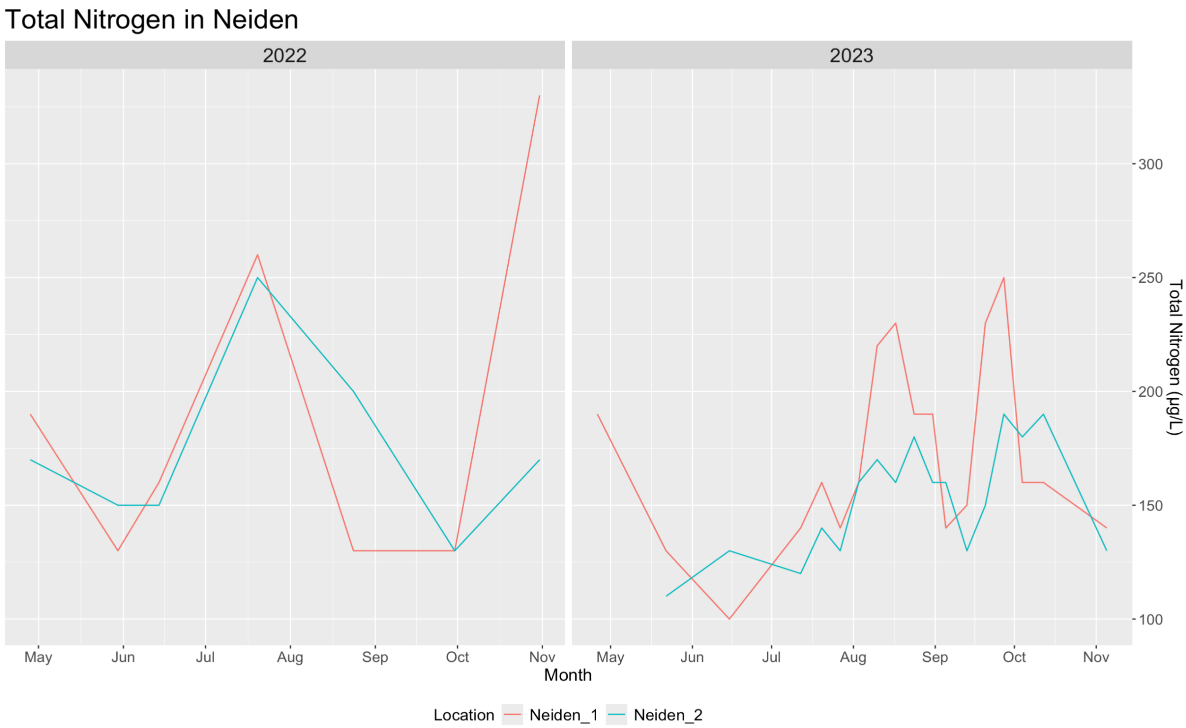
3.3.2 Total Nitrogen

Level of total nitrogen ranged between 91-130 µgN/L in Tana- and Pasvikelva from early June to early October (Norsk institutt for vannforskning, 2023). In the rivers of this study, the level slightly decreased from late April to early and middle of June (*Figure 14-16*). A peak was observed in mid-July, with Karpelva and Neiden showing values up to between 250 and 300 µgN/L, before decreasing until September and October. Levels then increased again towards the end of the season, with Neiden 1 notably ending at 330 µgN/L and Munkelva at 290 µgN/L. The mean for the season was 110 µgN/L for Grense Jakobselv 1 and between 148-190 µgN/L for the rest of the stations below the traps.

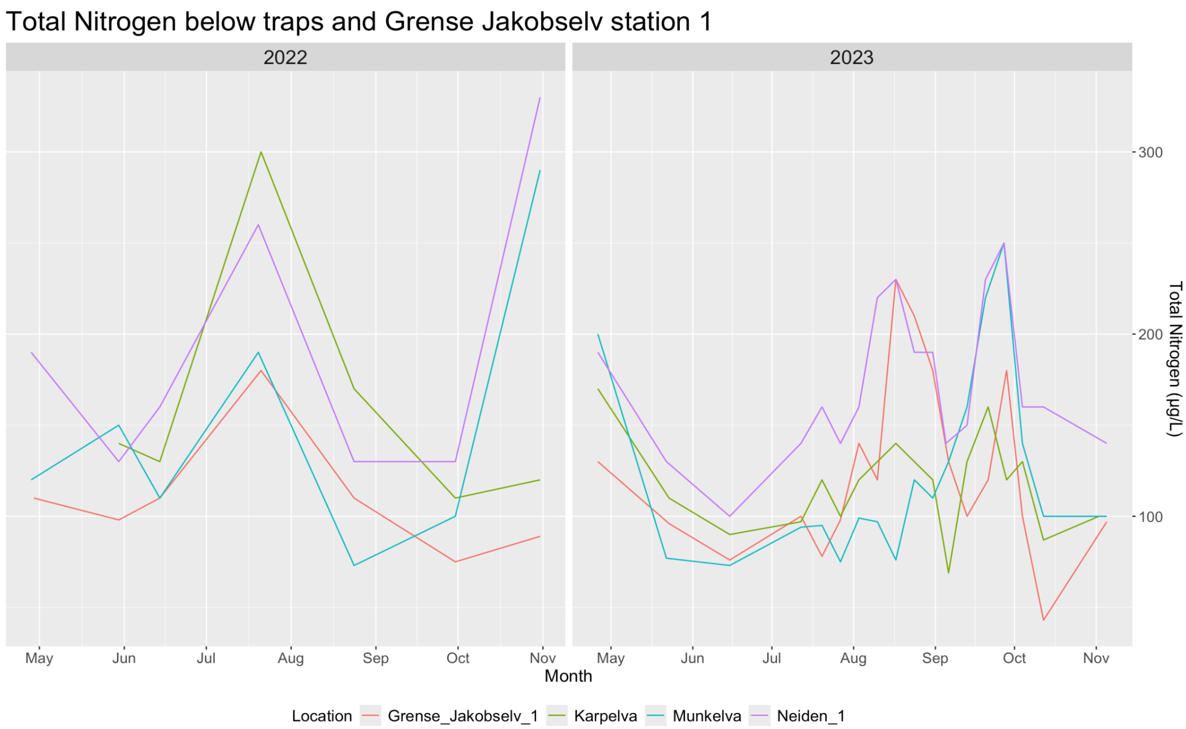
In 2023, the level of total nitrogen increased from mid-June with fluctuating values until late September. The highest values were measured at Grense Jakobselv 2 and 4, with 380 and 310 µgN/L respectively, and a much steeper decrease in early October for Grense Jakobselv compared to the other stations and the year before. The mean was 171 µgN/L at Neiden 1 and between 118-123 µgN/L for the rest of the rivers below traps. There was no significant difference between seasons at stations below the traps, or between stations in Grense Jakobselv in 2023. However, a significant difference was found between Neiden 1 and the other rivers below traps in 2023.



Figur 14 Measured level of Total Nitrogen in Grense Jakobselv. *From samples collected through 2022 and 2023 season. Each station/location is colored, with measured level on the right side.*



Figur 15 Measured level of Total Nitrogen in Neiden. *From samples collected through 2022 and 2023 season. Each station/location is colored, with measured level on the right side.*

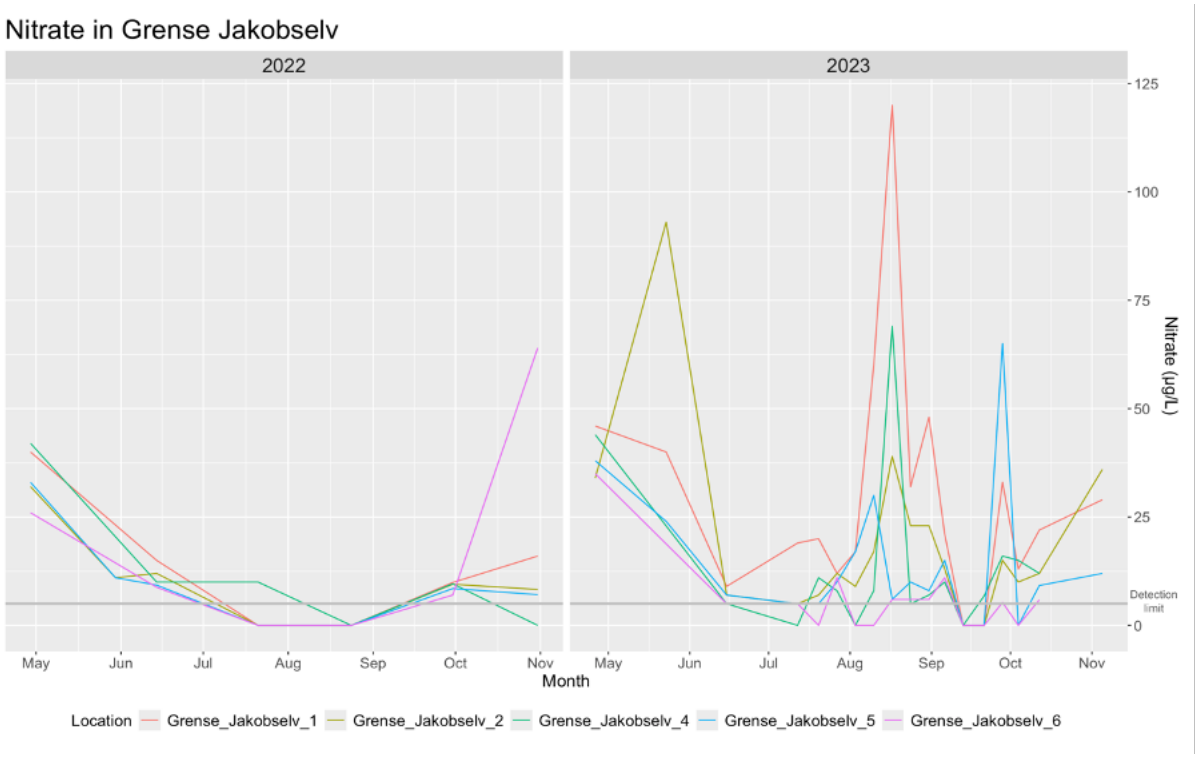


Figur 16 Measured level of Total Nitrogen below traps and Grense Jakobselv station 1. *From samples collected through 2022 and 2023 season. Each station/location is colored, with measured level on the right side.*

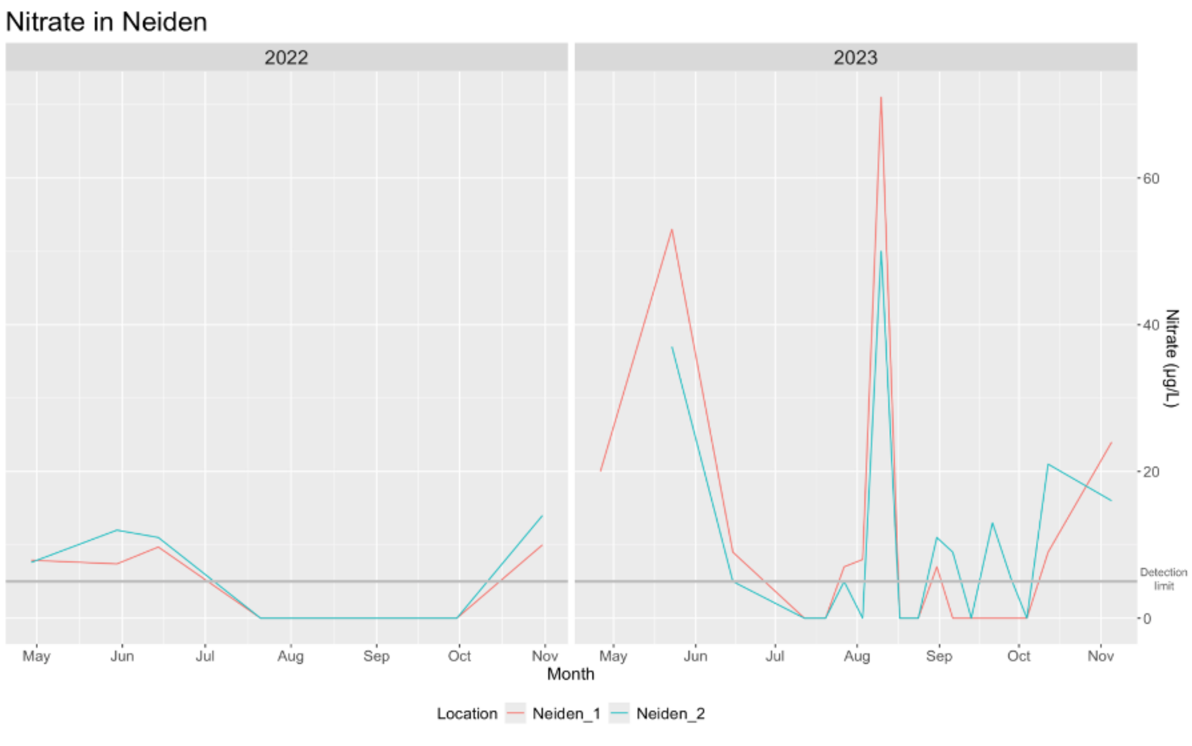
3.3.3 Nitrate

Measured nitrate levels in Tana and Pasvik rivers remained below 7 µg/L between late June and early October in 2022 (Norsk institutt for vannforskning, 2023). During the same season, this study's rivers were at their lowest below the detection limit, and at their highest at 64 µg/L in Grense Jakobselv 6 at the end of the season, three times higher than any values of any other rivers (*Figure 17-19*). The mean nitrate level was between 4.9-6.7 µg/L for Karpelva, Neiden 1 and Munkelva, and 14.9 µg/L for Grense Jakobselv 1.

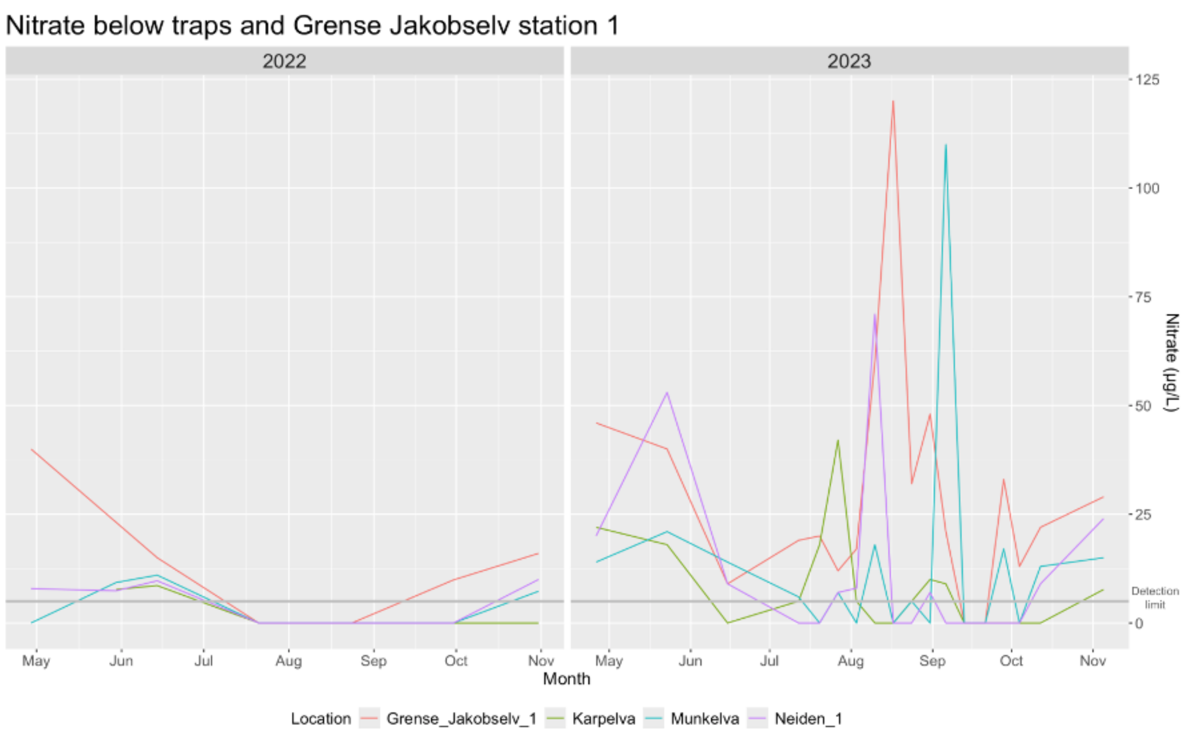
In general, nitrate levels were below the detection limit during late summer and early autumn in 2022. In 2023, fluctuations were observed from mid-July to early October. Levels ranged from below the detection limit for all stations in all rivers, to 120 and 110 µg/L in Grense Jakobselv 1 and Munkelva, respectively. Mean nitrate level for Karpelva, Neiden and Munkelva was between 9.5-14.6 µg/L, and 30.5 µg/L for Grense Jakobselv 1. There was a significant difference between the seasons at stations below the traps, more specifically Grense Jakobselv differed from the other rivers. Grense Jakobselv stations 1 and 2 were also significantly different from station 6.



Figur 17 Measured level of Nitrate in Grense Jakobselv. *From samples collected through 2022 and 2023 season. Each station/location is colored, with measured level on the right side. Lower detection limit <5µg/L.*



Figur 18 Measured level of Nitrate in Neiden. *From samples collected through 2022 and 2023 season. Each station/location is colored, with measured level on the right side. Lower detection limit <5µg/L.*

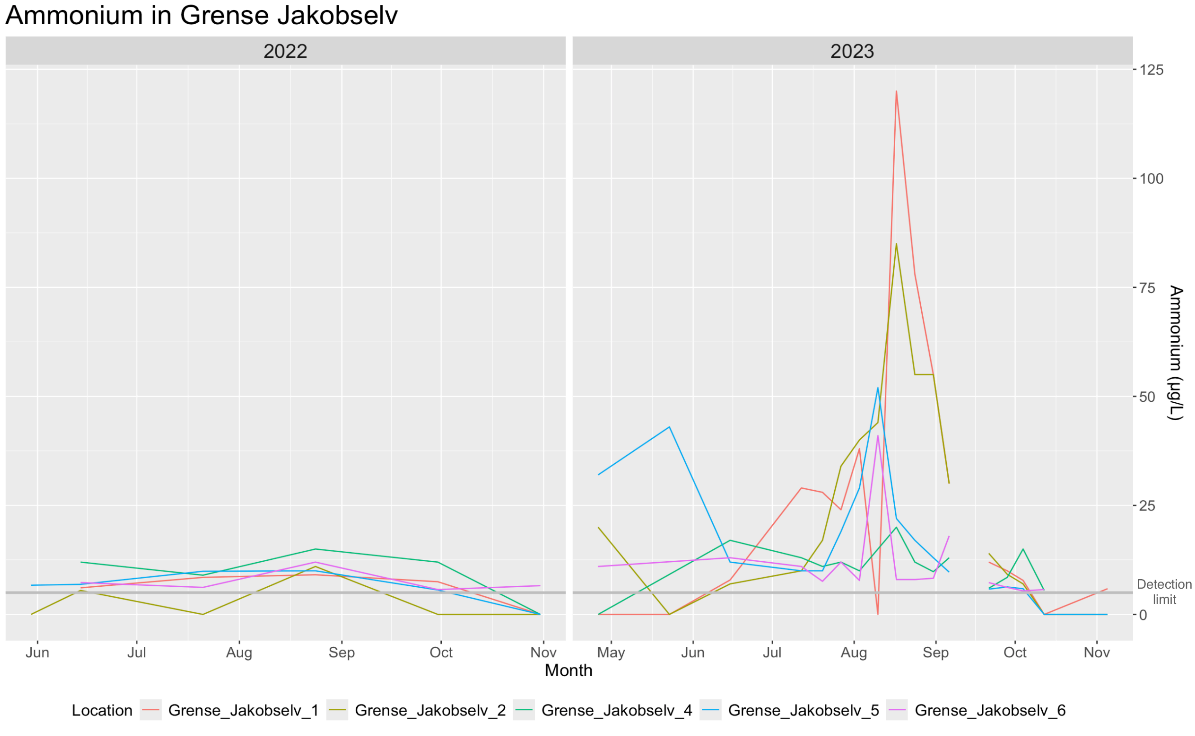


Figur 19 Measured level of Nitrate below traps and Grense Jakobselv station 1*. From samples collected through 2022 and 2023 season. Each station/location is colored, with measured level on the right side. Lower detection limit <5µg/L.*

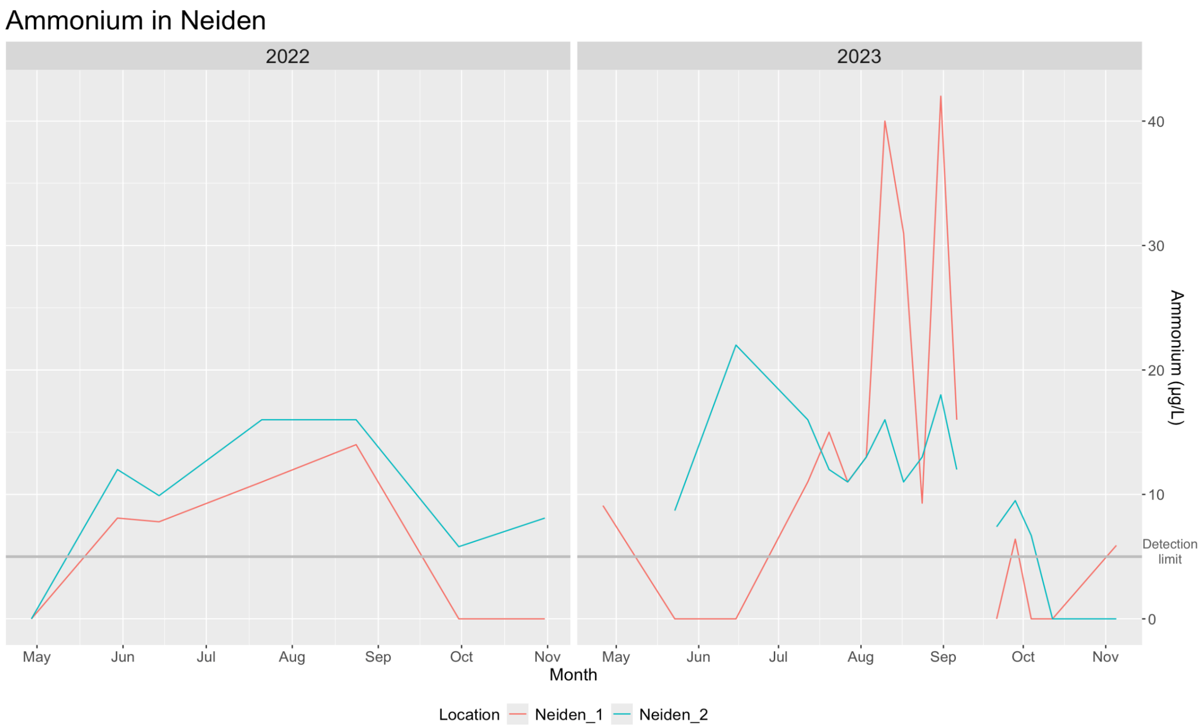
3.3.4 Ammonium

Measured ammonium levels in Tana and Pasvik rivers were below 13 µg/L between late June and early November in 2022 (Norsk institutt for vannforskning, 2023). During the same season, this study's rivers reached their lowest levels below the detection limit, and their highest in mid-July with levels between 14-16 µg/L at all stations in all rivers (*Figure 20-22*). The mean ammonium level was between 5.5-8.3 µg/L for Grense Jakobselv 1, Karpelva, Munkelva and Neiden 1.

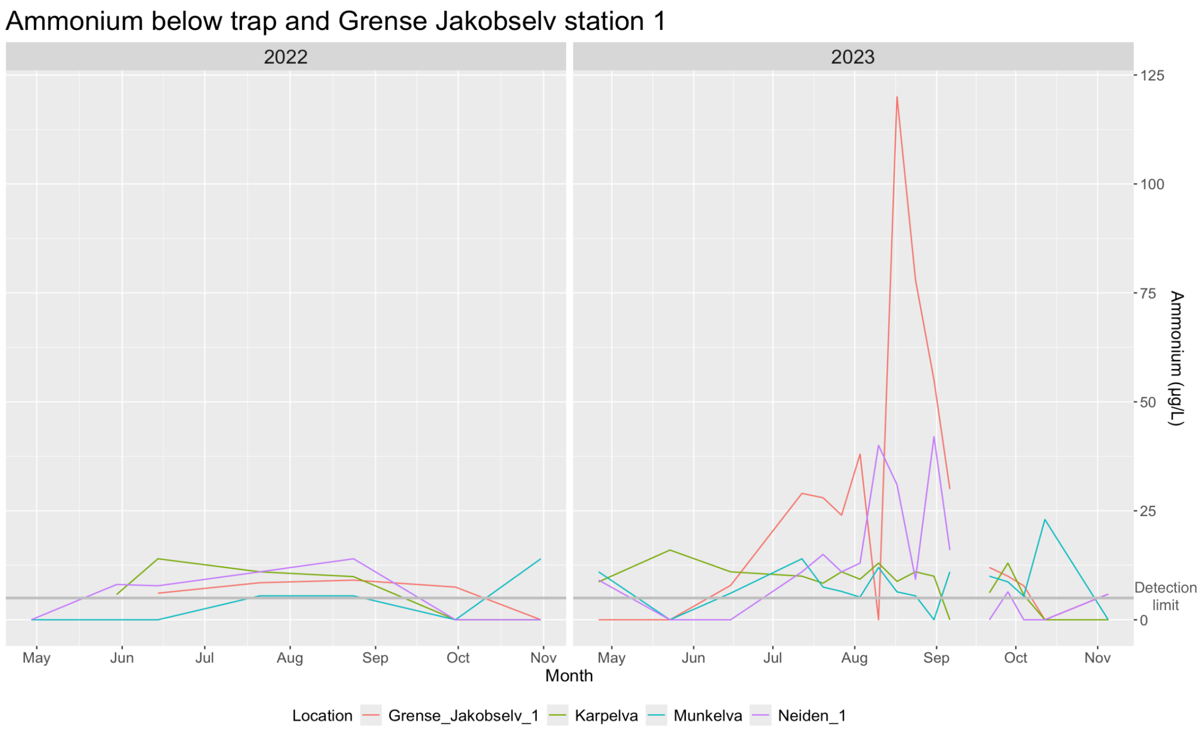
In 2023, ammonium levels fluctuated from middle of July to middle of October, ranging from below detection limit to 42 and 120 µg/L for Neiden 1 and Grense Jakobselv 1. The mean level was between 8.4-13.5 µg/L for Karpelva, Munkelva and Neiden 1, and 27 µg/L for Grense Jakobselv 1. There was no significant difference between the seasons at stations below the traps, between those stations in 2023, or between stations in Grense Jakobselv that season.



Figur 20 Measured level of Ammonium in Grense Jakobselv. *From samples collected through 2022 and 2023 season. Each station/location is colored, with measured level on the right side. Lower detection limit <5 µg/L.*



Figur 21 Measured level of Ammonium in Neiden. *From samples collected through 2022 and 2023 season. Each station/location is colored, with measured level on the right side. Lower detection limit <5 µg/L.*

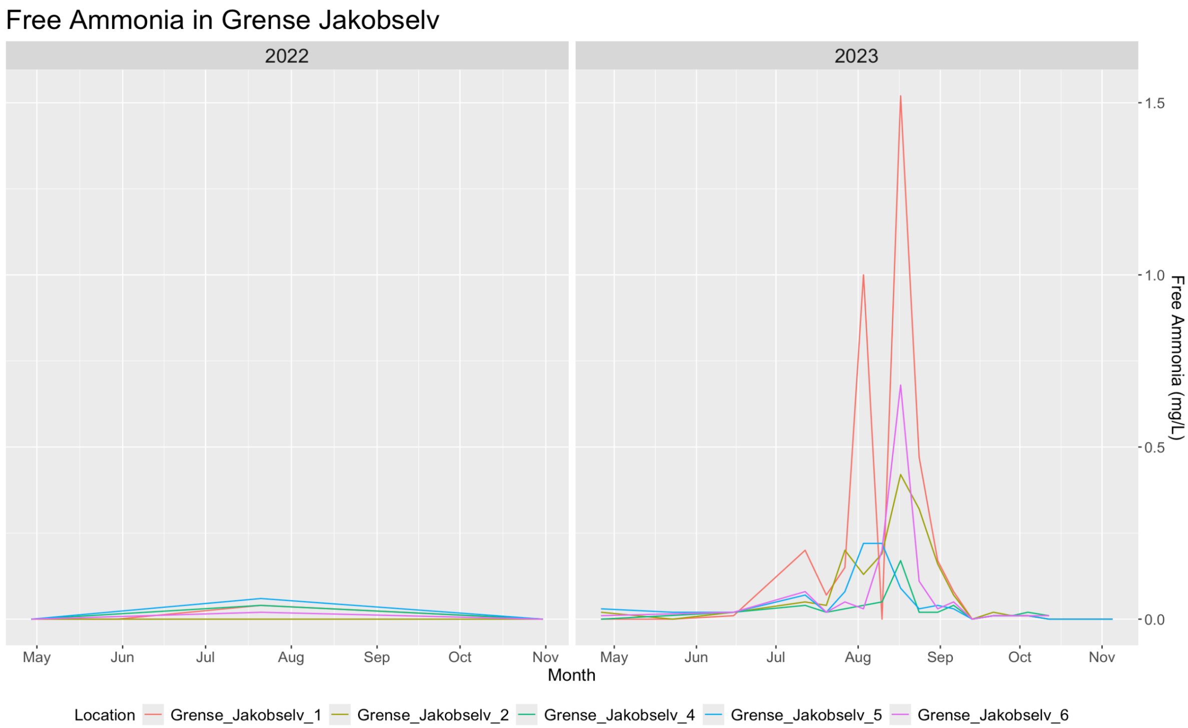


Figur 22 Measured level of ammonium at stations below trap and Grense Jakobselv station 1. *From samples collected through 2022 and 2023 season. Each station/location is colored, with measured level on the right side. Lower detection limit <5 µg/L.*

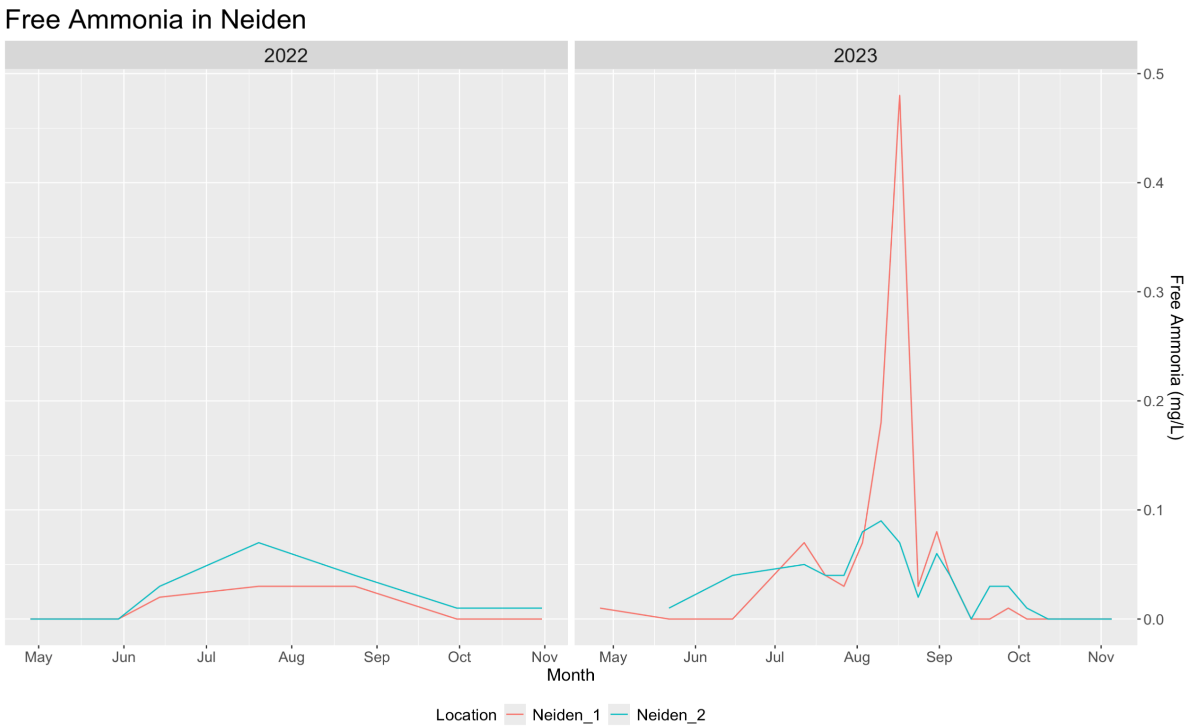
3.3.5 Free Ammonia

Measured levels of free ammonia for the 2022 season were slightly increasing between late April and late July at all stations in all rivers, (*Figure 23-25*), before slightly decreasing again until last sampling in late October. The level ranged from 0.00 mg/L at the lowest to 0.11 mg/L m at the highest, which was measured in Karpelva. The mean was between 0.01 and 0.03 mg/L for all stations in all rivers.

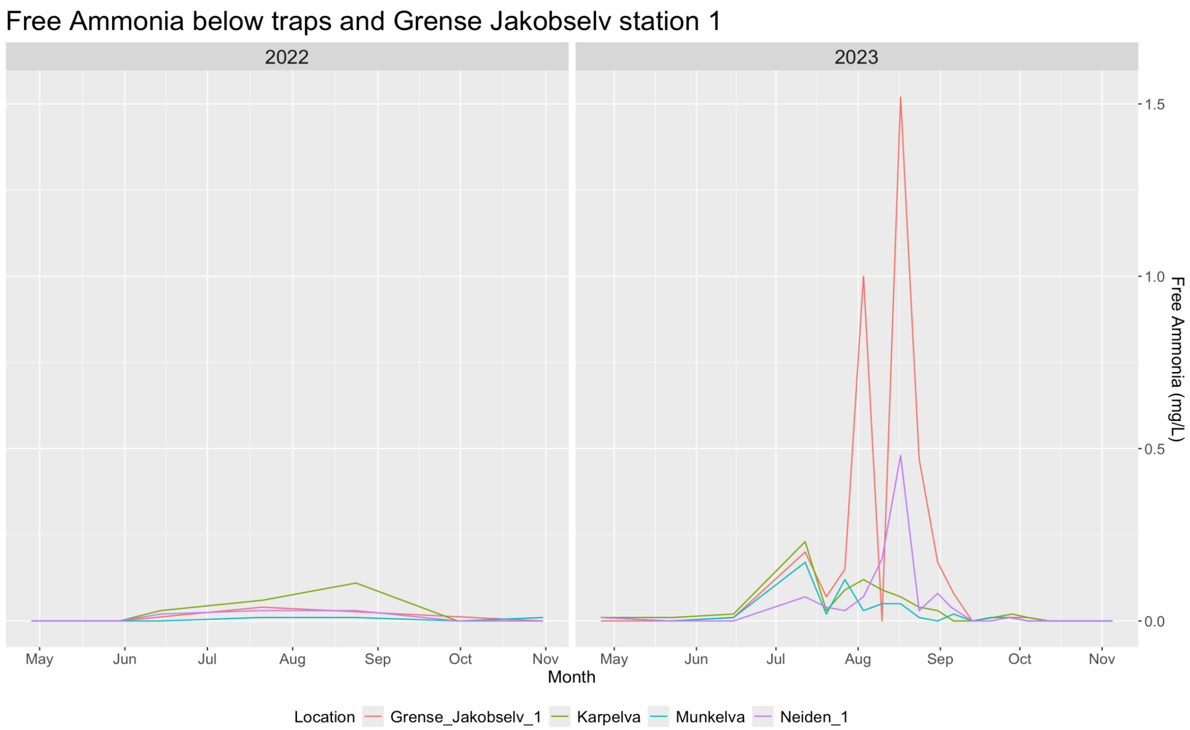
In 2023, the free ammonia level was mainly measured at 0.0 mg/L at the lowest for all stations but increased more steeply from mid-June compared to 2022. The period just past mid-July was characterized by a few large peaks, with Grense Jakobselv 1 and 6, and Neiden 1 showing values up to 1.52, 0.68 and 0.48 mg/L respectively. The mean was between 0.03-0.06 mg/L for Karpelva, Munkelv and Neiden. Noteworthy was the higher mean at Grense Jakobselv stations 2 and 6 at 0.09 mg/L and station 1 with 0.21 mg/L. There was no significant difference between seasons at stations below the traps, in 2023 between stations below traps or between stations in Grense Jakobselv in 2023.



Figur 23 Measured level of Free Ammonia in Grense Jakobselv. *From samples collected through 2022 and 2023 season. Each station/location are colored, with measured level on the right side.*



Figur 24 Measured level of Free Ammonia in Neiden. *From samples collected through 2022 and 2023 season. Each station/location are colored, with measured level on the right side.*

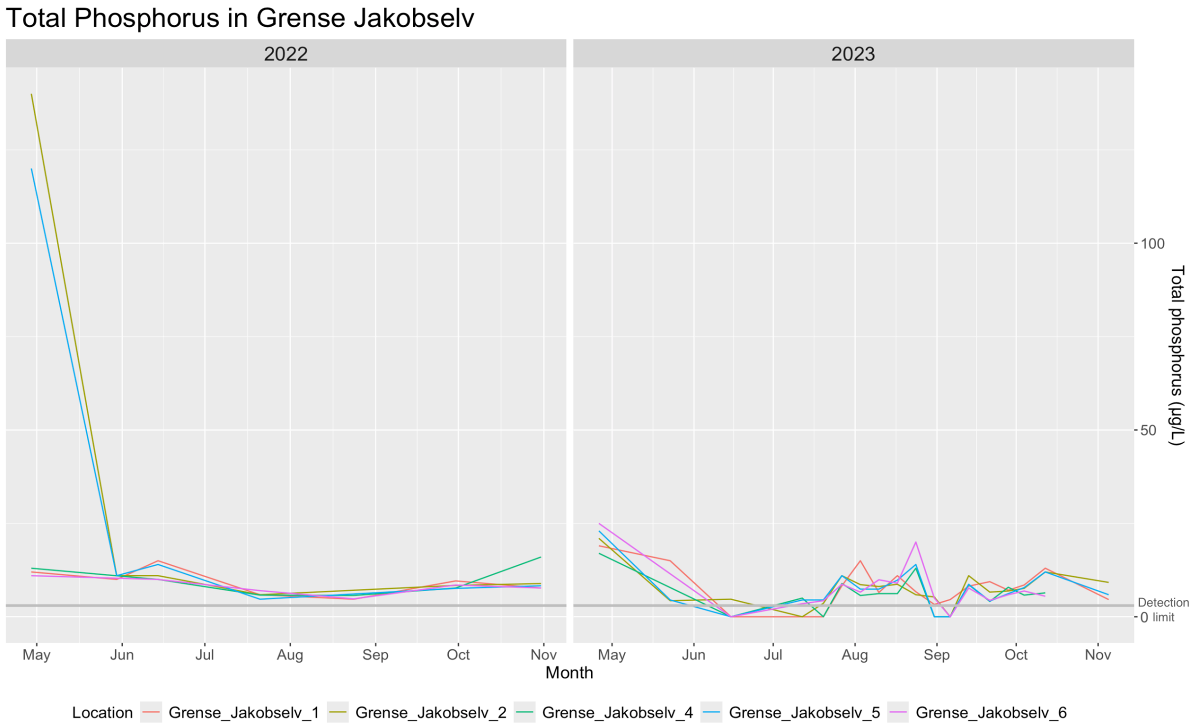


Figur 25 Measured level of Free Ammonia below traps and Grense Jakobselv station 1*. From samples collected through 2022 and 2023 season. Each station/location is colored, with measured level on the right side.*

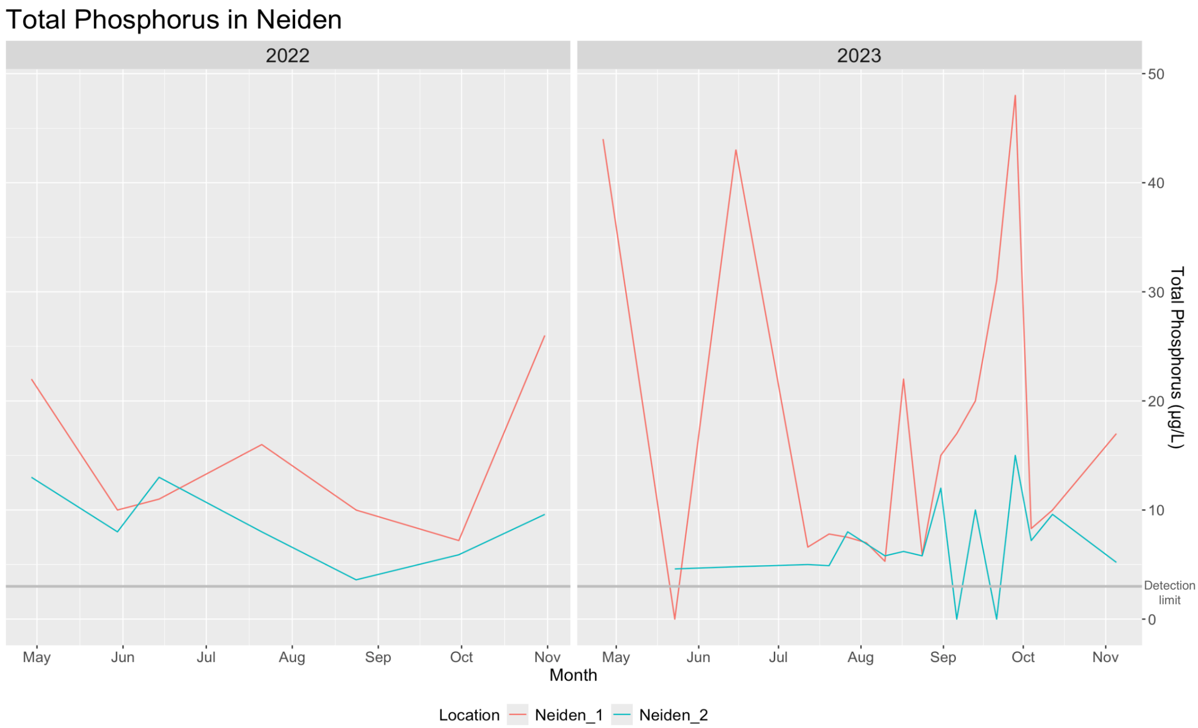
3.3.6 Total Phosphorus

Between early April and early November, level of total phosphorus was measured below 8 µg/L in Tana and Pasvik (Norsk institutt for vannforskning, 2023). This study's river Grense Jakobselv had at station 2 and 5 remarkably high levels at the start of 2022 season, with 140 and 120 µg/L, respectively (*Figure 26*). In general, levels at all stations decreased during start of season (*Figure 26-28*), was slightly elevated in June or July, at the lowest in September and October before increasing again through fall. Levels was at the lowest between 3.6 and 7.3 µg/L for all stations, with a mean between 8.2 and 8.9 µg/L, except for Grense Jakobselv stations 2 and 5 at 27.5 and 24.5 µg/L, and Neiden 1 with 14.6 µg/L.

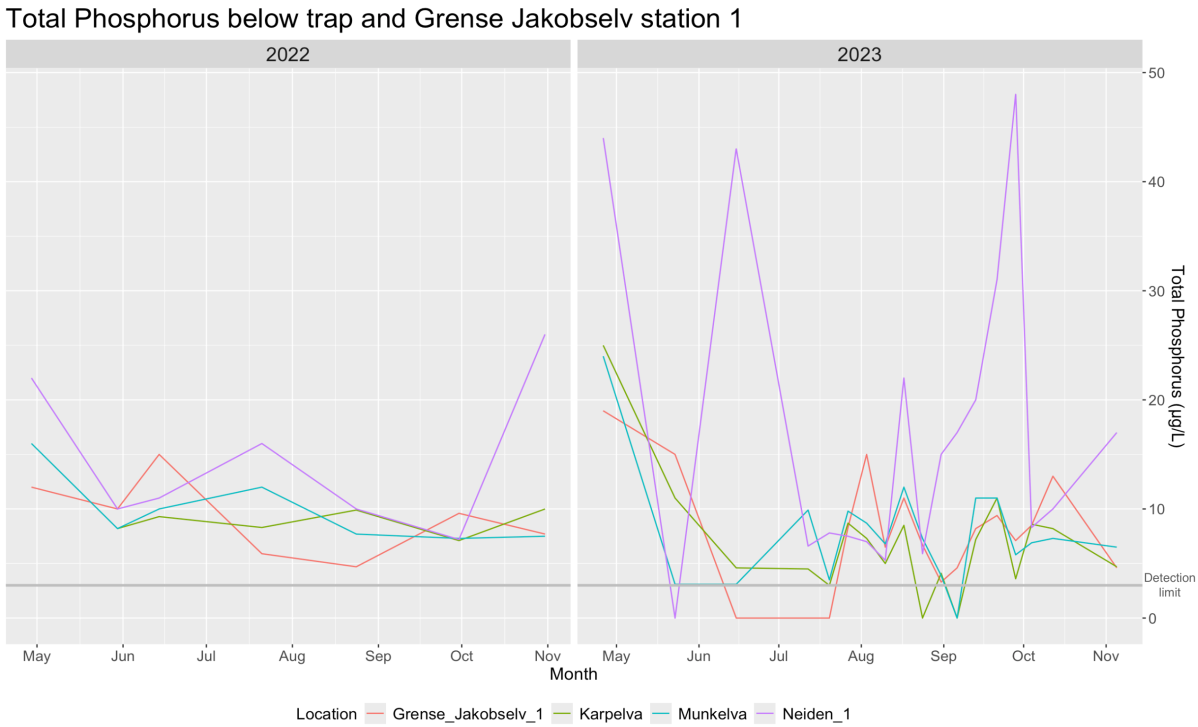
From mid-July, levels of total phosphorus were generally fluctuating at all stations, with levels ranging from below detection limit and up to 25 µg/L. Neiden 1 was more singular with values ranging over 40 µg/L in the start of the season, middle of June, and in late September. The mean was between 6.5 and 8.1 µg/L for all stations, and 17.6 µg/L for Neiden 1. There was no significant difference between the seasons for stations below trap, or between stations in Grense Jakobselv in 2023, but a significant difference between Karpelva and Neiden 1 that season.



Figur 26 Measured level of Total Phosphorus in Grense Jakobselv. *From samples collected through 2022 and 2023 season. Each station/location is colored, with measured level on the right side. Lower detecion limit <3µg/L.*



Figur 27 Measured level of Total Phosphorus in Neiden. *From samples collected through 2022 and 2023 season. Each station/location is colored, with measured level on the right side. Lower detecion limit <3 µg/L.*

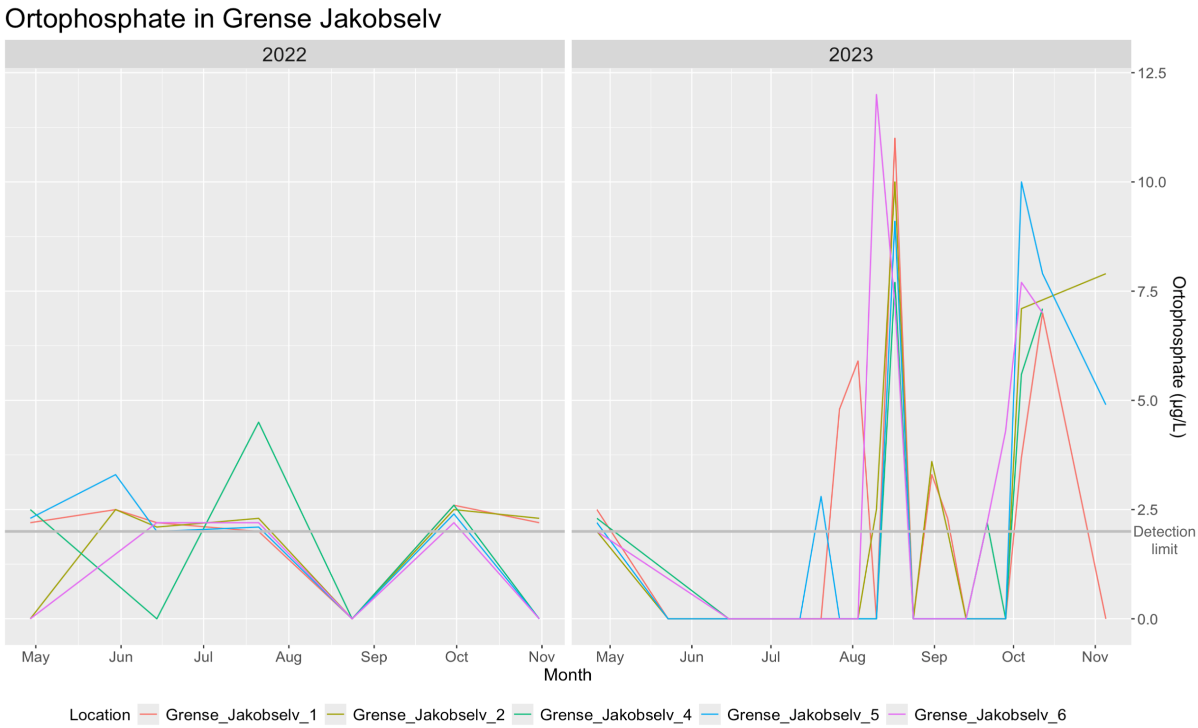


Figur 28 Measured level of Total Phosphorus below trap and Grense Jakobselv station 1. *From samples collected through 2022 and 2023 season. Each station/location is colored, with measured level on the right side. Lower detection limit <3µg/L.*

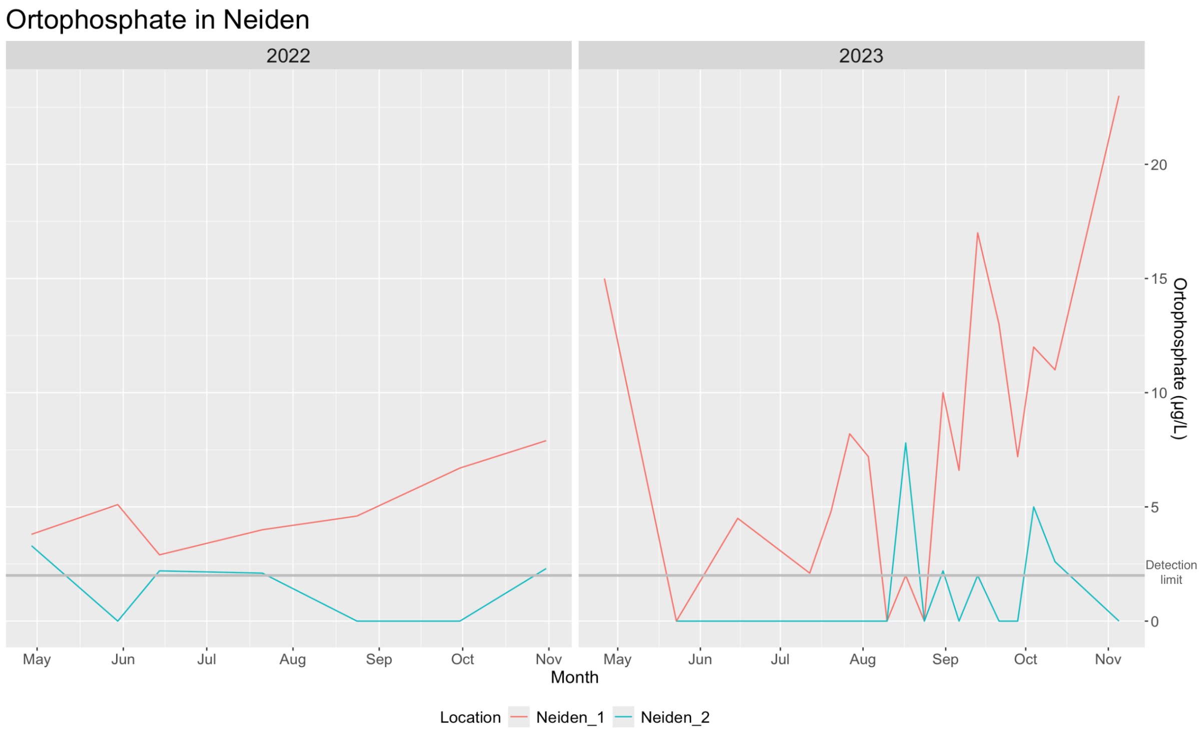
3.3.7 Orthophosphate

Measured levels of orthophosphate in Tana and Pasvik rivers remained below 3 µgP/L throughout the 2022-season (Norsk institutt for vannforskning, 2023). In the rivers of this study, the level gradually increased and decreased from below detection limit, and just above for most stations, with Grense Jakobselv 4 reaching up to 3.3 µg/L (*Figure 29-31*). Neiden station 1 had higher and gradually increasing levels throughout the season, ending it with 7.9 µg/L. The mean was between 1.8 and 2.6 µg/L for all stations, except Neiden 1 at 5.0 µg/L.

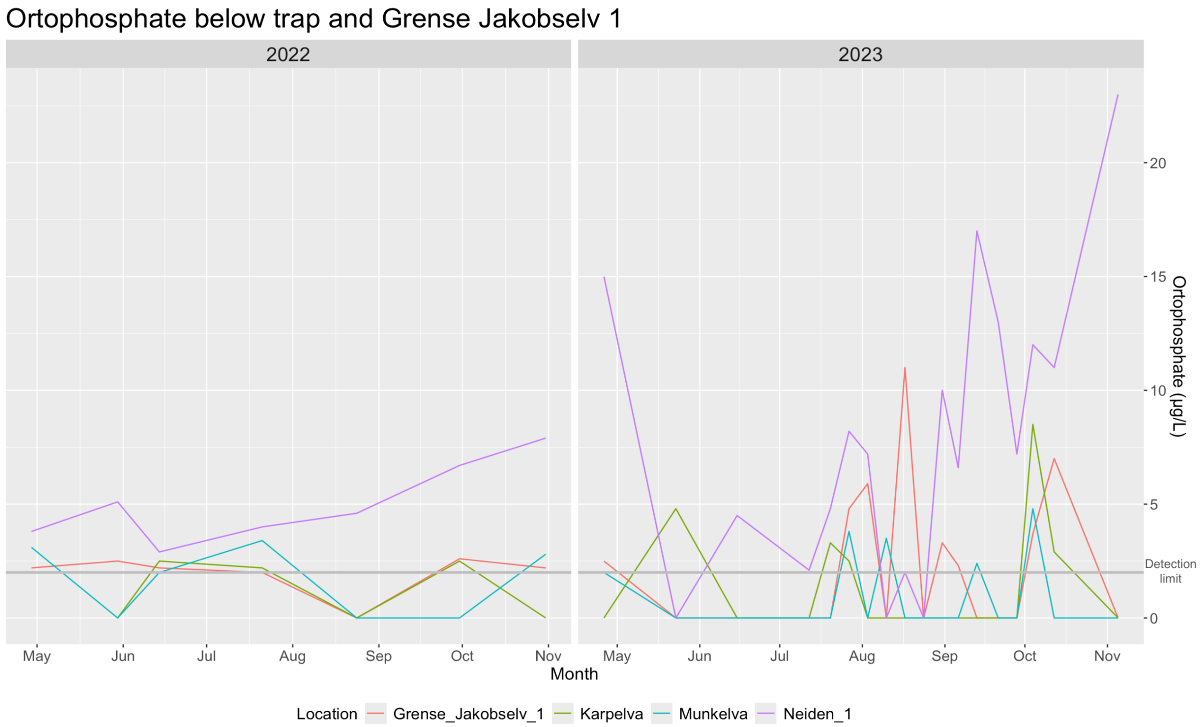
In 2023 levels of orthophosphate generally fluctuated from mid-July through august fluctuating, before decreasing to the detection limit in September and ending with a peak in early October. Values ranged from below the detection limit up to between 7.7-12 µg/L for stations in Grense Jakobselv, 8.5 µg/L for Karpelva, and 4.8 µg/L Munkelva. Neiden station 1 followed a more distinctive pattern, with a level of 15 µg/L at the start of the season, higher peak values compared to the rest of the rivers (one peak ranging up to 17 µg/L), and ending the season at 23 µg/L. The mean was between 2.13-3.5 µg/L for all rivers and stations, except Neiden 1 at 8.3 µg/L. There was no significant difference between the seasons at stations below traps or at stations in Grense Jakobselv in 2023, but a significant difference was observed between Neiden 1 and the rest of the stations below traps in that season.



Figur 29 Measured level of orthophosphate (µg/L) in Grense Jakobselv. *From samples collected through 2022 and 2023 season. Each station/location is colored, with measured level on the right side and detection limit > 2 µg/L.*



Figur 30 Measured level of Orthophosphate in Neiden. *From samples collected through 2022 and 2023 season. Each station/location is colored, with measured level on the right side. Detection limit <2 µg/L.*

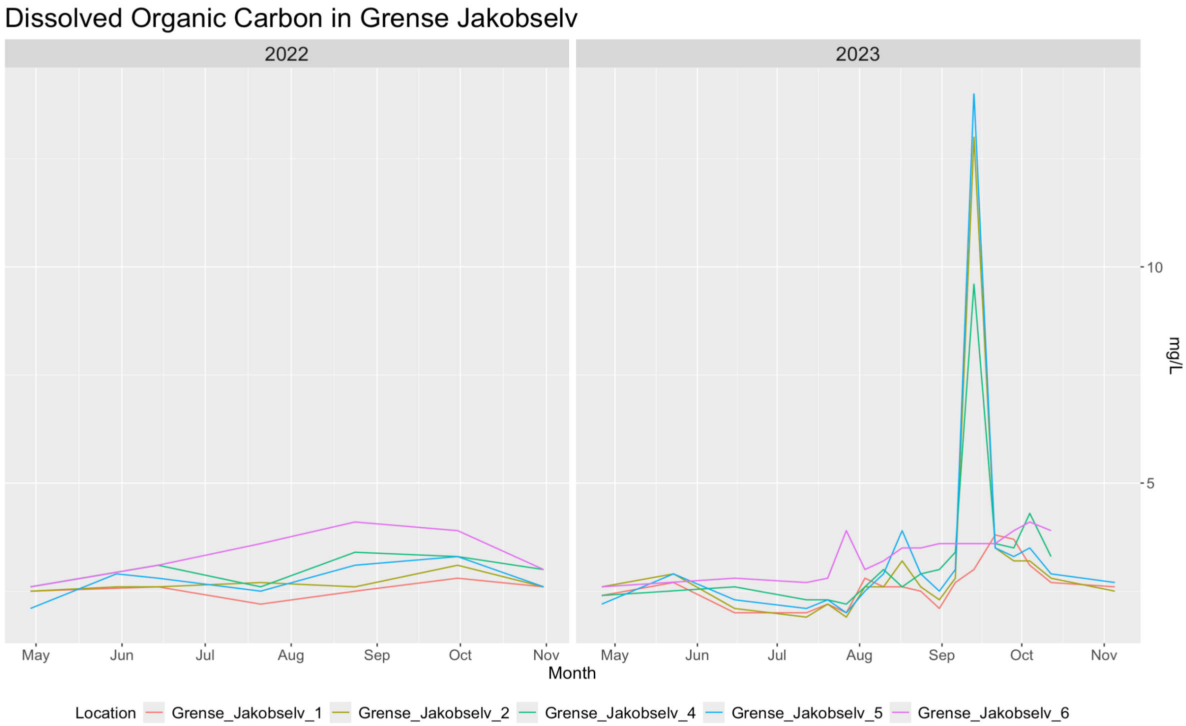


Figur 31 Measured level of Orthophosphate below traps and Grense Jakobselv station 1. *From samples collected through 2022 and 2023 season. Each station/location is colored, with measured level on the right side. Detection limit <2 µg/L.*

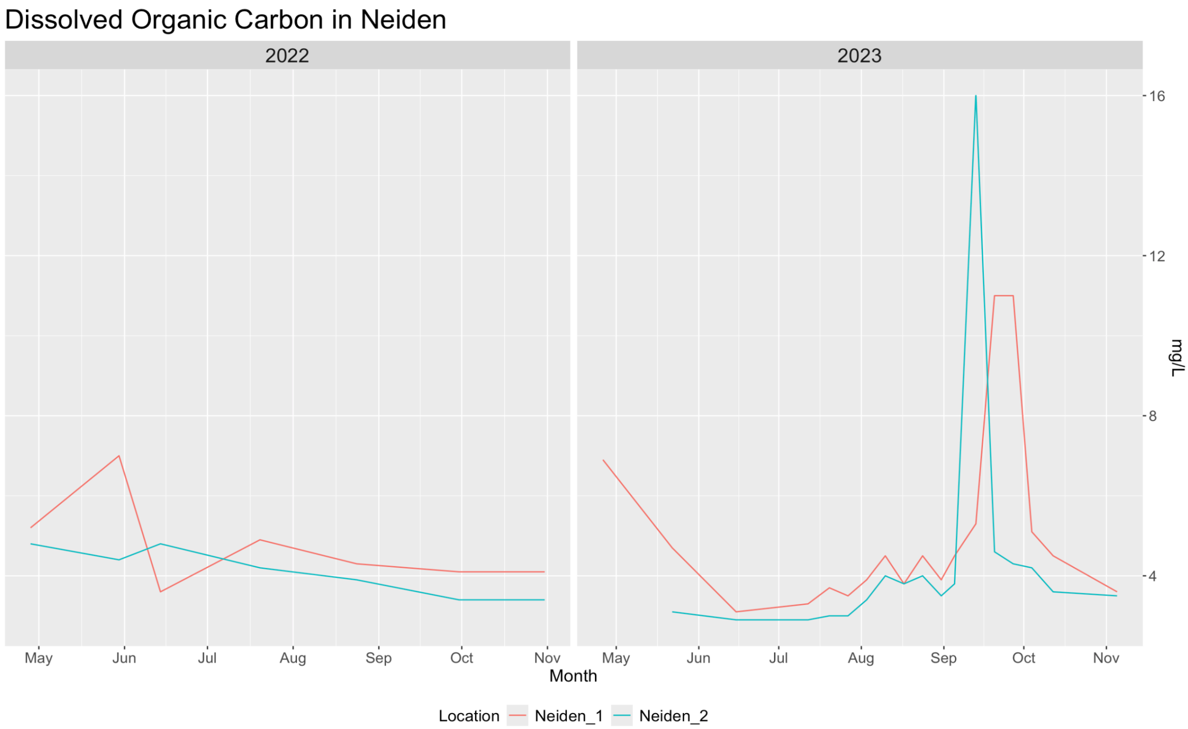
3.3.8 Dissolved Organic Carbon (DOC)

The highest measured value of DOC in Tana and Pasvik rivers was 4.3 mg/L throughout the whole 2022 season (Norsk institutt for vannforskning, 2023). In this study's rivers, the level of DOC varied between stations, but generally remained stable or slightly increasing or decreasing throughout the 2022 season (*Figure 32-34*). However, Munkelva and Neiden 1 showed a greater range, including values up to 6.3 and 7 mg/L. The mean was 2.6-3.4 mg/L for stations in Grense Jakobselv, and between 4.03 and 4.74 mg/L for the rest of the stations.

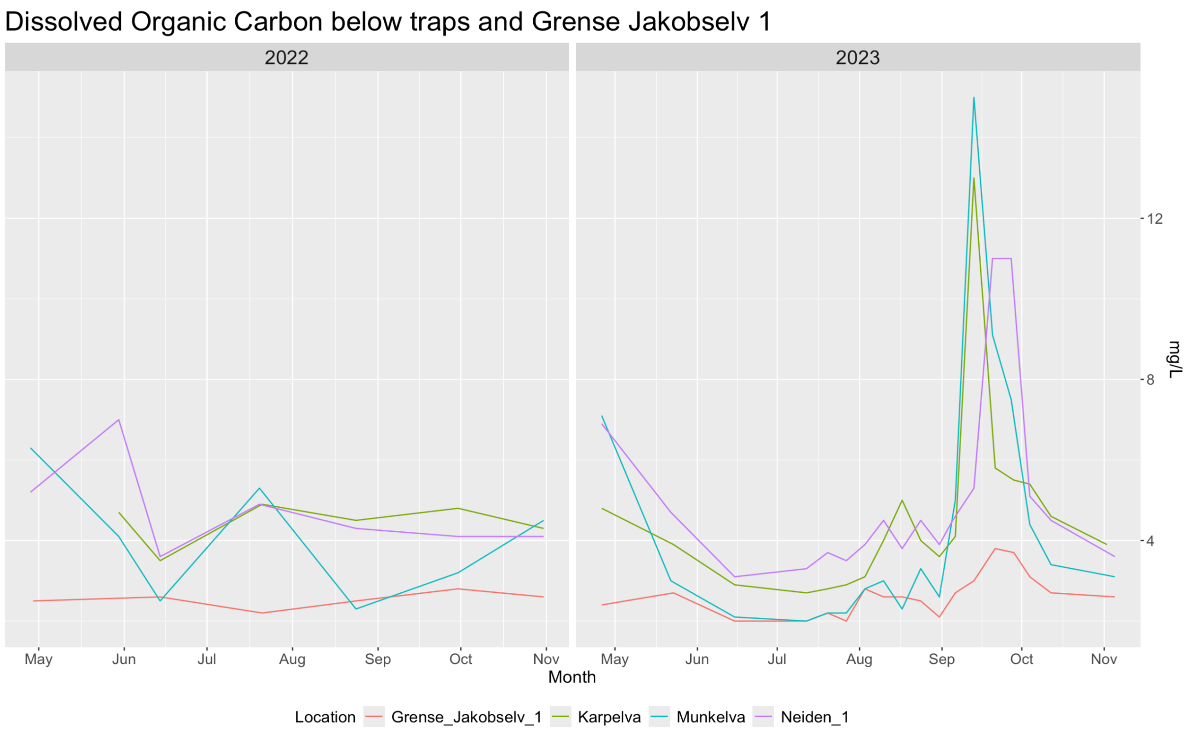
In 2023, the measured level of DOC had minor fluctuations from the middle of July through August, before a large peak in the first part of September. The values ranged up to 9.6, 13.0, and 14.0 mg/L for Grense Jakobselv 4, 2 and 5, and between 11.0-16.0 mg/L for Karpelva, Munkelv, and both stations in Neiden. The mean for stations in Grense Jakobselv was between 2.6 and 3.4 mg/L, and between 4.5 and 5.6 mg/L for stations in the remaining rivers. There was no significant difference between the seasons, but in 2023 a significant difference was observed for Grense Jakobselv 1 compared to Karpelva and Neiden, and for Grense Jakobselv station 6 compared to station 1 and 2.



Figur 32 Measured level of Dissolved Organic Carbon in Grense Jakobselv. *From samples collected through 2022 and 2023 season. Each station/location is colored, with measured level on the right side.*



Figur 33 Measured level of Dissolved Organic Carbon in Neiden*. From samples collected through 2022 and 2023 season. Each station/location is colored, with measured level on the right side.*

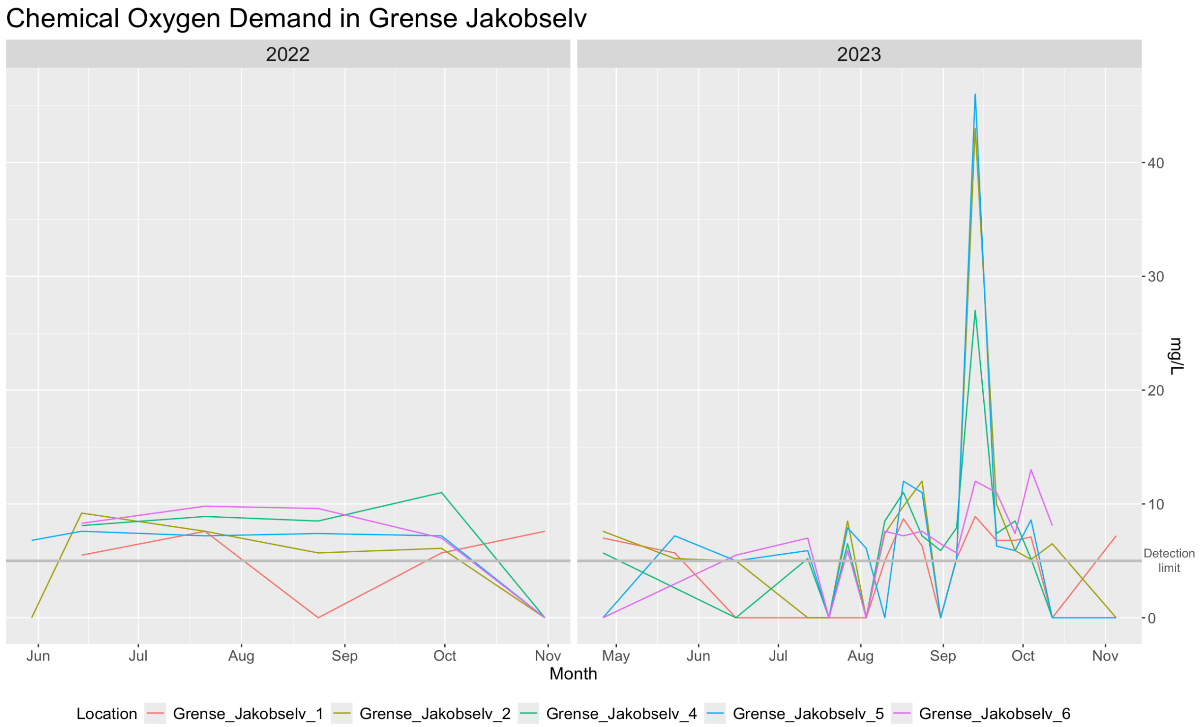


Figur 34 Measured level of Dissolved Organic Carbon below trap and Grense Jakobselv station 1*. From samples collected through 2022 and 2023 season. Each station/location is colored, with measured level on the right side.*

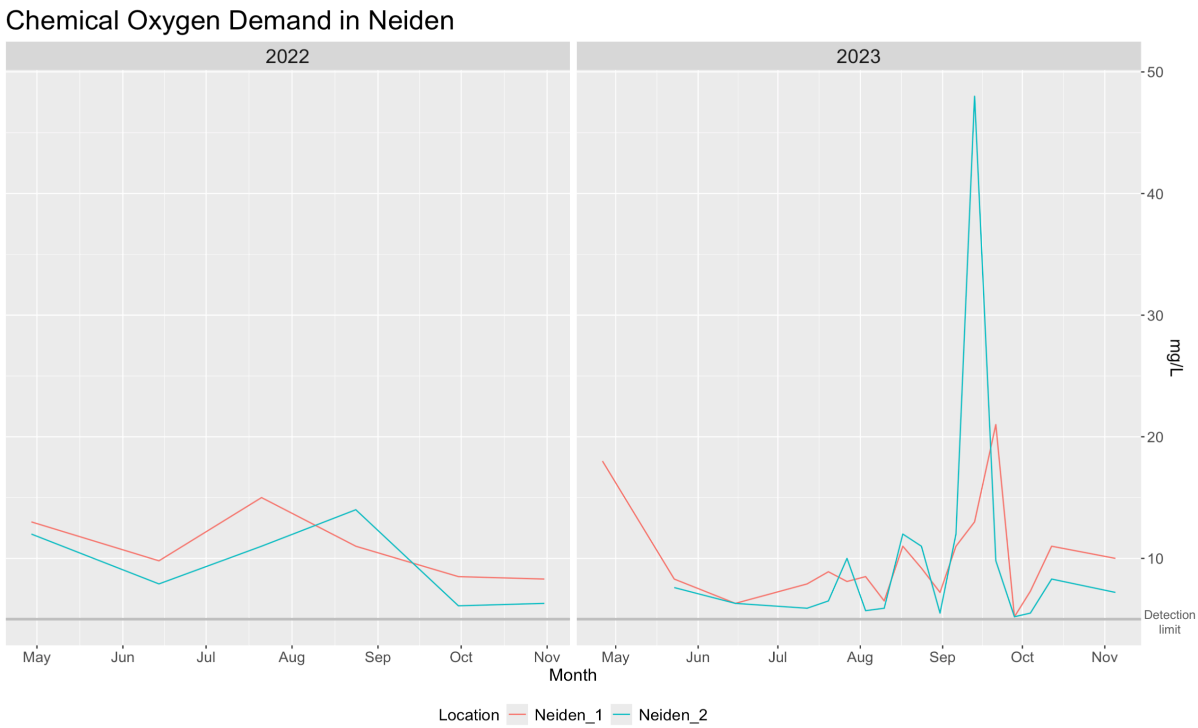
3.3.9 Chemical Oxygen Demand (COD)

Measured level of COD in 2022 remained stable or slightly increased and decreased for all stations in all rivers (*Figure 35-37*). In Grense Jakobselv, levels ranged from below the detection limit and up to 9.8 mg/L, while for the remaining rivers, levels reached between 13-15 mg/L. The mean was between 5.9 and 8.3 mg/L for stations in Grense Jakobselv, and between 9.6 and 11.2 mg/L for the remaining rivers.

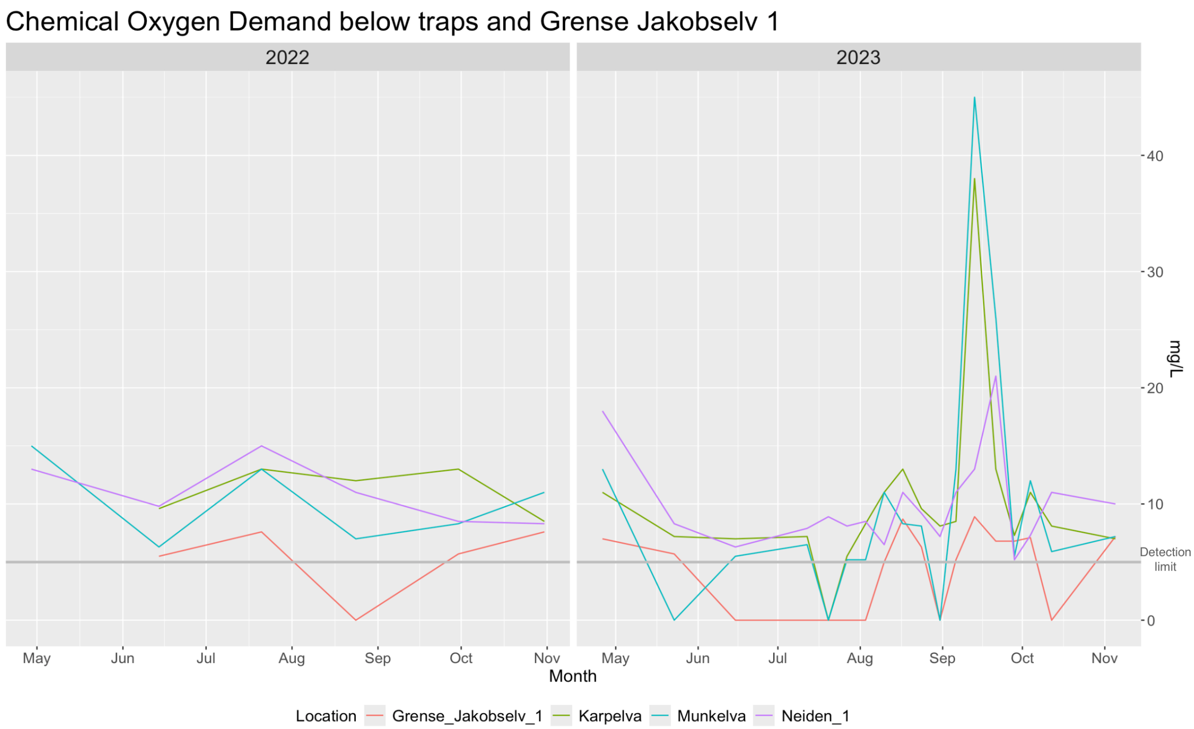
In 2023, levels of COD were measured lower at the start of season at all stations, compared to the previous year. From mid-July, fluctuating levels characterized the rest of the season, including a major peak in the first part of September with values reaching up to 43, 27 and 46 mg/L for station 2, 4 and 5 in Grense Jakobselv. Levels reached up to 21 mg/L for Neiden 1 and between 38 and 48 mg/L for Neiden 2, Karpelva, and Munkelva. There was no significant difference between the seasons or when comparing stations in Grense Jakobselv in 2023, but a significant difference was observed in the latter season between Grense Jakobselv 1 and both Karpelva and Neiden 1.



Figur 35 Measured level of Chemical Oxygen Demand in Grense Jakobselv. *From samples collected through 2022 and 2023 season. Each station/location is colored, with measured level on the right side.*



Figur 36 Measured level of Chemical Oxygen Demand in Neiden. *From samples collected through 2022 and 2023 season. Each station/location is colored, with measured level on the right side.*



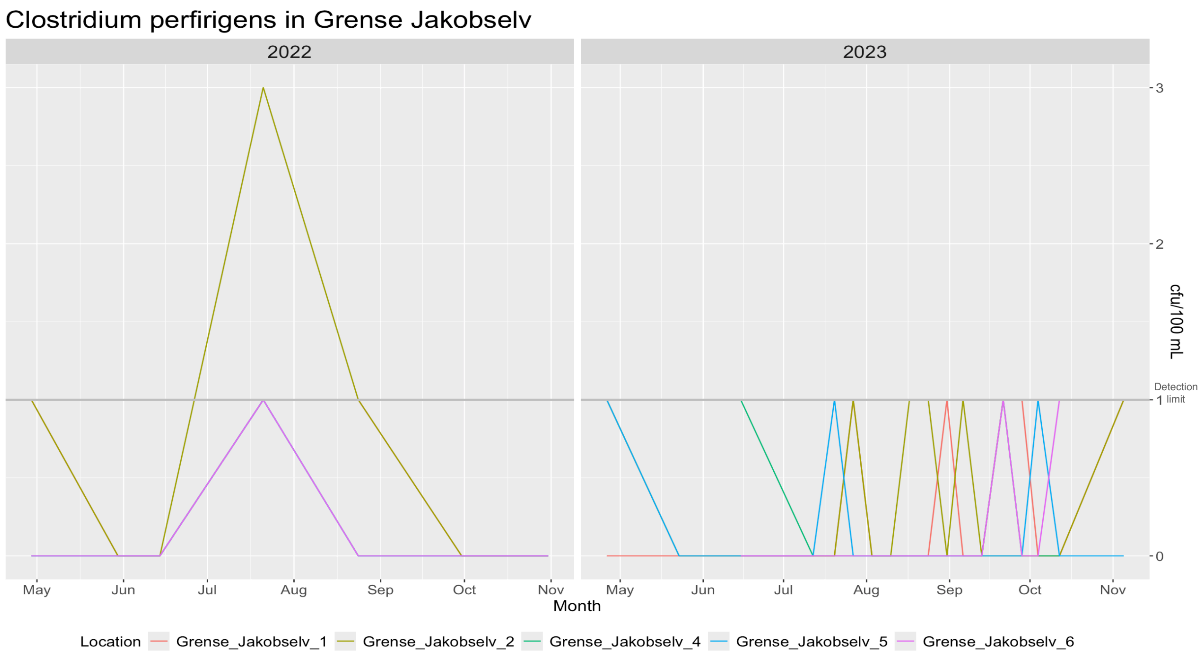
Figur 37 Measured level of Chemical Oxygen Demand below traps and Grense Jakobselv station 1. *From samples collected through 2022 and 2023 season. Each station/location is colored, with measured level on the right side.*

3.4 Microbial water quality

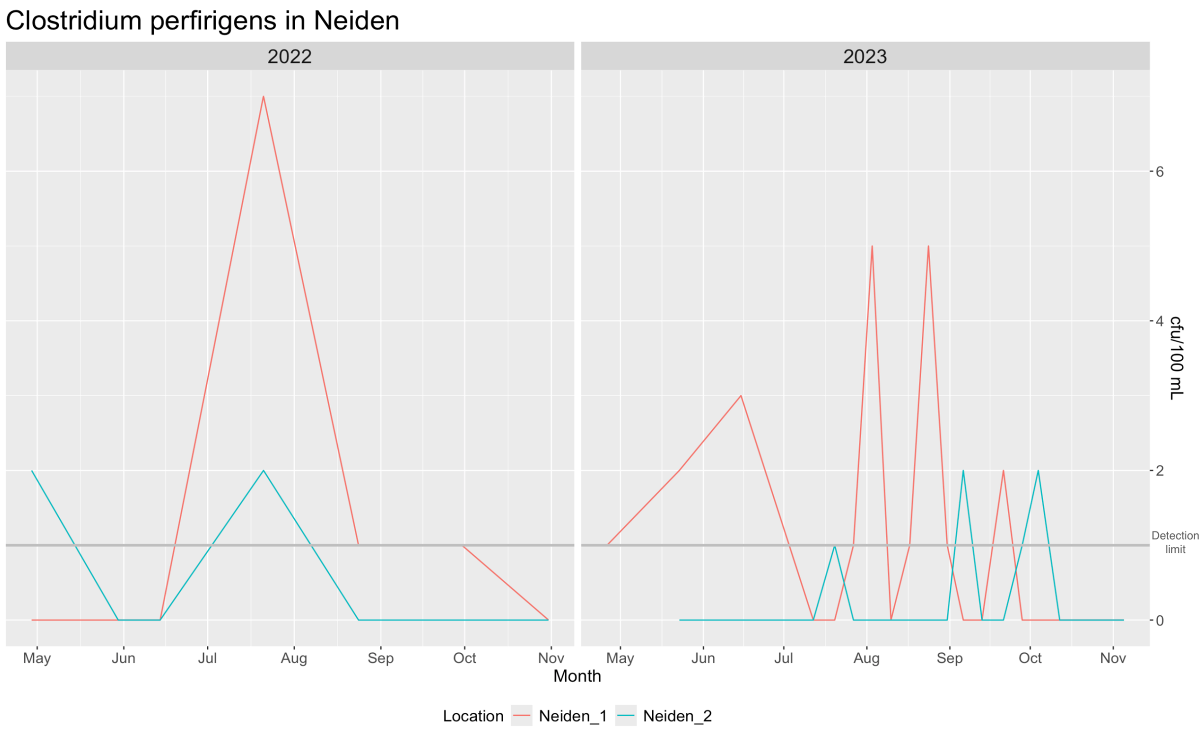
3.4.1 *Clostridium perfirigens*

The measured level of *Clostridium perfirigens* mainly stayed between below or just above detection limit throughout 2022 (*Figure 38-40*), except for one peak in the middle of July, with values ranging up to 13 cfu/100 mL for Munkelva and between 1-7 cfu/100 mL for the remaining stations. The mean was below the detection limit for the majority of stations in Grense Jakobselv, between 1.03 and 1.17 cfu/100 mL for Grense Jakobselv 2, Karpelva, stations in Neiden, and 2.35 cfu/100 mL for Munkelva.

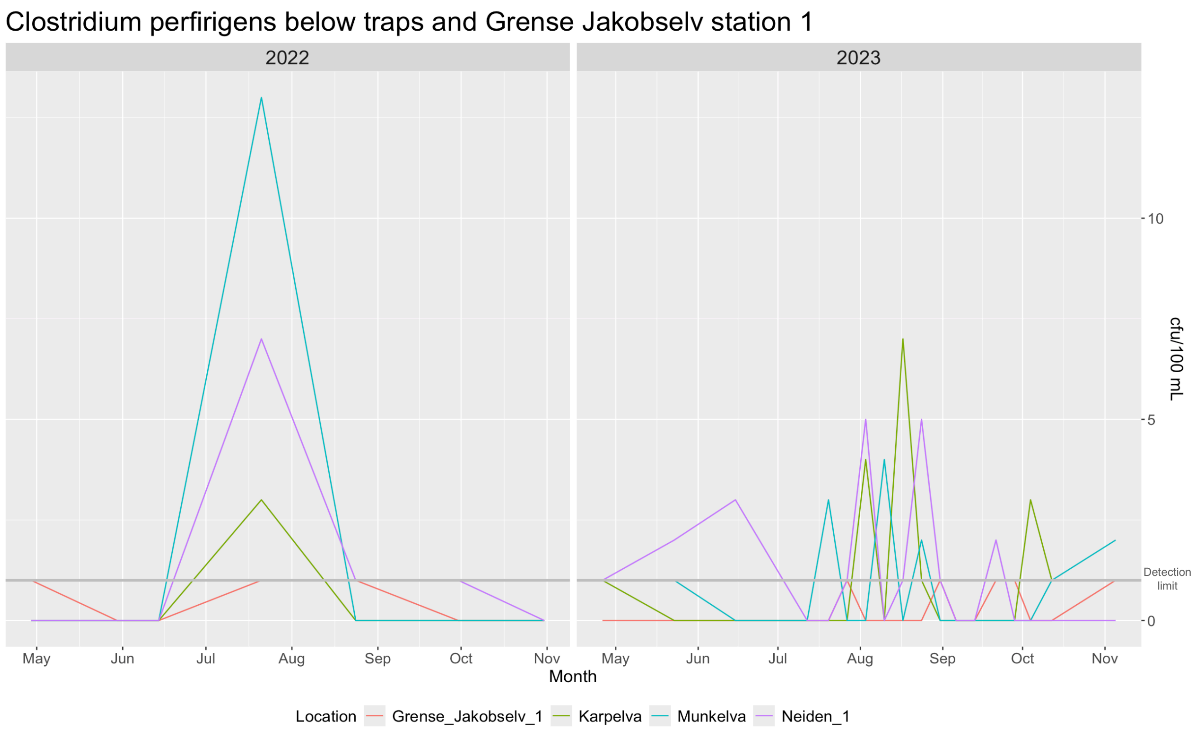
In 2023, all stations in Grense Jakobselv had levels below or just above detectable throughout the whole season. The other rivers had fluctuating values from the middle of July, at the lower range in first part of September before increasing again, with levels between the detection limit and in the upper range between 4-7 cfu/100 mL. The mean was between 1.18-1.51 cfu/100 mL for Karpelva, Munkelva and Neiden 1, and below the detection limit for the remaining stations.



Figur 38 Measured level of Clostridium perfirigens in Grense Jakobselv. *From samples collected through 2022 and 2023 season. Each station/location is colored, with measured level (cfu/100 mL) on the right side.*



Figur 39 Measured level of Clostridium in Neiden. *From samples collected through 2022 and 2023 season. Each station/location is colored, with measured level (cfu/100 mL) on the right side of figure.*

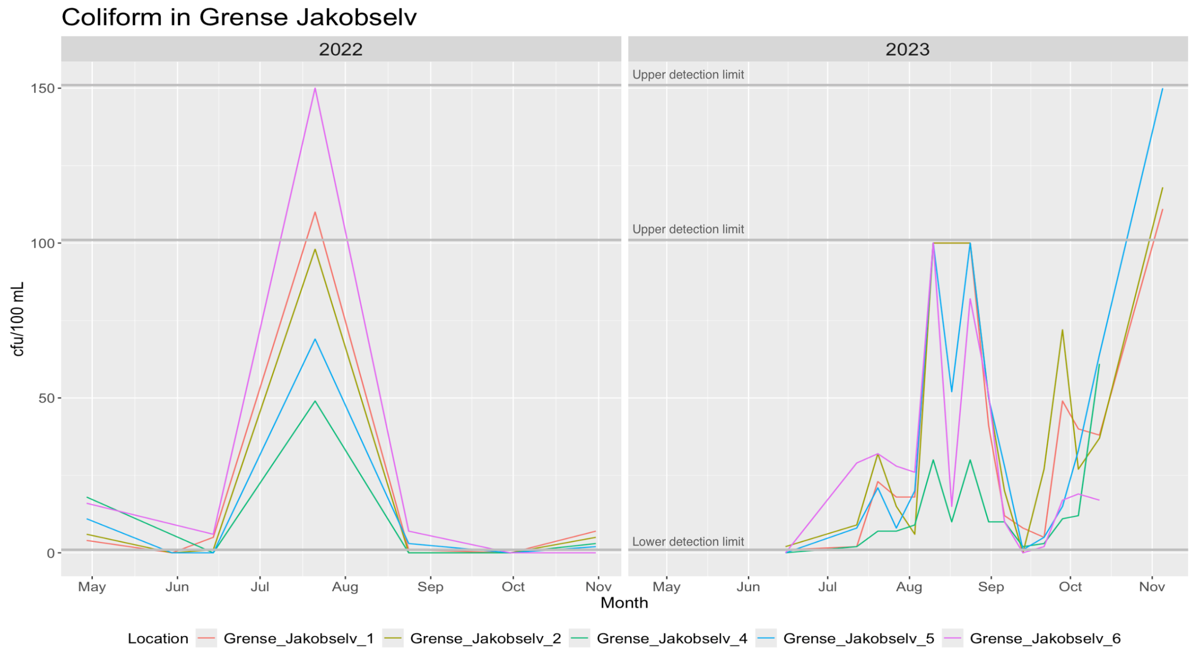


Figur 40 Measured level of Clostridium perfirigens below traps and Grense Jakobselv station 1. *From samples collected through 2022 and 2023 season. Each station/location is colored, with measured level (cfu/100 mL) on the right side.*

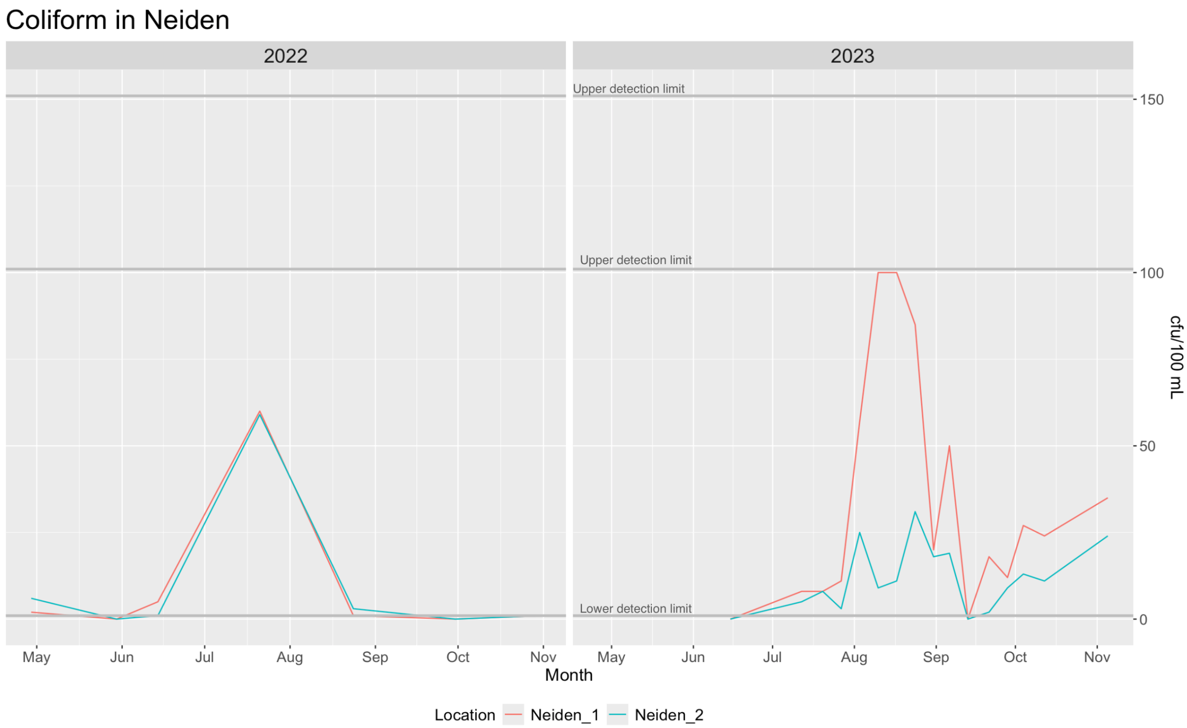
3.4.2 Coliform

The measured level of coliform at all stations in all rivers slightly decreased through the first months of sampling in 2022 (*Figure 41-43*), before a major peak in mid-July, followed by a sharp decrease to lower levels throughout the last months again. Values ranged from below detection limit, and at the peak, between 49 and 150 cfu/100 mL, the latter being the upper detection limit for this season. The mean for the whole season was between 10.1 and 12.5 cfu/100 mL for stations in Neiden and the middle stations of Grense Jakobselv. At the upper range, Karpelva, Munkelva, and Grense Jakobselv 6 had a mean between 24.2 and 30.0 cfu/100mL.

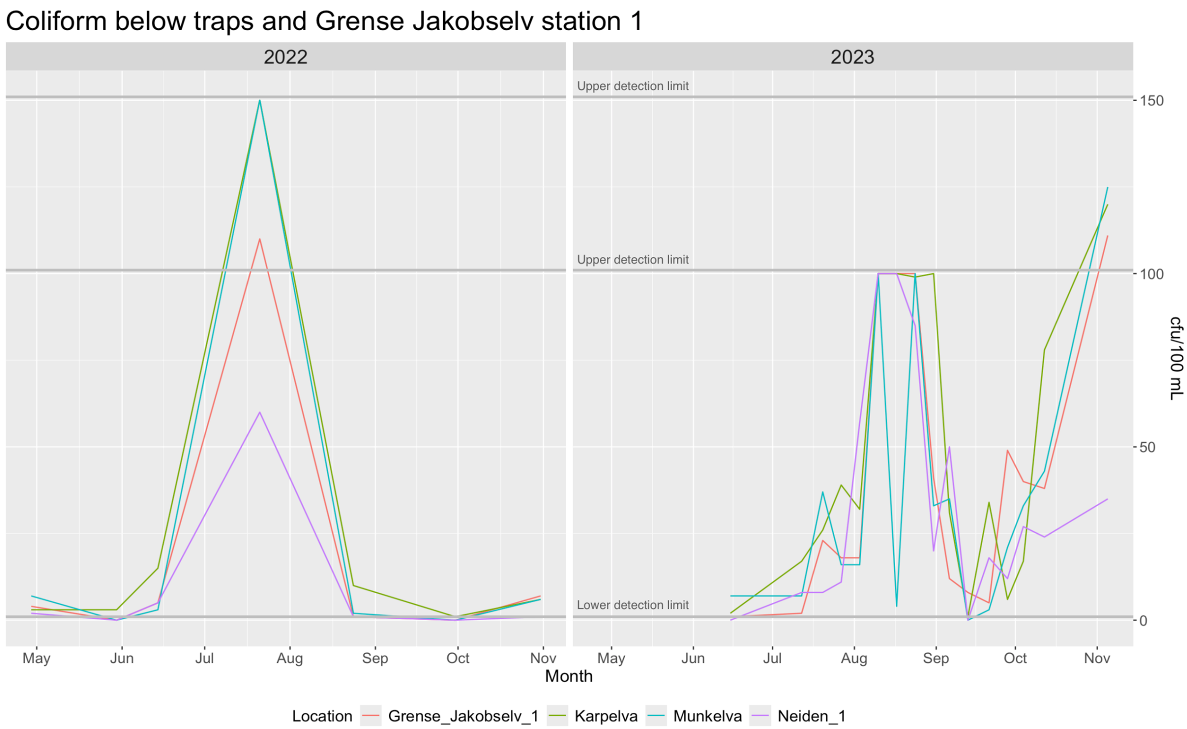
In 2023, there was a smaller peak in late July, followed by one or two major peaks reaching the upper detection limit for the season at 100 cfu/100 mL. This was followed by a steep decrease in the first part of September and an increase towards the season's last sampling, where some stations in Grense Jakobselv had values between 111 and 150 cfu/mL. The mean was between 27.4 and 47.5 cfu/100 mL for most stations, except Grense Jakobselv 4 with 14.2 cfu/100 mL and Neiden 2 with 11.8 cfu/100 mL. There was a significant difference between the seasons, but no significant difference between stations below traps in 2023 or between stations in Grense Jakobselv in the last-mentioned season.



Figur 41 Measured level of Coliform in Grense Jakobselv. *From samples collected through 2022 and 2023 season. Each station/location is colored, with measured level (cfu/100 mL) on the right side. Lower detection limit >1, upper detection limit was both <100 and <150 cfu/100 mL.*



***Figur 42 Measured level of Coliform in Neiden. From** samples collected through 2022 and 2023 season. Each station/location is colored, with measured level (cfu/100 mL) on the right side. Lower detection limit >1, upper detection limit was both <100 and <150.*

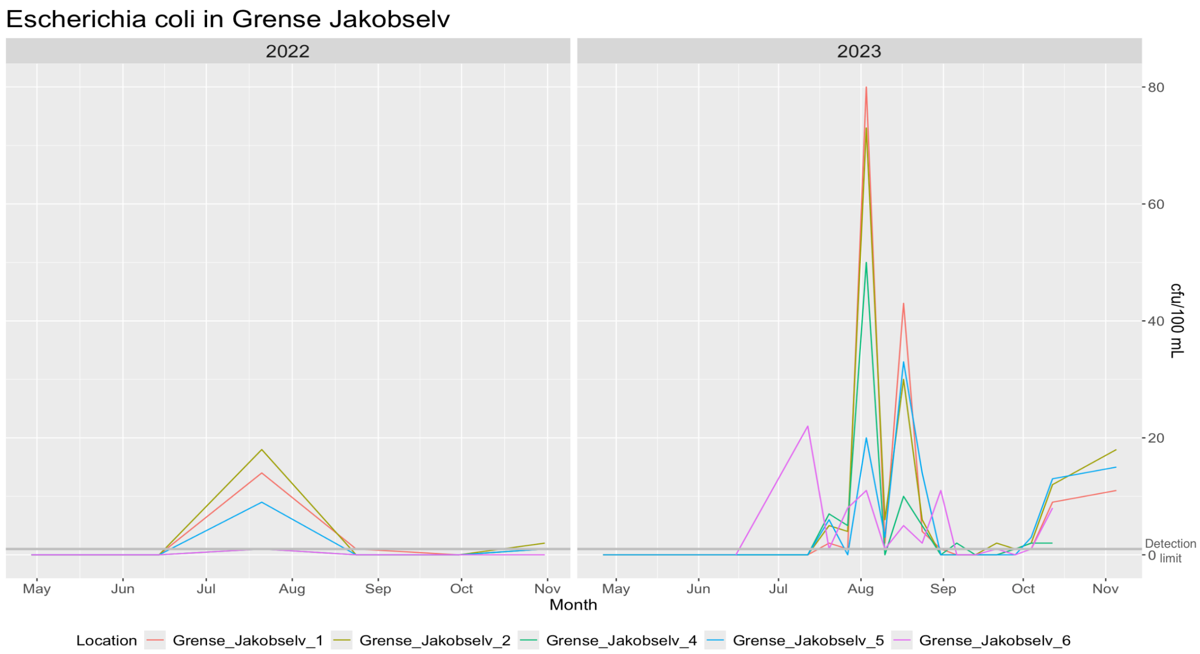


***Figur 43 Measured level of Coliform below traps and in Grense Jakobselv station 1.** From samples collected through 2022 and 2023 season. Each station/location is colored, with measured level (cfu/100 mL) on the right side. Lower detection limit >1, upper detection limit was both <100 and <150.*

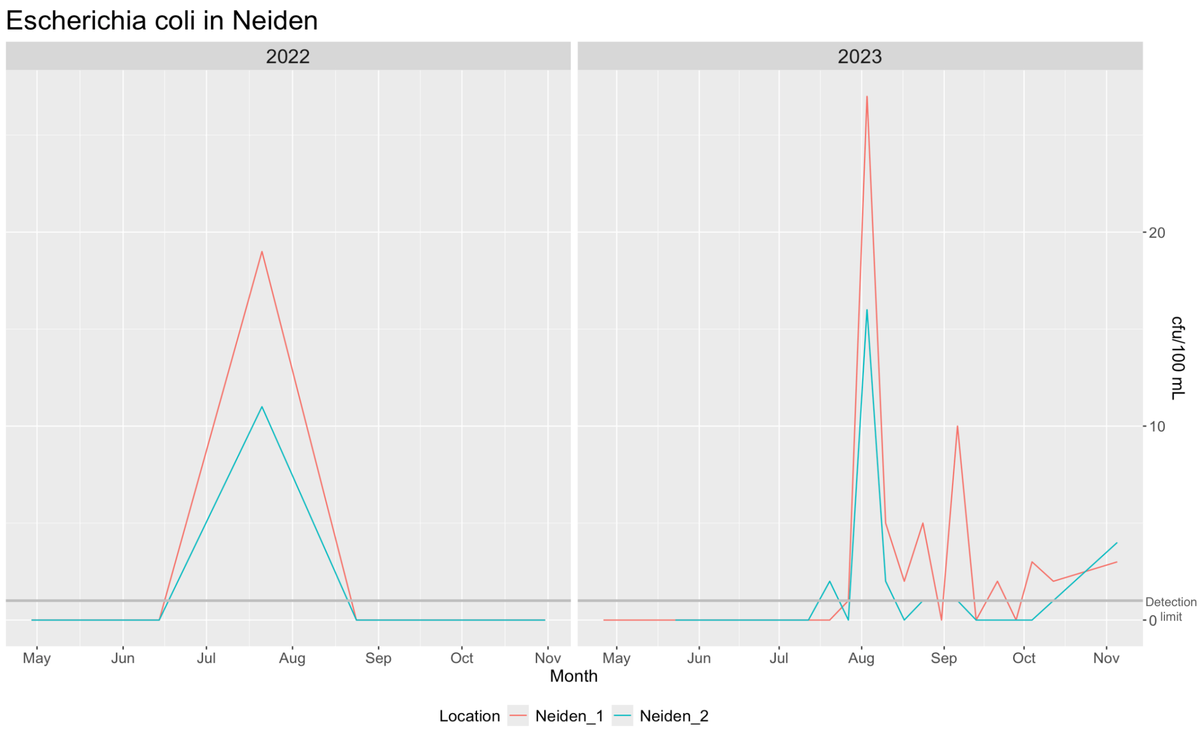
3.4.3 *Escherichia coli*

Measured levels of *E. coli* mainly stayed below detection limit at all stations in all rivers throughout the entire 2022 season (*Figure 44-46*), except for a peak in the middle of July and some lower levels at the end of the season. The peak in mid-July had a wide range, with the highest values measured in Karpelva and Munkelva at 45 and 68 cfu/100 mL. The mean ranged from below the detection limit to the highest at 7.4 and 10.4 cfu/100 mL for Karpelva and Munkelva.

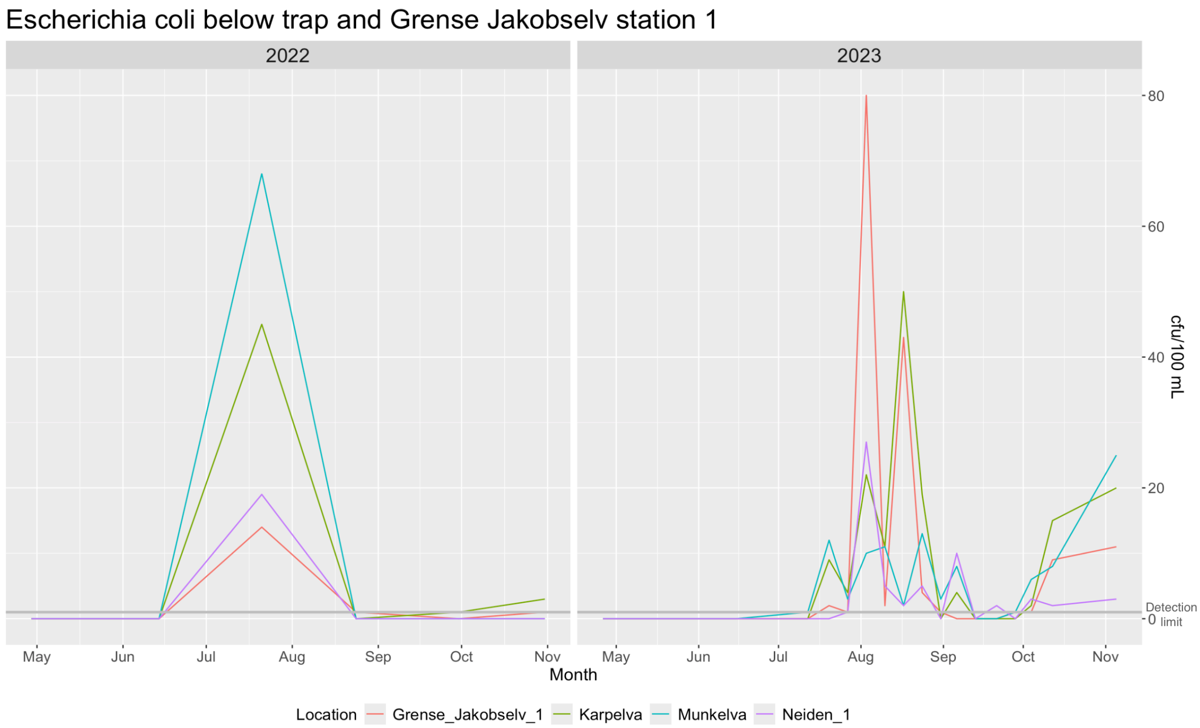
The 2023 season also had elevated values in the middle of July for all stations, where the level continued fluctuating throughout the following month. The highest values were measured between 50 and 80 cfu/100 mL for Karpelva and Grense Jakobselv station 1, 2 and 4. In September, there was a sudden decrease for most stations, before increasing towards the last sampling. The mean was lowest in Neiden with 2.1 and 3.7 cfu/100 mL, and for the remaining rivers between 4.7-9.1 cfu/100 mL. There was no significant difference between the seasons at stations below traps, those stations in 2023, or between stations in Grense Jakobselv that season.



***Figur 44 Measured level of Escherichia coli in Grense Jakobselv**. From samples collected through 2022 and 2023 season. Each station/location is colored, with measured level (cfu/100 mL) on the right side. Lower detection limit >1.*



Figur 45 Measured level of Escherichia coli in Neiden. *From samples collected through 2022 and 2023 season. Each station/location is colored, with measured level (cfu/100 mL) on the right side. Lower detection limit >1.*

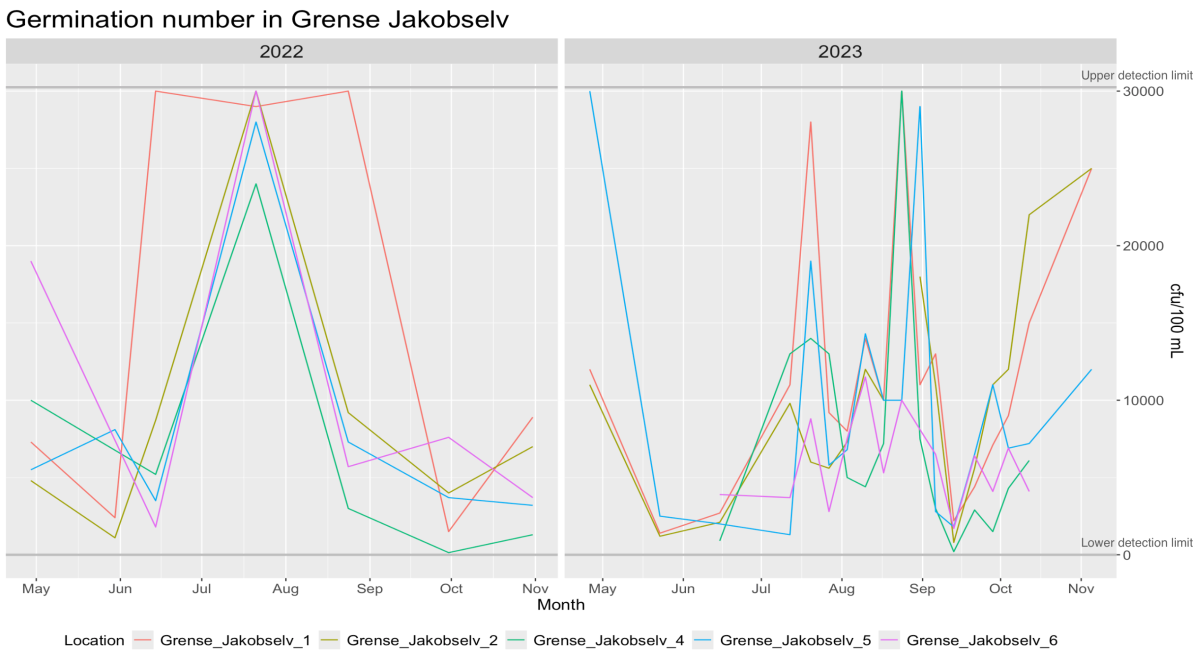


Figur 46 Measured level of Escherichia coli below traps and in Grense Jakobselv station 1. *From samples collected through 2022 and 2023 season. Each station/location is colored, with measured level (cfu/100 mL) on the right side. Lower detection limit <1.*

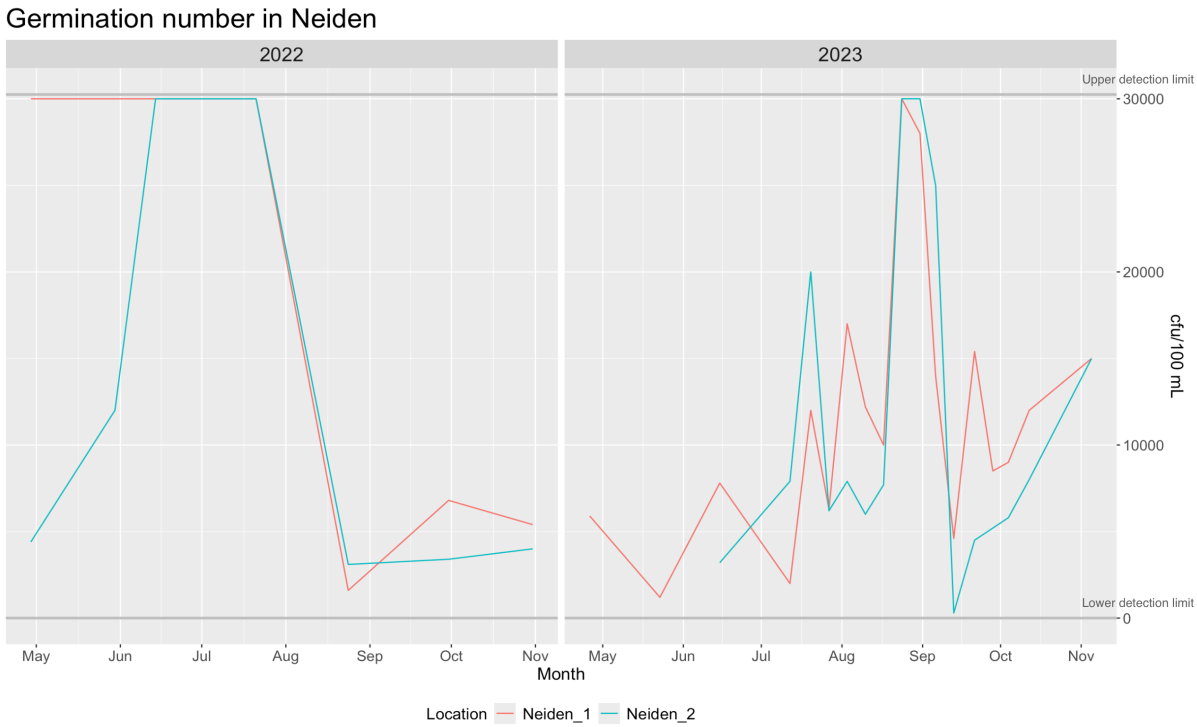
3.4.4 Germination number

The 2022 season started with decreasing values of germination number until late May for most stations (*Figure 47-49*), before reaching the upper detection limit between June and September, mainly centered around the middle of July. Values decreased in late August or September, with the lowest level measured in Grense Jakobselv 4 at 140 cfu/100 mL, before increasing towards the seasons last sampling. The mean for stations below the traps was between 14 242 cfu/100 mL at the lowest in Karpelva and up to 21 585 cfu/100 mL for Munkelva.

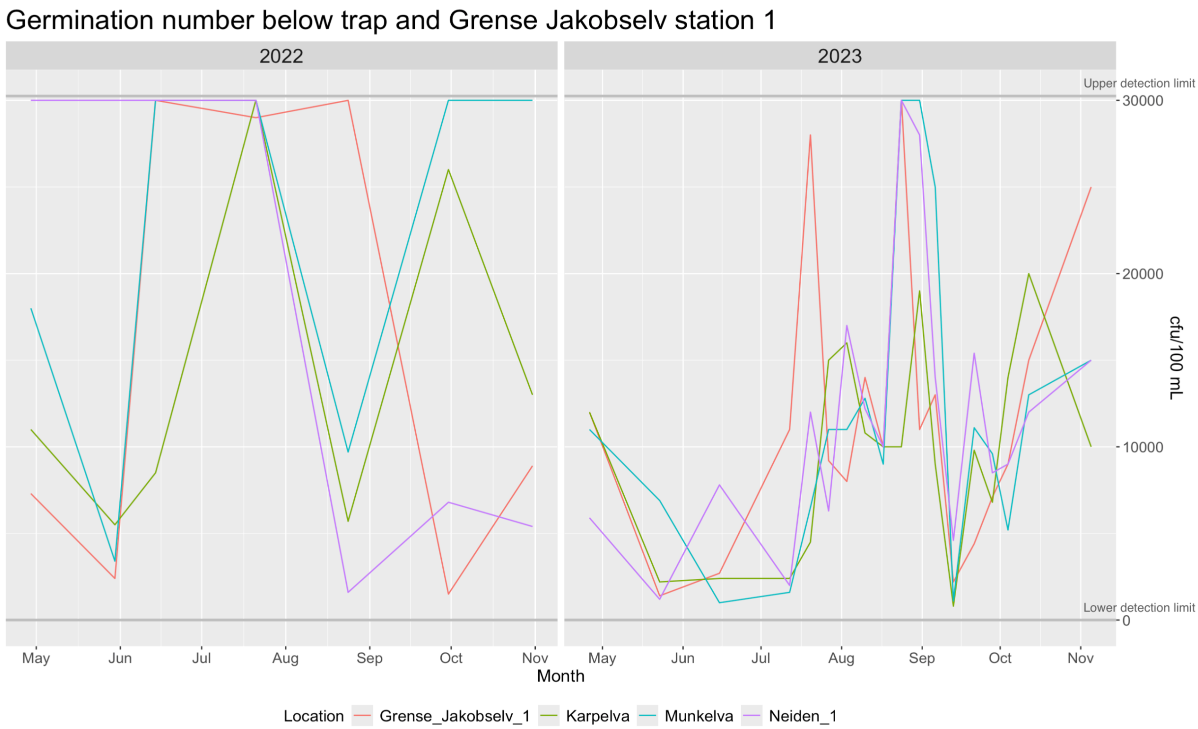
In 2023, levels of germination number started to fluctuate from the middle of July towards the end of the season, where most stations were almost or reaching the upper detection limit at 30 000 cfu/100 mL. This was only disrupted by a steeper decrease in the first part of September, with levels reaching down to 200-1700 cfu/100 mL. The mean was between 9705 and 11 833 cfu/100 mL for all stations, except Grense Jakobselv station 4 and 6 at 7875 and 6706 cfu/100 mL. There was no significant difference between seasons at stations below traps, between those stations in 2023, or between stations in Grense Jakobselv that season.



Figur 47 Measured level of germination number in Grense Jakobselv. *From samples collected through 2022 and 2023 season. Each station/location is colored, with measured level (cfu/100 mL) on the right side. Lower detection limit >1, upper detection limit <30 000.*



Figur 48 Measured level of germination number in Neiden. *From samples collected through 2022 and 2023 season. Each station/location is colored, with measured level (cfu/100 mL) on the right side. Lower detection limit >1, upper detection limit <30 000.*

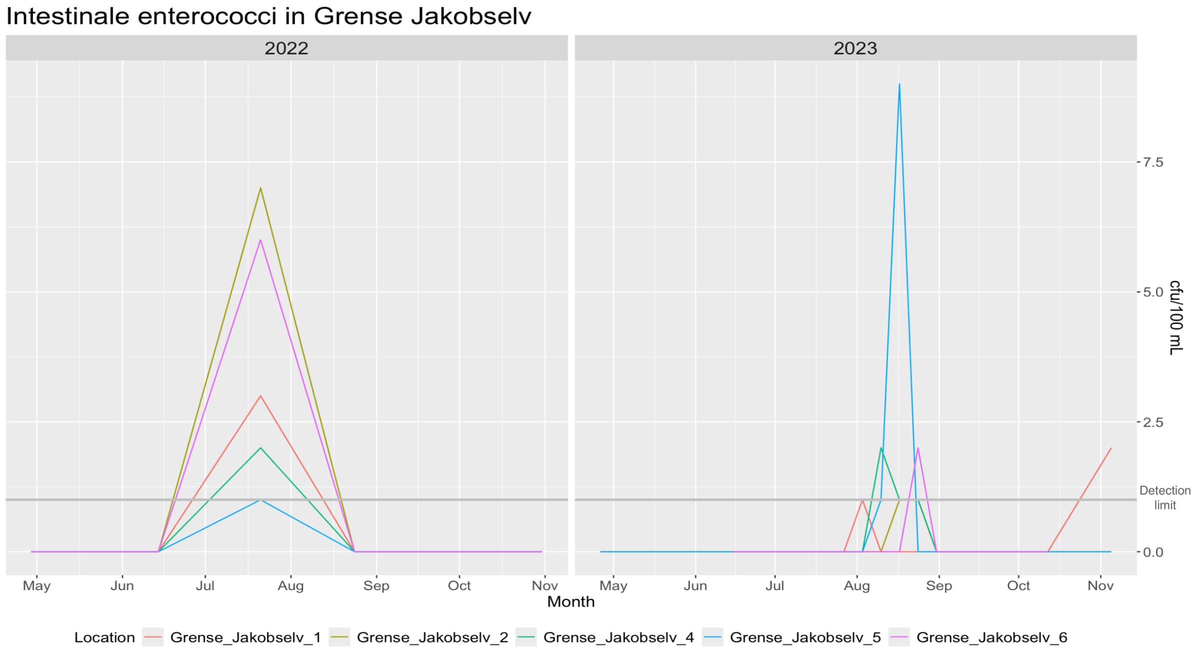


Figur 49 Measured level of germination number below traps and in Grense Jakobselv station 1. *From samples collected through 2022 and 2023 season. Each station/location is colored, with measured level (cfu/100 mL) on the right side. Lower detection limit >1, upper detection limit <30 000.*

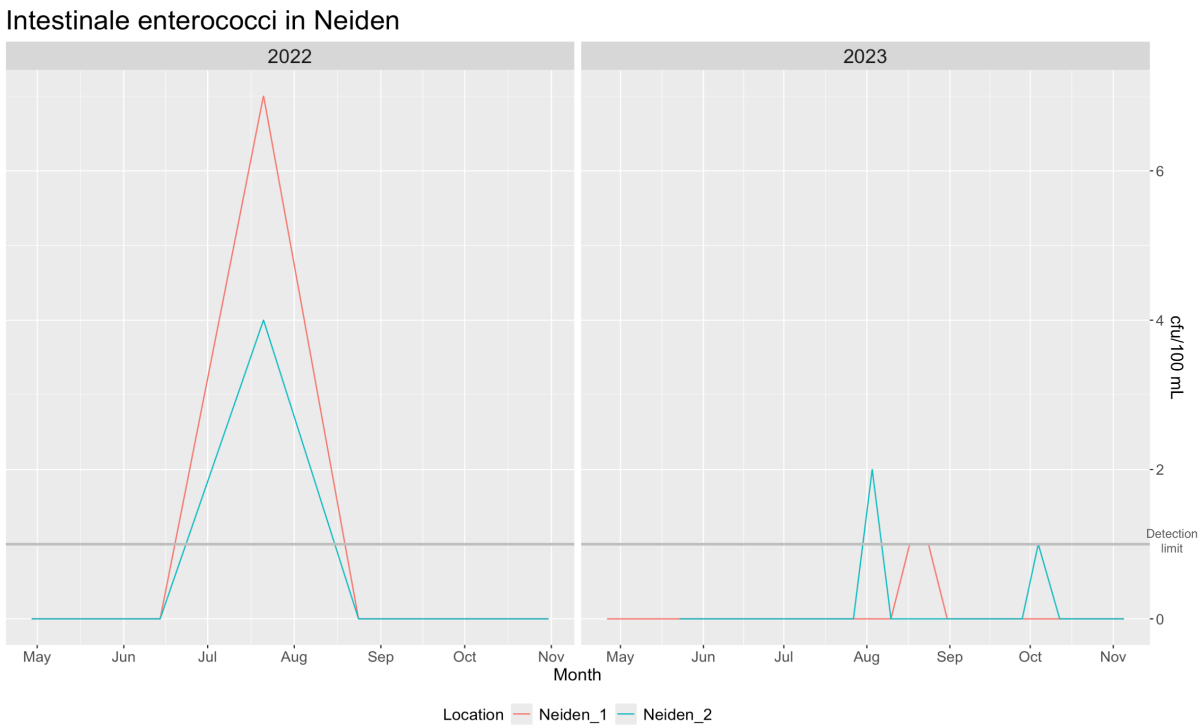
3.4.5 Intestinal enterococci

In 2022, levels of intestinal enterococci stayed below the detection limit for all rivers (*Figure 50-52*), except for a peak just past the middle of July, where values ranged from 2 – 18 cfu/100 mL. The mean was between below the detection limit and the highest for Munkelva at 3.12 cfu/100 mL.

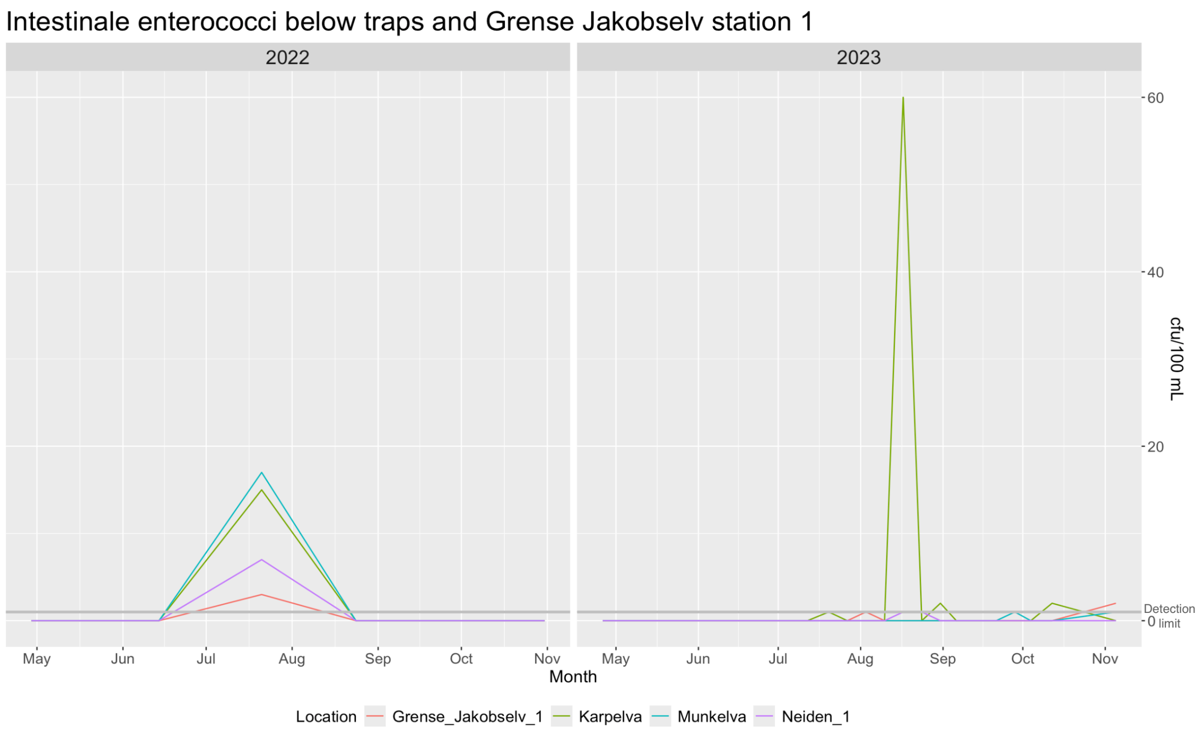
In 2023, the measured level of intestinal enterococci also mainly remained under detection limit, until early and middle of August when a few stations had increased levels, most notably in Karpelva with 60 cfu/100 mL and Grense Jakobselv station 5 at 9 cfu/100 mL. The mean was below detection limit, except for Karpelva at 4.2 and Grense Jakobselv 1.2 cfu/100 mL. No significance was calculated due to the few measurements above the detection limit.



Figur 50 Measured level of Intestinal enterococci in Grense Jakobselv. *From samples collected through 2022 and 2023 season. Each station/location is colored, with measured level (cfu/100 mL) on the right side and lower detection limit >1.*



Figur 51 Measured level of Intestinal enterococci in Neiden. From *samples collected through 2022 and 2023 season. Each station/location is colored, with measured level (cfu/100 mL) on the right side, and lower detection limit >1.*



Figur 52 Measured level of Intestinal enterococci below traps and Grense Jakobselv station 1. *From samples collected through 2022 and 2023 season. Each station/location is colored, with measured level (cfu/100 mL) on the right side. Lower detection limit >1.*

4 Discussion

Pink salmon carcasses left in rivers after spawning increase the riverine nutrient concentration in northern Norwegian rivers. The normal seasonal pattern represented by the 2022 season without pink salmon, began with an increase in river discharge as the river filled with melting water during the milder temperatures of spring. This melting water contains allochthonous organic matter, and nutrients taken up from the surroundings. Some of the variables of water chemistry increased throughout July, others decreased, whereas some remained stable throughout the entire summer season. This pattern continued until autumn, when decomposing litter supplies the river inflow with detritus and dead plant material, causing an elevation of nutrients again.

There were some differences between variables during the first period for both seasons, which could be explained by differential river discharge and other physical parameters affecting the water chemistry. However, during the season with pink salmon present, levels of pH, organic carbon, nutrients, and bacterial water quality generally started fluctuating from the middle of July until late September, with in general heightened values compared to the season before, most likely due to the presence, spawning, and senescence death of pink salmon. Rainfall, increasing the river discharge through the period, together with different stages of nutrient uptake by bacteria and photosynthetic organisms, including physical parameters, could explain the highly alternating levels.

During the season with pink salmon present, the level of ammonia showed a smaller peak in late July that correlated with when majority of pink salmon enter the rivers, followed by a drastic increase in the middle of August, when the fish started to decompose. Pink salmon typically stays alive less than three weeks at the spawning ground (Gende et al., 2002)), which is consistent with the observation mande by Pinay et. al. (2009) during their study. When comparing the station below and above the salmon-stair in Neiden, the most downstream station had over twice the value as the station upstream. In Grense Jakobselv, the level of ammonium followed a gradient of elevated levels for the most downstream stations. Station 1 had the highest values overall, as expected, being the only river without mitigation measures and the most downstream station. There was no significant difference between the seasons when comparing stations below trap during pink salmon presence compared to without. The lack of significance could be a result of comparing only the period from pink salmon entrance towards the end of season and included only four samplings in 2022, compared to 15 in 2023. Even if data from all stations below trap were pooled for each season to increase the number of samplings, it was mostly no clear significance. Samples for water chemistry and bacterial water quality had in many cases elevated values in middle of July in 2022 which could also influence the results.

Beside the increased level of ammonium in 2023, optimal temperatures and pH during the (Antoniou et al., 1990; Puyol et al., 2014) last part of the summer months could speed up the nitrification of the nutrient to nitrate. This may explain values over 15 times higher than those registered in Tana and Pasvik for station 1 in Grense Jakobselv during mid-August. All stations registered highly elevated levels, in contrast to the previous season when they remained under the detection limit during the same period. Noteworthy, the measurement uncertainty of analyzed samples was relatively high, up to 40% for some, but the levels would still be well above expected, even with that in mind. Moreover, the increased level of nitrate in Karpelva in late July could be a result of nitrification of excretion during high density of pink salmon present. There could also be a potential correlation between the major peak of pink salmon catches in Munkelva and the registered level of nitrate. The latter station had a major elevation of the nutrient in early September, which could be a result of its last peak of catches in mid-August. This potential relationship between nitrate and pink salmon density was also observed in Neiden. Station 2 in Neiden registered elevated levels in the first part of August, which could not be related to the pink salmon's presence, but probably rather due to pressure from the local community. However, the level at station 1 was over 20 µg higher than at station 2. Some of these elevations could probably be explained by livestock farming and agricultural activity, but they also reinforce the idea of a nitrate increase caused by pink salmon attendance. Aside from the visible seasonal differences during graphic comparison, the difference was also statistically significant. Grense Jakobselv station 1 stood out compared to other stations below traps, where the river included a significant difference between station 1 and 2, compared to station 6.

In 2023, peaks of free ammonia were observed during periods of more alkaline pH levels, specifically at the downstream station in Neiden, and Grense Jakobselv 1 and 6. The first mentioned station in Grense Jakobselv showed a level of ammonium during alkaline pH that nearly reached a toxic threshold in the middle of August. Even though agricultural activity could account for some of the difference between station 1 and 2 in Neiden, it likely did not cause the almost five times higher values registered at the most downstream station. When comparing between seasons in Grense Jakobselv, the registered level of free ammonia peaked past the middle of July in 2022 at a completely different scale, compared to the greatly expanded range of values registered in 2023. This confirms the effect of pink salmon on free ammonia levels, rather than these changes being a result of seasonal variations or increased pressure from tourists or the local community during the summer months.

Similar to ammonium, phosphorus levels have been registered to increase during pink salmon migration, followed by further elevated levels two weeks later, during its senescence (Pinay et al., 2009). This pattern corresponded with peaks of pink salmon entrance in Munkelva and Neiden, followed by increased levels of phosphorus about two weeks after. Neiden had a notably higher level of orthophosphate when comparing below and above the stair, were first mentioned station was outstanding when comparing significance between stations below traps. As Neiden over all seemed to have increased levels of both total phosphorus and orthophosphate could as mentioned partly be affected by the agriculture. But the measured level of orthophosphate also matched with the increased level of ammonium registered in middle of August in Grense Jakobselv and followed a gradient with higher levels more downstream, except for station 6 which remarkable, had the highest levels measured of all stations in the river. This could be a result of an accumulation of long-migrating salmons, suffering a more sudden senescence death caused by exhaustion of swimming the longer distance, as well as matching the timing of when the majority of salmons entered the river. As the nutrients could be stored in the sediments or biofilms for weeks or months (Pinay et al., 2009) could explain the sudden increase of orthophosphate during October again for all rivers, probably also including input of organic and nutrients during rainfall and decomposing litter in the autumn.

Nutrient and organic matter left behind in riverine system after pink salmon spawning increase growth of bacteria. Both seasons started with stable low or slightly decreasing level of bacteria, before increasing with a peak in late July. Grense Jakobselv, Munkelva and Neiden are frequently visited recreational areas of the local community, which inhabits cabins along the rivers. High season for summer vacation in middle of July and fishing season of Atlantic salmon, increases the pressure of people during the period. Waste water from cabins, inflow from agricultural areas, together with increased temperatures could result in the increase of bacteria in middle of July for both seasons, as the natural environment for the bacteria is the intestine of warm-blooded animals. Continuing with measured level of bacteria in the season without pink salmon spawning, the level was decreasing, remaining stable low or slightly increasing during the last part of autumn, representing the main seasonal pattern.

The bacteria, which was probably not brought with the pink salmon, but emerged from wastewater or existed natural in the environment, was given more favorable conditions to survive and grow during pink salmon presence and for longer periods than under its normal conditions, without. More specific by utilizing organic compounds released by decaying carcasses as dissolved organic carbon controls the growth rates for bacteria with anoxic photosynthesis under optimum temperatures and access to inorganic nutrients (Dodds & Whiles, 2010). Level of dissolved organic carbon was registered to a remarkable high level on the 13th of September, in Grense Jakobselv and Neiden 2 which is thought to be a result of contaminants during sampling, or of that kind of type. However, was the measured level on the two following samplings at Neiden station 1 over twice the values registered through both seasons for all stations, with a timing that could be related to the further decaying carcasses.

As for many of the variables of water chemistry, the period from last part of July during pink salmon presence, had for many of the certain bacteria, increased and highly fluctuating levels. Which also for bacteria matched with pink salmons timing of spawning and senescence death. Moreover, could the fluctuating level be explained by some of the reasons for nutrients, but more specific also affected by optimum temperatures. *C. perfirigens* and coliform was registered at elevated levels below stair in Neiden compared to above it, where last-mentioned bacteria had more than four times the values below, compared to above. In Grense Jakobselv, *E. coli* followed an approximately gradient with higher levels at more downstream stations. Many of the bacteria for determining the water quality (as well as orthophosphate and nitrate) had a sudden decrease in first part of September, which could be their growth reaching the systems carrying capacity, followed by collapsing. Beside the bacteria registered during this study, there were probably also several other strains, competing for the same nutrients. As the nutrient input increased again during fall, the bacterial growth raised again.

With a management perspective in mind, that recommends a level below 100 cfu/mL for germination number and 0 cfu/100 mL for rest of this study's bacteria (Lovdata, 2024), suggest not drinking the water during higher temperatures mid-summer of both seasons. However most important, be aware of spawning pink salmons' major effect on the bacterial water quality, ongoing from its appearance in late July, the following autumn and towards ice-covered river. As well as for swimming in the water, or other activities were it's a chance for consuming it. Moreover, for the many recreational *A. salmon* anglers to be aware of hygiene, as some strains of *E. coli* could also extraintestinal diseases (Jang et al., 2017).

Spawning pink salmon could have major impact on the river- and connected ecosystems in Northern Norway. Just through its presence, lead to spatial shifts for macroinvertebrate communities, avoiding their spawning's disturbance in the riffles (Campbell et al., 2012). But maybe more important could dissolved organic carbon and inorganic nutrient input from its carcasses (and presence alive), influence the competition between bacteria and phytoplankton (Stets & Cotner, 2008) at the base of the food-web, leading to further shifts of the ecosystem. Even if this study sites higher trophic levels lack the important nutrient-transferring bear, the local scavenging-community in Vesterelva had an estimated transferrer of about 36 kJ energy, 25 g nitrogen and 0.045 g phosphorus per m^2 to the surrounding riparian site each day (Dunlop. et al., 2021). The extra energy gained by these generalist scavengers, could lead to an apparent competition (Holt, 1977) through increased pressure of their prey in years without pink salmon, further impacting interactions of the recipient food-web.

In British Colombia and Alaska, the pink salmons' native range, invertebrates are also registered as an important vector for transport of nutrients to surrounding ecosystems. More specific Diptera flies and Coleoptera, including their predators been observed scavenging on majority of carcasses (Hocking & Reimchen, 2006; Hocking et al., 2009), species of relevance for also this study sites rivers. Moreover has recipient plant communities of pink salmon derived nutrients, been observed with an increased growth and decreased plant diversity (Hocking & Reynolds, 2011). Even if the rivers in British Colombia and Alaska consists of a more temperate climate with an ecosystem adapted for efficiently absorbing spawning pink salmons' subsequent input of nutrients, would this study sites pristine and more nutrient poor rivers- and ecosystems, receive a substantial input of relevance.

Spawning pink salmons' effect on native salmonid species has been a major discussion since the great invasion in 2017 as their spawning are primarily not overlapping (Mo et al., 2018). However, are the native *Salmo salar* already suffering of other pressures and the additional effect of pink salmon could drive it in a further negative course. The increased levels of both nitrate and nitrite could be an issue when converting hemoglobin to methemoglobin (Smith et al., 1997). Moreover are the threshold for toxic levels of free ammonia for fish measured at them resting, not fish that are migrating or exposed for extra stress (Randall & Tsui, 2002), which they probably are during spawning. As the fluctuations of certain nutrients at potential toxic levels primarily appears after pink salmons spawning and senescence death, would not negatively affect that salmonid-species the same way as for the later spawning, native ones, as well as for the native species' juveniles. As well as the increased level of bacteria could rise the risk for infections. However, could great amounts of eggs of pink salmon spawning, act as a potential energy source for native juvenile salmonids (Dunlop et al., 2021).

The decisions' taken of Norwegian mitigation management of pink salmon the nearest future could have potentially different outcomes for our ecosystems. Currently, the main task is not to eradicate the species, but to prevent as many individuals as possible to get access to, and spawn in the river (Mo et al., 2021), mainly with use of the "floating-salmontrap", sorting out pink salmon, and let the native salmonid species through it. It has been discussed whether to fish more of the pink salmon in the sea before it starts migrating up the river, but this could be difficult without impacting the native Atlantic salmon, Arctic char and sea trout (Mo et al., 2021). The mitigation measurements have largely depended on the local community's involvement, and their moral in the future plays an important role for the upcoming effort. Norway´s location between the source rivers, the Atlantic current, rest of Europe and the Artic Sea makes the decisions taken even more important for determine the future impact, and establishment of this invasive species in the Atlantic sea (Hindar et al., 2020).

5 Conclusion

This study shows, if not a statistically significant, but a visual graphic inequality between variables of water chemistry and bacterial water quality, between a season with pink salmon spawning, compared to a season without. It gives a unique insight in a less invested part of the pink salmon effect on water quality in northern Norwegian rivers. Further research is needed to determine the impacts in affected riverine and connecting ecosystems, and a more frequent sampling during season without pink salmon present, would give a comparison strengthening the difference between seasonality's effect in relation to pink salmon, on the certain variable. Including, investigating its input of nutrients effect at the base of the food web and pink salmon carcasses feeding scavengers, bringing nutrients into the riparian sites, with potentially cascading impacts at both trophic levels. Pink salmon spawns primarily odd years, which could provoke a biannual cycle, and by monitoring several years it could be possible to see a distinct increase of nutrients and bacteria in spawning years compared to without. Main levels that gradually increase over several years because of accumulating in the ecosystems.

Appendix 1 Parameters of analysis of water chemistry

Tabell 3 Parameters for analysis of water chemistry in 2022. *Overview of variable, method of lab-analysis, lower and upper detection limit, unit and replacement for values during calculations and for plots.*

Variable:	Method:	Detection limit: Lower	Upper	Measurement-insequrity	Unit:	Replacement of values below detection limit: For calculations; random number between:	For plots:
Temperature	Thermometre	-	-	-	°C	-	-
Total nitrogen	NS-EN ISO 11905-1	-	-	20%	µg/L	-	-
Ammonium (NH4-N)	NS-EN ISO 11732	5	-	40%	µg/L	2.5-4.99	0
Ammonia free (NH3)	Intern method	-	-	-	mg/L	-	-
Nitrate (NO3-N)	NS-EN ISO 13395	5	-	-	µg/L	2.5-4.99	0
Total Phosphorus	NS-EN ISO 15681-2	5	-	40%	µg/L	1.5-2.99	0
Ortophosphate (PO4-P)	NS-EN ISO 15681-2	2	-	30%	µg/L	1.0-1.99	0
Chemical Oxygen Demand	NS-ISO 15705	5	-	40%	mg/L	2.5-4.99	0
Dissolved Organic Carbon	NS-EN 1484	0.3	-	30%	mg/L	-	-
pH	NS-EN ISO 10523	1	-	0.2		-	-

Tabell 4 Parameters for analysis of water chemistry in 2023. *Overview of variable, method of lab-analysis, lower and upper detection limit, unit and replacement for values during calculations and for plots.*

Variable:	Method:	Detection limit: Lower	Upper	Measurement-insequrity	Unit:	Replacement of values below detection limit: For calculations; random number between:	For plots:
Temperature	Thermometre	-	-	-	°C	-	-
Total nitrogen	NS 4743	10	-	20%	µg/L	-	-
Ammonium (NH4-N)	NS-EN ISO 11732	5	-	40%	µg/L	2.5-4.99	0
Ammonia free (NH3)	Intern method		-	-	mg/L	0.0025-0.005 0.00025-0.0005	0
Nitrate (NO3-N)	NS-EN ISO 13395	5	-	30%	µg/L	2.5-4.99	0
Total Phosphorus	NS-EN ISO 15681-2	3	-	40%	µg/L	1.5-2.99	0
Ortophosphate (PO4-P)	NS-EN ISO 15681-2	2	-	30%	µg/L	1.0-1.99	0
Chemical Oxygen Demand	NS-ISO 15705	5	-	40%	mg/L	2.5-4.99	0
Dissolved Organic Carbon	NS-EN 1484	0.3	-	20%	mg/L	-	-
pH	NS-EN ISO 10523	1	-	0.2			-

Appendix 2 Parameters of bacteria analysis

Tabell 5 Parameters for analysis of bacterial water quality in 2022. *Overview of variable, method of lab-analysis, lower and upper detection limit, unit and replacement for values during calculations and for plots.*

Bacteria:	Method:	Detection limit:		Unit:	Replacement of values below detection limit:	
		Lower	Upper		For calculations; random number between:	For plots:
Clostridium perfirigens	EN ISO 14189	1	-	cfu/100mL	0.5-0.99	0
Coliform	E int. NS4792	1	150	cfu/100mL	0.5-0.99	0
Escherichia coli	E int. NS4792	1	-	cfu/100mL	0.5-0.99	0
Germination number	EN ISO 6222	1	300000	cfu/100mL	0.5-0.99	0
Intestinale enterococci	EN ISO 7899-2	1	-	cfu/100mL	0.5-0.99	0

Tabell 6 Parameters for analysis of bacterial water quality in 2023. *Overview of variable, method of lab-analysis, lower and upper detection limit, unit and replacement for values during calculations and for plots.*

Bacteria:	Method:	Detection limit:		Unit:	Replacement of values below detection limit:	
		Lower	Upper		For calculations; random number between:	For plots:
Clostridium perfirigens	EN ISO 14189	1	-	cfu/100mL	0.5-0.99	0
Coliform	NS-EN ISO 9308-1	1	100	cfu/100mL	0.5-0.99	0
Escherichia coli	NS-EN ISO 9308-1	1	-	cfu/100mL	0.5-0.99	0
Germination number	EN ISO 6222	1	300000	cfu/100mL	0.5-0.99	0
Intestinale enterococci	EN ISO 7899-2	1	-	cfu/100mL	0.5-0.99	0

Appendix 3 Pink salmon trap-catches

Tabell 7 Pink salmon catches of mitigation measurements. *In relation to the salmon-traps and stair in Karpelva, Munkelva and Neiden for the 2023 season. Data from Miljødirektoratet (2023).*

Location:	Summary of data:			Summary of dates:			Highest daily catch:		Fishing gear:				
	Individuals	Mean	Sd	First catched	Last catched	Range of days	Individuals	Date	Trap	Fish net	Salmon ladder	Seine	Other
Karpelva	4005	63.6	114.1	11th of July	11th of September	62	564	5th of August	3858	140			7
Munkelva	14754	163.5	225.9	16th of June	13th of September	89	1100	3rd of August	14754				
Neiden	14564	291.3	281.6	26th of June	15th of August	50	1259	14th of July		2987	10132	1445	

Appendix 4 River discharge

Tabell 8 River discharge for Karpelva and Neiden. *Overwiev of the rivers id, range of dates, number of samples, type of registration, mean, standard deviation, min, max and missing values.*

River	Id	Date range:		n-samples	Registered	Mean	Sd	Min	Max	Sum_na
Neiden	244.2.0	15/04/2022	15/11/2022	5136	as measured'	59.02924	56.51559	19.24595	315.3678	4
		15/04/2023	15/11/2023	4211	as measured'	53.84245	61.68364	12.01359	324.5876	75
Karpelva	247.3.0	15/04/2022	15/11/2022	5137	as measured'	3.935845	4.720541	0.5359671	29.84767	0
		15/04/2023	15/11/2023	5137	as measured'	2.830165	4.689416	0.4612529	32.22935	0

Appendix 5 Statistic comparison in Grense Jakobselv 2023

Tabell 9 Statistic comparison of stations in Grense Jakobselv 2023. *Overview of variable, method, comparison of stations, Z, P-value unadjusted and P-value adjusted.*

Method: dunn.Test(, method='bonferroni')

Variable	Group	Comparison	Z	P.unadj	P.adj
Total nitrogen	Grense Jakobselv	Grense_Jakobselv_1 - Grense_Jakobselv_2	-0.2759407	0.78259362	1
		Grense_Jakobselv_1 - Grense_Jakobselv_4	0.866684	0.38611519	1
		Grense_Jakobselv_2 - Grense_Jakobselv_4	1.1378253	0.25519343	1
		Grense_Jakobselv_1 - Grense_Jakobselv_5	1.3710803	0.17034992	1
		Grense_Jakobselv_2 - Grense_Jakobselv_5	1.647021	0.09955373	0.9955373
		Grense_Jakobselv_4 - Grense_Jakobselv_5	0.4805496	0.63083662	1
		Grense_Jakobselv_1 - Grense_Jakobselv_6	0.9847031	0.32476993	1
		Grense_Jakobselv_2 - Grense_Jakobselv_6	1.2558444	0.20917237	1
		Grense_Jakobselv_4 - Grense_Jakobselv_6	0.1160355	0.90762444	1
		Grense_Jakobselv_5 - Grense_Jakobselv_6	-0.3625305	0.71695562	1
Nitrate	Grense Jakobselv	Grense_Jakobselv_1 - Grense_Jakobselv_2	1.40779239	0.15919256	1
		Grense_Jakobselv_1 - Grense_Jakobselv_4	2.67475646	0.00747836	0.07478355
		Grense_Jakobselv_2 - Grense_Jakobselv_4	1.29144929	0.19654793	1
		Grense_Jakobselv_1 - Grense_Jakobselv_5	2.62185187	0.00874534	0.08745343
		Grense_Jakobselv_2 - Grense_Jakobselv_5	1.21405949	0.22472501	1
		Grense_Jakobselv_4 - Grense_Jakobselv_5	-0.0985055	0.92153091	1
		Grense_Jakobselv_1 - Grense_Jakobselv_6	4.28831267	1.8004E-05	0.00018004
		Grense_Jakobselv_2 - Grense_Jakobselv_6	2.90500549	0.00367247	0.03672467
		Grense_Jakobselv_4 - Grense_Jakobselv_6	1.58643568	0.11264051	1
		Grense_Jakobselv_5 - Grense_Jakobselv_6	1.71206169	0.0868853	0.868853
Ammonium	Grense Jakobselv	Grense_Jakobselv_1 - Grense_Jakobselv_2	-0.1960095	0.8446027	1
		Grense_Jakobselv_1 - Grense_Jakobselv_4	1.0822591	0.27913741	1
		Grense_Jakobselv_2 - Grense_Jakobselv_4	1.2746046	0.20244923	1
		Grense_Jakobselv_1 - Grense_Jakobselv_5	1.3768475	0.16855941	1
		Grense_Jakobselv_2 - Grense_Jakobselv_5	1.572857	0.11575193	1
		Grense_Jakobselv_4 - Grense_Jakobselv_5	0.2688506	0.78804463	1
		Grense_Jakobselv_1 - Grense_Jakobselv_6	2.062391	0.03917052	0.3917052
		Grense_Jakobselv_2 - Grense_Jakobselv_6	2.2547365	0.02414987	0.2414987
		Grense_Jakobselv_4 - Grense_Jakobselv_6	0.9624705	0.33581333	1
		Grense_Jakobselv_5 - Grense_Jakobselv_6	0.7112813	0.47690992	1
Ammonia Free	Grense Jakobselv	Grense_Jakobselv_1 - Grense_Jakobselv_2	-0.1864024	0.8521292	1
		Grense_Jakobselv_1 - Grense_Jakobselv_4	0.7931877	0.4276685	1
		Grense_Jakobselv_2 - Grense_Jakobselv_4	0.9763481	0.328892	1
		Grense_Jakobselv_1 - Grense_Jakobselv_5	0.5982215	0.5496921	1
		Grense_Jakobselv_2 - Grense_Jakobselv_5	0.7846239	0.4326741	1
		Grense_Jakobselv_4 - Grense_Jakobselv_5	-0.2053708	0.8372824	1
		Grense_Jakobselv_1 - Grense_Jakobselv_6	0.1725115	0.8630354	1
		Grense_Jakobselv_2 - Grense_Jakobselv_6	0.3556718	0.7220864	1
		Grense_Jakobselv_4 - Grense_Jakobselv_6	-0.610244	0.5417002	1
		Grense_Jakobselv_5 - Grense_Jakobselv_6	-0.4153054	0.6779183	1
Total phosphorus	Grense Jakobselv	Grense_Jakobselv_1 - Grense_Jakobselv_2	-0.1204993	0.9040876	1
		Grense_Jakobselv_1 - Grense_Jakobselv_4	1.0617051	0.2883696	1
		Grense_Jakobselv_2 - Grense_Jakobselv_4	1.1801086	0.237957	1
		Grense_Jakobselv_1 - Grense_Jakobselv_5	0.1377135	0.8904668	1
		Grense_Jakobselv_2 - Grense_Jakobselv_5	0.2582128	0.7962427	1
		Grense_Jakobselv_4 - Grense_Jakobselv_5	-0.9263868	0.354245	1
		Grense_Jakobselv_1 - Grense_Jakobselv_6	0.4636465	0.6429011	1
		Grense_Jakobselv_2 - Grense_Jakobselv_6	0.58205	0.560533	1
		Grense_Jakobselv_4 - Grense_Jakobselv_6	-0.5880065	0.5565279	1
		Grense_Jakobselv_5 - Grense_Jakobselv_6	0.3283281	0.7426636	1
Orthophosphate	Grense Jakobselv	Grense_Jakobselv_1 - Grense_Jakobselv_2	-0.3743624	0.7081347	1
		Grense_Jakobselv_1 - Grense_Jakobselv_4	0.5668775	0.5707974	1
		Grense_Jakobselv_2 - Grense_Jakobselv_4	0.93472874	0.3499281	1
		Grense_Jakobselv_1 - Grense_Jakobselv_5	0.09466635	0.9245798	1
		Grense_Jakobselv_2 - Grense_Jakobselv_5	0.46902875	0.6390491	1
		Grense_Jakobselv_4 - Grense_Jakobselv_5	-0.4738576	0.6356014	1
		Grense_Jakobselv_1 - Grense_Jakobselv_6	-0.3165091	0.7516161	1
		Grense_Jakobselv_2 - Grense_Jakobselv_6	0.05134213	0.9590529	1
		Grense_Jakobselv_4 - Grense_Jakobselv_6	-0.8685387	0.3850995	1
		Grense_Jakobselv_5 - Grense_Jakobselv_6	-0.409529	0.6821515	1

DOC	Grense Jakobselv	Grense_Jakobselv_1 - Grense_Jakobselv_2	-0.2629408	0.7925962	1
		Grense_Jakobselv_1 - Grense_Jakobselv_4	-1.558979	0.11900134	1
		Grense_Jakobselv_2 - Grense_Jakobselv_4	-1.3006115	0.19339148	1
		Grense_Jakobselv_1 - Grense_Jakobselv_5	-1.0690052	0.28506731	1
		Grense_Jakobselv_2 - Grense_Jakobselv_5	-0.8060644	0.4202057	1
		Grense_Jakobselv_4 - Grense_Jakobselv_5	0.5085666	0.61105603	1
		Grense_Jakobselv_1 - Grense_Jakobselv_6	-3.4876597	0.00048727	0.00487268
		Grense_Jakobselv_2 - Grense_Jakobselv_6	-3.2292921	0.00124097	0.01240971
		Grense_Jakobselv_4 - Grense_Jakobselv_6	-1.8962635	0.0579252	0.57925205
		Grense_Jakobselv_5 - Grense_Jakobselv_6	-2.4372473	0.01479956	0.14799556
COD	Grense Jakobselv	Grense_Jakobselv_1 - Grense_Jakobselv_2	-0.6327582	0.52689157	1
		Grense_Jakobselv_1 - Grense_Jakobselv_4	-1.3891252	0.16479469	1
		Grense_Jakobselv_2 - Grense_Jakobselv_4	-0.7673723	0.44286017	1
		Grense_Jakobselv_1 - Grense_Jakobselv_5	-0.5897134	0.5553828	1
		Grense_Jakobselv_2 - Grense_Jakobselv_5	0.04304477	0.96566584	1
		Grense_Jakobselv_4 - Grense_Jakobselv_5	0.80966844	0.41813076	1
		Grense_Jakobselv_1 - Grense_Jakobselv_6	-1.7788537	0.07526376	0.7526376
		Grense_Jakobselv_2 - Grense_Jakobselv_6	-1.1571008	0.24723118	1
		Grense_Jakobselv_4 - Grense_Jakobselv_6	-0.3831779	0.70158783	1
		Grense_Jakobselv_5 - Grense_Jakobselv_6	-1.1993969	0.23037365	1
pH	Grense Jakobselv	Grense_Jakobselv_1 - Grense_Jakobselv_2	0.70084943	0.48339699	1
		Grense_Jakobselv_1 - Grense_Jakobselv_4	2.10410168	0.03536958	0.3536958
		Grense_Jakobselv_2 - Grense_Jakobselv_4	1.41544186	0.15693898	1
		Grense_Jakobselv_1 - Grense_Jakobselv_5	0.35480502	0.72273567	1
		Grense_Jakobselv_2 - Grense_Jakobselv_5	-0.3460444	0.72930934	1
		Grense_Jakobselv_4 - Grense_Jakobselv_5	-1.7554677	0.07917935	0.7917935
		Grense_Jakobselv_1 - Grense_Jakobselv_6	0.06118005	0.95121582	1
		Grense_Jakobselv_2 - Grense_Jakobselv_6	-0.6274798	0.5303448	1
		Grense_Jakobselv_4 - Grense_Jakobselv_6	-2.0085844	0.04458123	0.4458123
		Grense_Jakobselv_5 - Grense_Jakobselv_6	-0.287454	0.77376473	1
E. coli	Grense Jakobselv	Grense_Jakobselv_1 - Grense_Jakobselv_2	-0.3018125	0.762795	1
		Grense_Jakobselv_1 - Grense_Jakobselv_4	0.59917862	0.5490538	1
		Grense_Jakobselv_2 - Grense_Jakobselv_4	0.89574177	0.3703907	1
		Grense_Jakobselv_1 - Grense_Jakobselv_5	0.39666781	0.6916124	1
		Grense_Jakobselv_2 - Grense_Jakobselv_5	0.69848028	0.4848769	1
		Grense_Jakobselv_4 - Grense_Jakobselv_5	-0.2094099	0.8341283	1
		Grense_Jakobselv_1 - Grense_Jakobselv_6	-0.0363139	0.9710321	1
		Grense_Jakobselv_2 - Grense_Jakobselv_6	0.2602493	0.7946715	1
		Grense_Jakobselv_4 - Grense_Jakobselv_6	-0.6248112	0.532095	1
		Grense_Jakobselv_5 - Grense_Jakobselv_6	-0.4260826	0.6700477	1
Germ number		Grense_Jakobselv_1 - Grense_Jakobselv_2	-0.3018125	0.762795	1
		Grense_Jakobselv_1 - Grense_Jakobselv_4	0.59917862	0.5490538	1
		Grense_Jakobselv_2 - Grense_Jakobselv_4	0.89574177	0.3703907	1
		Grense_Jakobselv_1 - Grense_Jakobselv_5	0.39666781	0.6916124	1
		Grense_Jakobselv_2 - Grense_Jakobselv_5	0.69848028	0.4848769	1
		Grense_Jakobselv_4 - Grense_Jakobselv_5	-0.2094099	0.8341283	1
		Grense_Jakobselv_1 - Grense_Jakobselv_6	-0.0363139	0.9710321	1
		Grense_Jakobselv_2 - Grense_Jakobselv_6	0.2602493	0.7946715	1
		Grense_Jakobselv_4 - Grense_Jakobselv_6	-0.6248112	0.532095	1
		Grense_Jakobselv_5 - Grense_Jakobselv_6	-0.4260826	0.6700477	1
C. Perfirigens		Grense_Jakobselv_1 - Grense_Jakobselv_2	0.3242205	0.74577114	1
		Grense_Jakobselv_1 - Grense_Jakobselv_4	2.4045311	0.01619323	0.1619323
		Grense_Jakobselv_2 - Grense_Jakobselv_4	2.0859497	0.03698318	0.3698318
		Grense_Jakobselv_1 - Grense_Jakobselv_5	1.9842292	0.0472303	0.472303
		Grense_Jakobselv_2 - Grense_Jakobselv_5	1.6600087	0.0969127	0.969127
		Grense_Jakobselv_4 - Grense_Jakobselv_5	-0.4548129	0.64924386	1
		Grense_Jakobselv_1 - Grense_Jakobselv_6	1.034631	0.30084125	1
		Grense_Jakobselv_2 - Grense_Jakobselv_6	0.7160496	0.4739607	1
		Grense_Jakobselv_4 - Grense_Jakobselv_6	-1.3468749	0.17802054	1
		Grense_Jakobselv_5 - Grense_Jakobselv_6	-0.9150872	0.36014588	1
Coliform		Grense_Jakobselv_1 - Grense_Jakobselv_2	-0.1766213	0.85980582	1
		Grense_Jakobselv_1 - Grense_Jakobselv_4	2.449345	0.01431163	0.14311631
		Grense_Jakobselv_2 - Grense_Jakobselv_4	2.6228944	0.00871863	0.08718629
		Grense_Jakobselv_1 - Grense_Jakobselv_5	0.2110841	0.83282169	1
		Grense_Jakobselv_2 - Grense_Jakobselv_5	0.3877054	0.69823406	1
		Grense_Jakobselv_4 - Grense_Jakobselv_5	-2.2419322	0.02496575	0.24965754
		Grense_Jakobselv_1 - Grense_Jakobselv_6	0.8030441	0.42194925	1
		Grense_Jakobselv_2 - Grense_Jakobselv_6	0.9765935	0.32877042	1
		Grense_Jakobselv_4 - Grense_Jakobselv_6	-1.61863	0.1055269	1
		Grense_Jakobselv_5 - Grense_Jakobselv_6	0.5956313	0.55142153	1

Appendix 6 Statistic comparison below trap 2023

Tabell 10 Statistic comparison between stations below trap in 2023. *Overview of variable, method, comparison of stations, Z, P-value unadjusted and P-value adjusted.*

			Method: dunnTest(, method='bonferroni')		
Variable	**Group**	**Comparing**	**Z**	**P.unadj**	**P.adj**
Total nitrogen	Below trap 23	Grense_Jakobselv_1 - Karpelva	0.4825707	0.6294006	1
		Grense_Jakobselv_1 - Munkelva	0.5612507	0.57462665	1
		Karpelva - Munkelva	0.07868	0.93728715	1
		Grense_Jakobselv_1 - Neiden_1	-3.1419548	0.00167824	0.01006944
		Karpelva - Neiden_1	-3.6245255	0.00028949	0.00173696
		Munkelva - Neiden_1	-3.7032055	0.00021289	0.00127735
Nitrate	Below trap 23	Grense_Jakobselv_1 - Karpelva	3.06910839	0.00214699	0.01288192
		Grense_Jakobselv_1 - Munkelva	3.053423	0.00226247	0.01357481
		Karpelva - Munkelva	-0.01568539	0.98748538	1
		Grense_Jakobselv_1 - Neiden_1	3.22596231	0.0012555	0.00753299
		Karpelva - Neiden_1	0.15685392	0.87535998	1
		Munkelva - Neiden_1	0.17253931	0.86301356	1
Ammonium	Below trap 23	Grense_Jakobselv_1 - Karpelva	2.1682231	0.03014172	0.1808503
		Grense_Jakobselv_1 - Munkelva	2.2841708	0.02236149	0.134169
		Karpelva - Munkelva	0.1159478	0.90769394	1
		Grense_Jakobselv_1 - Neiden_1	0.9971507	0.31869135	1
		Karpelva - Neiden_1	-1.1710724	0.24156969	1
		Munkelva - Neiden_1	-1.2870201	0.19808727	1
Ammonia Free	Below trap 23	Grense_Jakobselv_1 - Karpelva	0.74889039	0.4539233	1
		Grense_Jakobselv_1 - Munkelva	1.49778079	0.1341902	0.8051413
		Karpelva - Munkelva	0.74889039	0.4539233	1
		Grense_Jakobselv_1 - Neiden_1	0.81262575	0.4164327	1
		Karpelva - Neiden_1	0.06373535	0.949181	1
		Munkelva - Neiden_1	-0.68515504	0.4932461	1
Total phosphorus	Below trap 23	Grense_Jakobselv_1 - Karpelva	0.805217	0.42069445	1
		Grense_Jakobselv_1 - Munkelva	-0.3660077	0.7143593	1
		Karpelva - Munkelva	-1.1712248	0.24150844	1
		Grense_Jakobselv_1 - Neiden_1	-2.2587907	0.02389641	0.1433785
		Karpelva - Neiden_1	-3.0640077	0.00218393	0.0131036
		Munkelva - Neiden_1	-1.8927829	0.05838675	0.3503205
Orthophosphate	Below trap 23	Grense_Jakobselv_1 - Karpelva	1.4637665	0.14325776	0.85954659
		Grense_Jakobselv_1 - Munkelva	0.2875256	0.77370994	1
		Karpelva - Munkelva	-1.1762409	0.23949862	1
		Grense_Jakobselv_1 - Neiden_1	-2.8386614	0.00453032	0.02718192
		Karpelva - Neiden_1	-4.3024279	1.6894E-05	0.00010136
		Munkelva - Neiden_1	-3.126187	0.00177089	0.01062534
DOC	Below trap 23	Grense_Jakobselv_1 - Karpelva	-3.7662221	0.00016574	0.00099442
		Grense_Jakobselv_1 - Munkelva	-2.040037	0.04134664	0.24807987
		Karpelva - Munkelva	1.7261851	0.08431411	0.50588469
		Grense_Jakobselv_1 - Neiden_1	-4.2160764	2.4859E-05	0.00014915
		Karpelva - Neiden_1	-0.4498543	0.6528155	1
		Munkelva - Neiden_1	-2.1760394	0.02955231	0.17731388

COD	Below trap 23	Grense_Jakobselv_1 - Karpelva	-3.2130919	0.00131314	0.00787886
		Grense_Jakobselv_1 - Munkelva	-2.156016	0.03108241	0.18649447
		Karpelva - Munkelva	1.0570758	0.29047698	1
		Grense_Jakobselv_1 - Neiden_1	-3.4642782	0.00053166	0.00318994
		Karpelva - Neiden_1	-0.2511863	0.80167005	1
		Munkelva - Neiden_1	-1.3082622	0.1907844	1
pH	Below trap 23	Grense_Jakobselv_1 - Karpelva	-0.45916627	0.6461148	1
		Grense_Jakobselv_1 - Munkelva	0.48027736	0.6310302	1
		Karpelva - Munkelva	0.93944363	0.347503	1
		Grense_Jakobselv_1 - Neiden_1	-0.44333295	0.6575249	1
		Karpelva - Neiden_1	0.01583332	0.9873674	1
		Munkelva - Neiden_1	-0.92361031	0.3556892	1
E. coli	Below trap 23	Grense_Jakobselv_1 - Karpelva	-0.7069835	0.4795767	1
		Grense_Jakobselv_1 - Munkelva	-0.9478816	0.3431897	1
		Karpelva - Munkelva	-0.2408981	0.8096341	1
		Grense_Jakobselv_1 - Neiden_1	0.4399009	0.6600089	1
		Karpelva - Neiden_1	1.1468844	0.2514294	1
		Munkelva - Neiden_1	1.3877825	0.1652033	0.9912198
Germ number	Below trap 23	Grense_Jakobselv_1 - Karpelva	0.50227477	0.6154743	1
		Grense_Jakobselv_1 - Munkelva	0.06278435	0.9499382	1
		Karpelva - Munkelva	-0.43949042	0.6603062	1
		Grense_Jakobselv_1 - Neiden_1	-0.29299361	0.769527	1
		Karpelva - Neiden_1	-0.79526838	0.4264574	1
		Munkelva - Neiden_1	-0.35577796	0.7220069	1
C. Perfirigens	Below trap 23	Grense_Jakobselv_1 - Karpelva	-0.2362185	0.8132631	1
		Grense_Jakobselv_1 - Munkelva	0.8871318	0.3750079	1
		Karpelva - Munkelva	1.1233503	0.2612887	1
		Grense_Jakobselv_1 - Neiden_1	0.3569524	0.7211274	1
		Karpelva - Neiden_1	0.593171	0.5530667	1
		Munkelva - Neiden_1	-0.5301794	0.5959876	1
Coliforme	Below trap 23	Grense_Jakobselv_1 - Karpelva	-0.38252423	0.7020726	1
		Grense_Jakobselv_1 - Munkelva	0.61308678	0.539819	1
		Karpelva - Munkelva	0.99561102	0.3194392	1
		Grense_Jakobselv_1 - Neiden_1	0.58688649	0.5572799	1
		Karpelva - Neiden_1	0.96941073	0.3323403	1
		Munkelva - Neiden_1	-0.02620029	0.9790976	1

Appendix 7 Statistic comparison of 2022 and 2023 season

Tabell 11 Statistic comparison of variables of stations below traps between 2022 and 2023 season (data from all stations pooled). *Overview of variable, method, comparison of stations, Z, P-value unadjusted and P-value adjusted.*

		Method: wilcox.test(, equal=T, paired=F)		
Variable	**Group**	**Comparison**	**W**	**p**
Total nitrogen	Below trap	22 - 23 season	542.5	0.4284
Nitrate	Below trap	22 - 23 season	302	0.0237
Ammonium	Below trap	22 - 23 season	321.5	0.8767
Ammonia free	Below trap	22 - 23 season	529	0.1265
Total phosphorus	Below trap	22 - 23 season	371	0.1667
Orthophosphate	Below trap	22 - 23 season	521.5	0.6014
DOC	Below trap	22 - 23 season	517.5	0.6371
COD	Below trap	22 - 23 season	616	0.08385
pH	Below trap	22 - 23 season	602.5	0.1162
E. coli	Below trap	22 - 23 season	358	0.121
Germination number	Below trap	22 - 23 season	572	0.234
Clostridium perfirigens	Below trap	22 - 23 season	432	0.5431
Coliform	Below trap	22 - 23 season	272	0.008109

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Antoniou, P., Hamilton, J., Koopman, B., Jain, R., Holloway, B., Lyberatos, G., & Svoronos, S. A. (1990). Effect of temperature and ph on the effective maximum specific growth rate of nitrifying bacteria. *Water Research*, *24*(1), 97-101. https://doi.org/https://doi.org/10.1016/0043-1354(90)90070-M

Armstrong, J. D., Bean, C. W., & Wells, A. (2018). The Scottish invasion of pink salmon in 2017. *Journal of Fish Biology*, *93*(1), 8-11.

Bauer, F. D. (1972). Constructing confidence sets using rank statistics. *Journal of the American Statistical Association*, *67*, 687-690. https://doi.org/10.1080/01621459.1972.10481279

Berntsen, H. H., Sandlund, O. T., Ugedal, O., Thorstad, E., Fiske, P., Urdal, K., Skaala, Ø., Fjeldheim, P. T., Skoglund, H., Florø-Larsen, B., Muladal, R., & Uglem, I. (2018). *Pukkellaks i Norge, 2017*.

Bonde, B. M. (2023). *Aggregative response in white-tailed eagles - an initial study of the terrestrial implications of invasive Pacific pink salmons (Onchorhynchus gorbuscha) in northern Norway* Universitetet i Tromsø].

Campbell, E. Y., Merritt, R. W., Cummins, K. W., & Benbow, M. E. (2012). Spatial and temporal variability of macroinvertebrates in spawning and non-spawning habitats during a salmon run in southeast Alaska. *PLoS One*, *7*(6), e39254.

Cederholm, C. J., Kunze, M. D., Murota, T., & Sibatani, A. (1999). Pacific salmon carcasses: essential contributions of nutrients and energy for aquatic and terrestrial ecosystems. *Fisheries*, *24*(10), 6-15.

Christie, K., & Reimchen, T. (2005). Post-reproductive Pacific salmon, Oncorhynchus spp., as a major nutrient source for large aggregations of gulls, Larus spp. *The Canadian Field-Naturalist*, *119*(2), 202-207.

Cotner, J., & Biddanda, B. (2002). Small Players, Large Role: Microbial Influence on Biogeochemical Processes in Pelagic Aquatic Ecosystems. *Ecosystems*, *5*, 105-121. https://doi.org/10.1007/s10021-001-0059-3

Craun, G. F., Berger, P. S., & Calderon, R. L. (1997). Coliform bacteria and waterborne disease outbreaks. *Journal ‐ American Water Works Association*, *89*(3), 96-104.

Diaz Pauli, B., Berntsen, H. H., Thorstad, E. B., Homrum, E. ì., Lusseau, S. M., Wennevik, V., & Utne, K. R. (2023). Geographic distribution, abundance, diet, and body size of invasive pink salmon (Oncorhynchus gorbuscha) in the Norwegian and Barents Seas, and in Norwegian rivers. *ICES Journal of marine Science*, *80*(1), 76-90.

Dodds, W. K., & Whiles, M. R. (2010). *Freshwater Ecology: Concepts and Environmental Applications of Limnology* (2,2nd ed.). San Diego: Elsevier Science & Technology.

Dubin, K., & Pamer, E. G. (2017). Enterococci and their interactions with the intestinal microbiome. *Microbiology spectrum*, *5*(6), 10.1128/microbiolspec. bad-0014-2016.

Dunlop, K., Eloranta, A. P., Schoen, E., Wipfli, M., Jensen, J. L., Muladal, R., & Christensen, G. N. (2021). Evidence of energy and nutrient transfer from invasive pink salmon (Oncorhynchus gorbuscha) spawners to juvenile Atlantic salmon (Salmo salar) and brown trout (Salmo trutta) in northern Norway. *Ecology of Freshwater Fish*, *30*(2), 270-283.

Dunlop., K. M., Wipfli, M., Muladal, R., & Wierzbinski, G. (2021). Terrestrial and semi-aquatic scavengers on invasive Pacific pink salmon (Oncorhynchus gorbuscha) carcasses in a riparian ecosystem in northern Norway. *Biological invasions*, *23*(4), 973-979. https://doi.org/10.1007/s10530-020-02419-x

Dunn, A. M. (2009). Chapter 7 Parasites and Biological Invasions. In *Advances in Parasitology* (Vol. 68, pp. 161-184). Academic Press. https://doi.org/https://doi.org/10.1016/S0065-308X(08)00607-6
Dunn, O. J. (1964). Multiple comparisons using rank sums. *Technometrics*, *6*, 241–252. https://doi.org/10.1080/ 00401706.1964.10490181
Effler, S. W., Brooks, C. M., Auer, M. T., & Doerr, S. M. (1990). Free Ammonia and Toxicity Criteria in a Polluted Urban Lake. *Research Journal of the Water Pollution Control Federation*, *62*(6), 771-779. http://www.jstor.org/stable/25043912
Erkinaro, J., Orell, P., Pohjola, J. P., Kytökorpi, M., Pulkkinen, H., & Kuusela, J. (2022). Development of invasive pink salmon (Oncorhynchus gorbuscha Walbaum) eggs in a large Barents Sea river. *Journal of Fish Biology*, *101*(4), 1063-1066.
Gende, S. M., Edwards, R. T., Willson, M. F., & Wipfli, M. S. (2002). Pacific Salmon in Aquatic and Terrestrial Ecosystems: Pacific salmon subsidize freshwater and terrestrial ecosystems through several pathways, which generates unique management and conservation issues but also provides valuable research opportunities. *BioScience*, *52*(10), 917-928.
Gende, S. M., Quinn, T. P., & Willson, M. F. (2001). Consumption choice by bears feeding on salmon. *Oecologia*, *127*(3), 372-382. https://doi.org/10.1007/s004420000590
Gende, S. M., Quinn, T. P., Willson, M. F., Heintz, R., & Scott, T. M. (2004). *Magnitude and Fate of Salmon-Derived Nutrients and Energy in a Coastal Stream Ecosystem* [149-160]. La Crosse, Wis. :.
Google. (2024). *Google My Maps*. https://www.google.com/maps/d/
Gordeeva, N., Salmenkova, E., & Altukhov, Y. P. (2005). Genetic differentiation of Pacific pink salmon during colonization of a new area. Doklady Biological Sciences,
Gordeeva, N., Salmenkova, E., & Prusov, S. (2015). Variability of biological and population genetic indices in pink salmon, Oncorhynchus gorbuscha transplanted into the White Sea basin. *Journal of Ichthyology*, *55*, 69-76.
Gordeeva, N. V., & Salmenkova, E. A. (2011). Experimental microevolution: transplantation of pink salmon into the European North. *Evolutionary Ecology*, *25*, 657-679.
Groot, C., & Margolis, L. (1991). *Pacific salmon life histories*. UBC press.
Gurevitch, J., & Padilla, D. K. (2004). Are invasive species a major cause of extinctions? *Trends in Ecology & Evolution*, *19*(9), 470-474. https://doi.org/https://doi.org/10.1016/j.tree.2004.07.005
Heard, W. R. (1991). Life history of pink salmon (Oncorhynchus gorbuscha). *Pacific salmon life histories*, 119-230.
Hendry, A. P., & Berg, O. K. (1999). Secondary sexual characters, energy use, senescence, and the cost of reproduction in sockeye salmon. *Canadian Journal of Zoology*, *77*(11), 1663-1675.
Hickman, J. E., Ashton, I. W., Howe, K. M., & Lerdau, M. T. (2013). The native–invasive balance: implications for nutrient cycling in ecosystems. *Oecologia*, *173*, 319-328.
Hindar, K., Hole, L. R., Kausrud, K. L., Malmstrøm, M., Rimstad, E., Robertson, L., Sandlund, O. T., Thorstad, E. B., Vollset, K., de Boer, H., Eldegard, K., Järnegren, J., Kirkendall, L. R., Måren, I. E., Nilsen, E. B., Rueness, E. K., Nielsen, A., & Velle, G. (2020). Assessment of the risk to Norwegian biodiversity and aquaculture from pink salmon (Oncorhynchus gorbuscha). Scientific Opinion of the Panel on Alien Organisms and Trade in Endangered Species of the Norwegian Scientific Committee for Food and Environment.
Hocking, M. D., & Reimchen, T. E. (2006). *Consumption and distribution of salmon (Oncorhynchus spp.) nutrients and energy by terrestrial flies* [2076-2086]. Ottawa.

Hocking, M. D., & Reynolds, J. D. (2011). Impacts of salmon on riparian plant diversity. *Science*, *331*(6024), 1609-1612.
Hocking, M. D., Ring, R. A., & Reimchen, T. E. (2009). The ecology of terrestrial invertebrates on Pacific salmon carcasses. *Ecological Research*, *24*(5), 1091-1100. https://doi.org/10.1007/s11284-009-0586-5
Hogan, J., & Larry Smith, K. (2003). *Coliform mastitis* [507-519]. Paris :.
Hollander, M., & Wolfie, A. D. (1973). *Nonparametric Statistical Methods.* John Wiley & Sons.
Holt, R. D. (1977). Predation, apparent competition, and the structure of prey communities. *Theoretical Population Biology*, *12*(2), 197-229. https://doi.org/https://doi.org/10.1016/0040-5809(77)90042-9
Ip, Y., Chew, S., & Randall, D. (2001). Ammonia toxicity, tolerance, and excretion. *Fish physiology*, *20*, 109-148.
Ishii, S., & Sadowsky, M. J. (2008). *Escherichia coli in the Environment: Implications for Water Quality and Human Health* [101-108]. [Tagajo?] :.
Jang, J., Hur, H. G., Sadowsky, M. J., Byappanahalli, M. N., Yan, T., & Ishii, S. (2017). Environmental Escherichia coli: ecology and public health implications—a review. *J Appl Microbiol*, *123*(3), 570-581. https://doi.org/10.1111/jam.13468
Kalff, J. (2002). *Limnology : inland water ecosystems*. Prentice Hall.
Lennox, R. J., Berntsen, H. H., Garseth, Å. H., Hinch, S. G., Hindar, K., Ugedal, O., Utne, K. R., Vollset, K. W., Whoriskey, F. G., & Thorstad, E. B. (2023). Prospects for the future of pink salmon in three oceans: From the native Pacific to the novel Arctic and Atlantic. *Fish and fisheries (Oxford, England)*, *24*(5), 759-776. https://doi.org/10.1111/faf.12760
Liu, Y., Ngo, H. H., Guo, W., Peng, L., Wang, D., & Ni, B. (2019). *The roles of free ammonia (FA) in biological wastewater treatment processes: A review* [10-19]. [Oxford ; New York] :.
Lockwood, J. L., Cassey, P., & Blackburn, T. (2005). The role of propagule pressure in explaining species invasions. *Trends in Ecology & Evolution*, *20*(5), 223-228.
Forskrift om vannforsyning og drikkevann, (2024).
Mack, R. N., Simberloff, D., Mark Lonsdale, W., Evans, H., Clout, M., & Bazzaz, F. A. (2000). *BIOTIC INVASIONS: CAUSES, EPIDEMIOLOGY, GLOBAL CONSEQUENCES, AND CONTROL* [689-710]. Tempe, AZ :.
Maduna, S. N., Aspholm, P. E., Hansen, A. S. B., Klütsch, C. F., & Hagen, S. B. (2024). Ecological niche modelling and population genomics provide insights into the geographic and demographic ‘explosion’ of a non‐indigenous salmonid. *Diversity and Distributions*, *30*(3), e13811.
Meilink, W. R. M., Arntzen, J. W., van Delft, J. J. C. W., & Wielstra, B. (2015). Genetic pollution of a threatened native crested newt species through hybridization with an invasive congener in the Netherlands. *Biological Conservation*, *184*, 145-153. https://doi.org/https://doi.org/10.1016/j.biocon.2015.01.022
Miljødirektoratet. (2024). *Pukkellaks uttak.* https://www.miljodirektoratet.no/aktuelt/datavisualisering/pukkellaks-uttak/
Millane, M., Walsh, L., Roche, W. K., & Gargan, P. G. (2019). Unprecedented widespread occurrence of Pink Salmon Oncorhynchus gorbuscha in Ireland in 2017. *Journal of Fish Biology*, *95*(2), 651-654.
Mo, T. A., Berntsen, H. H., Frøiland, E., Thorstad, E. B., Hindar, K., & Sandlund, O. T. (2021). *Forslag til handlingsplan mot pukkellaks*.
Mo, T. A., Thorstad, E. B., Sandlund, O. T., Berntsen, J. H. H., Fiske, P., & Uglem, I. (2018). The pink salmon invasion: a Norwegian perspective. https://doi.org/10.1111/jfb.13682

Morbey, Y. E., Brassil, C. E., & Hendry, A. P. (2005). Rapid senescence in Pacific salmon. *The American Naturalist*, *166*(5), 556-568.
Muladal, R. (2024). *Pink salmon in Grense Jakobselv.* (
Naiman, R. J., Bilby, R. E., Schindler, D. E., & Helfield, J. M. (2002). Pacific Salmon, Nutrients, and the Dynamics of Freshwater and Riparian Ecosystems. *Ecosystems*, *5*(4), 399-417. https://doi.org/10.1007/s10021-001-0083-3
Nielsen, J., Rosing‐Asvid, A., Meire, L., & Nygaard, R. (2020). *Widespread occurrence of pink salmon (Oncorhynchus gorbuscha) throughout Greenland coastal waters* [1505-1507]. London :.
Norges Geologiske Undersøkelse. (2024). *Geologiske kart*.
Norges Vassdrags- og Energidirektorat. (2024). *Sildre*. https://sildre.nve.no/map
Norsk institutt for vannforskning. (2023). *The Norwegian River Monitoring Programme 2022 - water quality, status and trends*.
Ojaveer, H., Galil, B. S., Minchin, D., Olenin, S., Amorim, A., Canning-Clode, J., Chainho, P., Copp, G. H., Gollasch, S., & Jelmert, A. (2014). Ten recommendations for advancing the assessment and management of non-indigenous species in marine ecosystems. *Marine Policy*, *44*, 160-165.
Pinay, G., O'Keefe, T. C., Edwards, R. T., & Naiman, R. J. (2009). *Nitrate removal in the hyporheic zone of a salmon river in Alaska* [367-375]. Chichester, West Sussex, UK :.
Posit team. (2024). *RStudio: Integrated Development for R.* In (Version 2023.12.1.402) Posit software, PBC. http://www.posit.co/
Puyol, D., Carvajal-Arroyo, J. M., Li, G. B., Dougless, A., Fuentes-Velasco, M., Sierra-Alvarez, R., & Field, J. A. (2014). High pH (and not free ammonia) is responsible for Anammox inhibition in mildly alkaline solutions with excess of ammonium. *Biotechnology Letters*, *36*(10), 1981-1986. https://doi.org/10.1007/s10529-014-1564-8
Quinn, T. P. (2007). *The behavior and ecology of Pacific salmon and trout*. University of British Columbia Press.
Randall, D. J., & Tsui, T. K. N. (2002). Ammonia toxicity in fish. *Marine Pollution Bulletin*, *45*(1), 17-23. https://doi.org/https://doi.org/10.1016/S0025-326X(02)00227-8
Ricciardi, A., Hoopes, M. F., Marchetti, M. P., & Lockwood, J. L. (2013). *Progress toward understanding the ecological impacts of nonnative species* [263-282]. Durham, N.C. :.
Rood, J. I., & Cole, S. T. (1991). *Molecular genetics and pathogenesis of Clostridium perfringens* [621-648]. [Washington, D.C.] :.
Roughgarden, J., & Diamond, J. (1986). Overview: the role of species interactions in community ecology. *Community ecology*, 333-343.
Sandlund, O. T., Berntsen, H. H., Fiske, P., Kuusela, J., Muladal, R., Niemelä, E., Uglem, I., Forseth, T., Mo, T. A., & Thorstad, E. B. (2019). Pink salmon in Norway: the reluctant invader. *Biological invasions*, *21*, 1033-1054.
Shapiro, S. S., & Wilk, M. B. (1965). An analysis of variance test for normality (complete samples). *Biometrika*, *52(3–4)*, 591-611. https://doi.org/10.1093/biomet/52.3-4.591
Simberloff, D. (2011). How common are invasion-induced ecosystem impacts? *Biological invasions*, *13*(5), 1255-1268. https://doi.org/10.1007/s10530-011-9956-3
Smith, R. V., Burns, L. C., Doyle, R. M., Lennox, S. D., Kelso, B. H. L., Foy, R. H., & Stevens, R. J. (1997). Free ammonia inhibition of nitrification in river sediments leading to nitrite accumulation. *Journal of environmental quality*, *26*(4), 1049-1055. https://doi.org/10.2134/jeq1997.00472425002600040016x
Stets, E. G., & Cotner, J. B. (2008). The Influence of Dissolved Organic Carbon on Bacterial Phosphorus Uptake and Bacteria-Phytoplankton Dynamics in Two Minnesota Lakes. *Limnology and oceanography*, *53*(1), 137-147. https://doi.org/10.4319/lo.2008.53.1.0137

Systad, G. H., Strann, K.-B., & Frivoll, V. (2004). *Biologisk mangfold : Sør-Varanger kommune* (Vol. 829). Norsk institutt for naturforskning.
Villaverde, S., García-Encina, P. A., & Fdz-Polanco, F. (1997). Influence of pH over nitrifying biofilm activity in submerged biofilters. *Water Research*, *31*(5), 1180-1186. https://doi.org/https://doi.org/10.1016/S0043-1354(96)00376-4
Vitousek, P. M., d'Antonio, C. M., Loope, L. L., & Westbrooks, R. (1996). Biological invasions as global environmental change. *American scientist*, *84*(5), 468-478.
Wetzel, R. G. (2001). *Limnology : lake and river ecosystems* (3rd ed.). Academic Press.
Wickham, H. (2016). *ggplot2: Elegant Graphics for Data Analysis*. In https://ggplot2.tidyverse.org
Willette, T. (2001). Foraging behaviour of juvenile pink salmon (Oncorhynchus gorbuscha) and size‐dependent predation risk. *Fisheries Oceanography*, *10*, 110-131.
Willson, M. F., Gende, S. M., & Marston, B. H. (1998). Fishes and the forest. *BioScience*, *48*(6), 455-462.