Short-term effects of habitat restoration on brown trout and salmon

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Abstract

During the 1800´s and 1900´s, Swedish rivers were heavily modified to support log driving, this led to significant decrease of ecological function and integrity in the river systems. In recent time, restoration has become an important tool to recover the ecological status, especially following the acceptance of the EU Water Framework Directive. This study analyses the short-term effects of restoration measures implemented on the ReBorN LIFE project on brown trout and salmon in Lögdeälven. Using electrofishing data from 11 different survey sites dating back to the year 2000 and up until 2024, I analyse trout and salmon densities, before and after restoration using linear mixed models and trend plots. No significant difference were observed between the before- and after period on either salmon or trout. The trends indicate a decline in densities in both species, trout with a negative trend from the start (year 2000), and salmon with a positive trend before restoration but a negative trend after. Several factors may influence the result both in trend and in lack of significance, for example, disease, river broadening, environmental factors, and changes in electrofishing gear. It is possible that the short time-period of post restoration monitoring is not enough to capture the restoration effects. This study points towards the need for long term monitoring, and potentially new assessment methods to accurately study the full effects of restoration on fish populations.

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1. Introduction

1.1 Introduction

During the 1800´s and the major part of the 1900´s the lumber industry was growing in Sweden. Sawmills were commonly located close to seaports and, hence, placed far away from the main lumber production area. Rivers were used to transport logs downstream to the sawmills at the coast, a practise called log-driving (Nilsson et al. 2007). To make the floating of logs as smooth as possible, the rivers planform was modified in different ways to avoid logjams due to the presence of boulders, fallen trees, side channels, riverbanks and riffles (Törnlund & Östlund 2002). Rivers were cleared from structure like larger rocks and fallen trees, partly routed other ways or channelized (straightened and deepened) and water levels heightened with variety of dams (Nilsson et al. 2007). This has led to reduction in ecological, hydraulic, and geomorphic status of Swedish rivers.

River restoration is modifications to degraded parts of the river system with the goal of restoring it towards a former state, including hydraulic, geomorphic and ecological features (Wohl et al. 2015). Consequently, river restoration is presumably a useful practise to regain more natural river systems with higher ecological values (Wohl et al. 2015). In the year 2000 the Water Framework Directive (WFD; Directive 2000/60/EC of the European Parliament and of the Council) was accepted by the EU Member States and has since become the leading law when it comes to protecting water ecosystem resources in the EU. The WDF's objective is to ensure good status (both chemical and ecological) in our water bodies by protecting and when needed restoring aquatic ecological functions. The objective of the WFD is still a driving force for restoration in the EU and helps ensure reaching the goal of water bodies with good status (Smith et al. 2014).

River restoration efforts have in several cases, led to positive result on trout and salmon populations, with abundance reaching higher values after measures compered to before (Pierce et al. 2013; Marttila et al. 2019). This however is not true in every case. In a recent study on short-term effects of habitat restoration on brown trout habitat availability, researchers found that the results varied (Richer et al. 2019). In some parts of the river the results were positive with increased areas of suitable habitat, the first years following the measure but then declining. Other parts showed positive trends throughout all the analysed years (Richer et al. 2019). This shows a potential context dependence, as well as the importance of monitoring both the short-term effects and the less commonly studied, long-term effects.

1.2 Aim

The aim of this work was to analyse the short-term effects of a habitat restoration project (ReBorN LIFE "Restoration of Boreal Nordic Rivers"; https://www.rebornlife.org) on brown trout (*Salmo trutta;* henceforth "trout") and Atlantic (Baltic) salmon (*Salmo salar*; henceforth "salmon") in the river Lögdeälven, northern Sweden. The ReBorN restoration target species were salmon, otter (*Lutra lutra*) and freshwater pearl mussel (*Margaritifera margaritifera*), which are three species that also share habitat with trout.

The general research question to be answered was: *What impact does restoration measures have on the trout and salmon population densities over the first few years (3-8 years) after restoration?* The hypothesis is that river restoration would improve habitat quality and spawning conditions for juvenile salmon and trout. Hence, my prediction is that juvenile densities and total densities would increase in the after-restoration time-period, compared to the before-restoration time-period.

2. Method

2.1 Restoration model: Lögdeälven

Lögdeälven is a river located in Västerbotten, in northern Sweden. It is generally characterized as a forest-river and travels 200 km from the lake Gransjön to the Gulf of Bothnia. The river starts as a slow-moving water but quickly turns into faster flowing hydromorphology. It passes through the lake Lögdasjön and continues down to the sea, just south of Nordmaling. In the lower section of the river, the water once again slows down and flows in meanders.

The restoration measures applied in the project were mainly located in parts of the river that had been anthropogenically altered for the purpose of log-driving. The three most common measures were: i) adding dead wood, ii) rearranging substrate in the river, and iii) broadening the river channel (Länsstyrelsen 2025b). Other measures such as making spawning beds, re-opening side-channels and re-meandering were also applied but either in lesser frequency, or in other parts of the river compared to the locations investigated in this study.

Table 1. List of restoration measures with descriptions

Restoration measure	**Description**
Adding dead wood	Adding dead wood that historically has been cleared to make a free pathway for logs to travel.
Rearranging substrate	Rearranging substrate such as different size rocks and blocks, dead wood in the river or on the riverbank.
Broadening the river	Adding substrate to the bottom of the river and thereby lowering the depth and broadening the area of water.
Making spawning beds	Addition of specific-size gravel suitable for the fish to lay their eggs in.
Re-meandering	Re-shaping the waters pathway that historically has been straightened.
Re-opening side-channels	Opening previous side-channels that was connected to the main-channel so the water can travel through it again.

2.2 Data

Electrofishing data were gathered from the Swedish electrofishing database (SERS; https://www.slu.se/elfiskeregistret) using the standardized result output file "Elfiskeresultat_VIX_VIXmorf.docx" (2025-03-31) obtained from the data host at the Institute of Freshwater Research (SLU Aqua). The data were filtered based on the following criteria:

- the electrofishing site should at least have six surveys from different years.
- the last result should be from 2023 or 2024 to provide decent contribution to assessment of the effect after restoration.
- samples that were taken on deviating months (i.e. outside the standard electrofishing period, July-September) were removed.

Furthermore, all data from before the year 2000 were removed due to earlier studies showing a general increase in salmon and trout population densities, from lower levels, leading up to the year 2000 (Rivinoja & Carlsson 2008). The data from before 2000 would lower the average of the "before restoration" data and is not very relevant when looking at the abundance of fish close before restoration. This resulted in the inclusion of data from 11 sites in the evaluation.
Information about the restoration measures was found in the County Administrative Board database on aquatic management measures, "*Åtgärder i vatten*" (https://atgarderivatten.lansstyrelsen.se/). Restored sections are illustrated as brown stretches on the map in Figure 3; electrofishing sites are shown as red dots in the same figure. Distance between electrofishing site and restoration site, along the river's pathway, was measured from orthophotos using the Eniro web application and its "measure in map" function (https://www.eniro.se/kartor). The average distance to measure were around 110 meters, varying between 0 and 540 meters. Average distance to sea were 53 047 meters, varying between 15 250 and 96 280 meters.

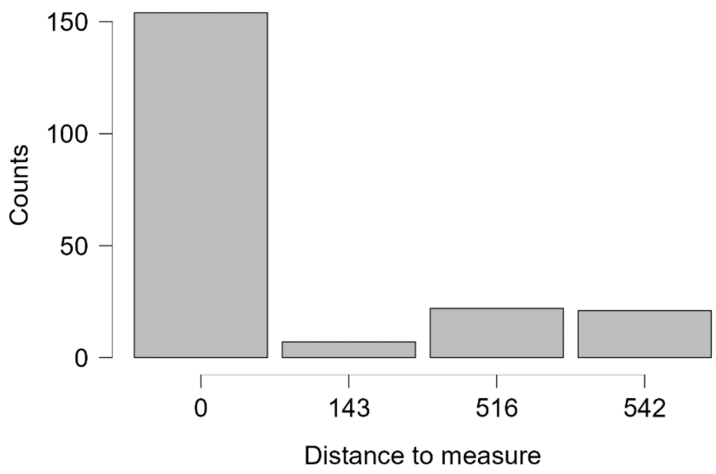

Figure 1: Distribution of samples based on distance to measure, split into four bins. All electrofishing data are included, and the same site occurs several times.

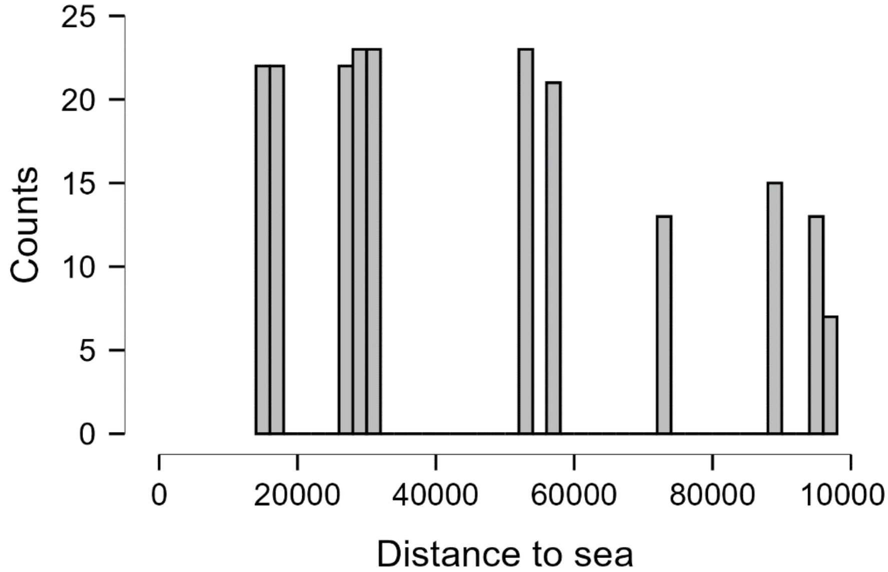

Figure 2: Distribution of samples based on distance to sea. Each bar represents one electrofishing site and the height of the bar represents the number of electrofishing samples from that site.

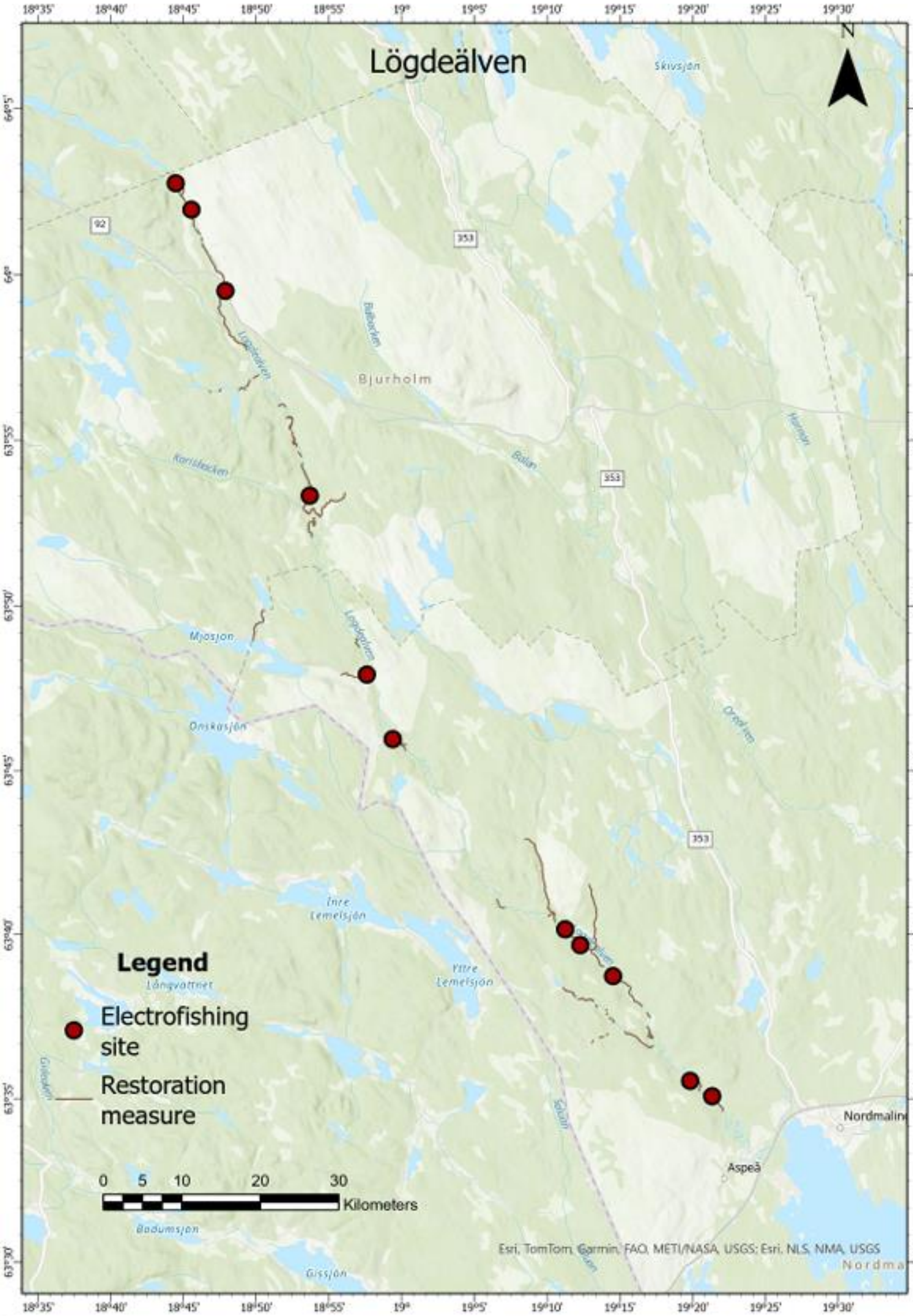

Figure 3: Map showing Lögdeälven with restoration stretches in brown colour and electrofishing sites marked as red dots. GIS layer provided through Geodatakatalogen (Länsstyrelsen 2025a).

2.3 Electrofishing

The electrofishing (Figure 3) was conducted using the Swedish standardized method (Bergquist et al. 2014; Petersson et al. 2023). Electrofishing is a sampling method used to collect fish for examination, without killing or severely harming the fish (Bohlin et al. 1989). The electricity comes from a power unit which is connected to an electric fishing pole which creates an electric field that attracts and stuns the fish. Once stunned, the fish is caught with a handnet, examined (e.g. weighed and measured), and released back into the water after recovery (Bergquist et al. 2014). Density calculations are made when entering data into SERS, using a maximum-likelihood model (if multiple electrofishing passes have been conducted), or using an average catchability estimate (if a single electrofishing pass has been conducted) (Bohlin et al. 1989; Bergquist et al. 2014).

2.4 Statistical analyses

The analyses were conducted in JASP (Love et al. 2019) which is a graphical interface statistics program based on the R programming language (R Core Team 2024). Linear mixed models were run for both salmon and trout densities [transformed: log(density+1)] as the dependent variable, "time-period" was added as a fixed effect variable, and "site" as grouping (random) factor. Analyses focussed on the total density of each species (i.e. combining different year classes). The JASP Flexplot function was used to create graphs to illustrate trends for these two species of fish over time. For both species, data was plotted for the total density as well as for young-of-the-year and older individuals separately. Here the species was set as dependent variable, "years" as independent variable and the trend line were based on none-linear loess regression.

3. Results

3.1 Brown trout

3.1.1 Trend plots

Based on available electrofishing data the three plots (Figure 4) show a general negative trend indicating a decrease in brown trout densities over the whole period (2000 to 2024), i.e. including after restoration. When analysing the results based on categorized time-periods (before-, during- and after restoration), the estimated differences are without clear significant support as shown in the ANOVA table ($p = 0.066$; Table 2, Figure 5). The estimated contrast between the before and after periods (after - before) was -0,606 individuals per 100 m^2 (Table 3, Figure 5). Given that the contrast is negative, there is no support for increased trout densities after restoration, using the available electrofishing data. Instead, the tendency goes in the opposite direction, although non-significantly.

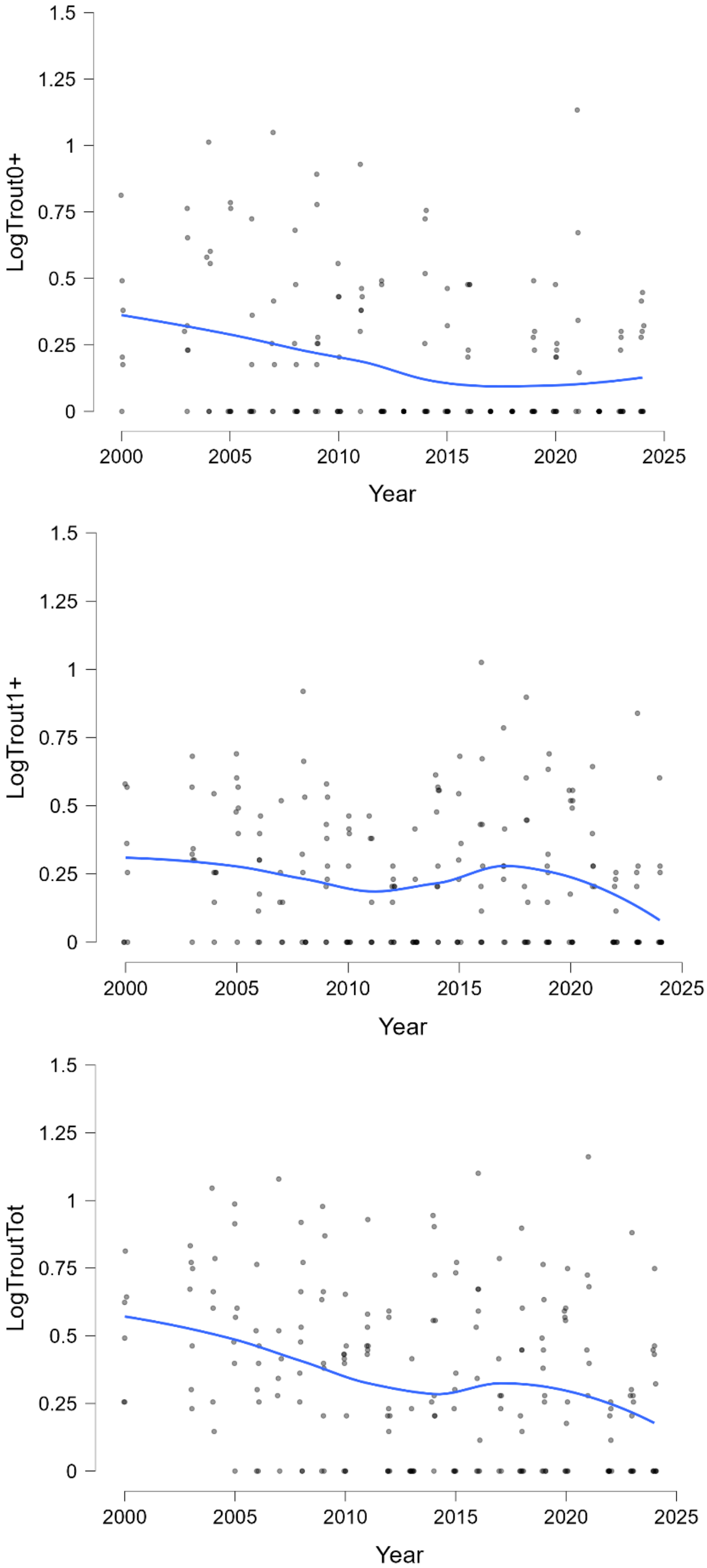

Figure 4: Plots showing abundance of trout over time, with log(density+1) on the y-axel and years on the x-axel. The first plot illustrates yearling over time, second plot older than yearlings over time and the third plot both yearlings and older combined over time.

3.1.2 Linear mixed model

Table 2: ANOVA analyses on density of trout between three different periods of time. Effect = factor, df = degrees of freedom, F = F-statistic for the model, p = p-value.

Effect	df	*F*	*p*
Time period	2, 16.24	3.223	0.066

Table 3: Recalculated estimated marginal means from log(density+1) to number of individuals on trout. Estimate = average density, SE = standard error of the estimate; 95% CI = upper and lower margins for the 95% confidence intervals of the estimate.

			95% CI	
Time period	Estimate	SE	Lower	Upper
1.Before	3.328	0.052	2.841	3.944
2.During	3.432	0.112	2.466	5.036
3.After	2.722	0.044	2.413	3.094

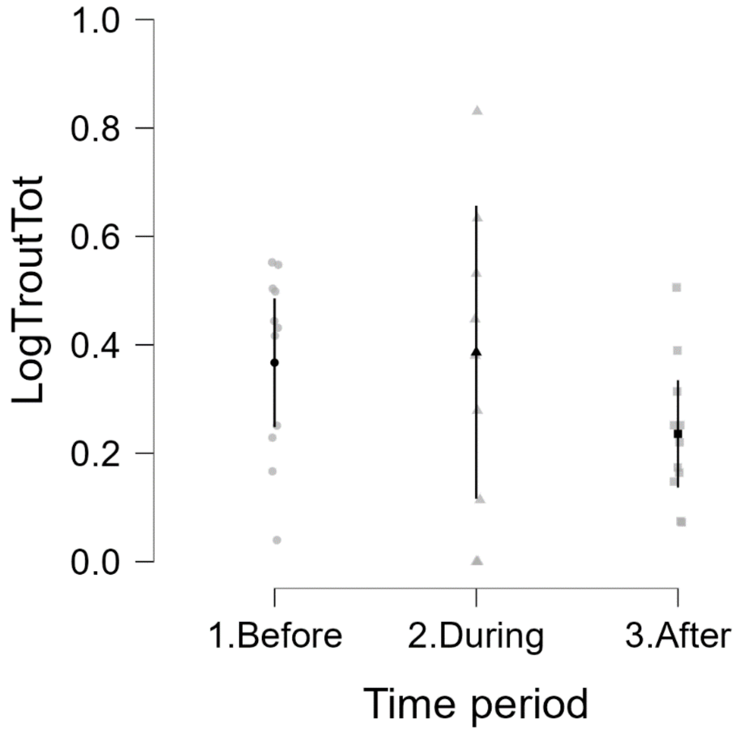

Figure 5: Linear mixed model showing estimated density of trout before, after and during restoration with site as grouping factor. The graph shows estimated marginal means for each category, with error bars showing 95 % confidence interval. Data are shown transformed, using log(density+1).

3.2 Salmon

3.2.1 Trend plots

Based on the salmon electrofishing data the plots show a negative trend indicating a decrease in salmon density the years after restoration (Figure 6). When analysing the results based on categorized time-periods (before-, during- and after restoration), the estimated differences are without clear significant support, as shown in the ANOVA table (p = 0.342; Table 4, Figure 7). The estimated contrast between the before and after period (after - before) was -0,385 individuals per 100 m^2 (Table 5, Figure 7). Given that the contrast is negative, there is no support for increased salmon densities after restoration, using the available electrofishing data.

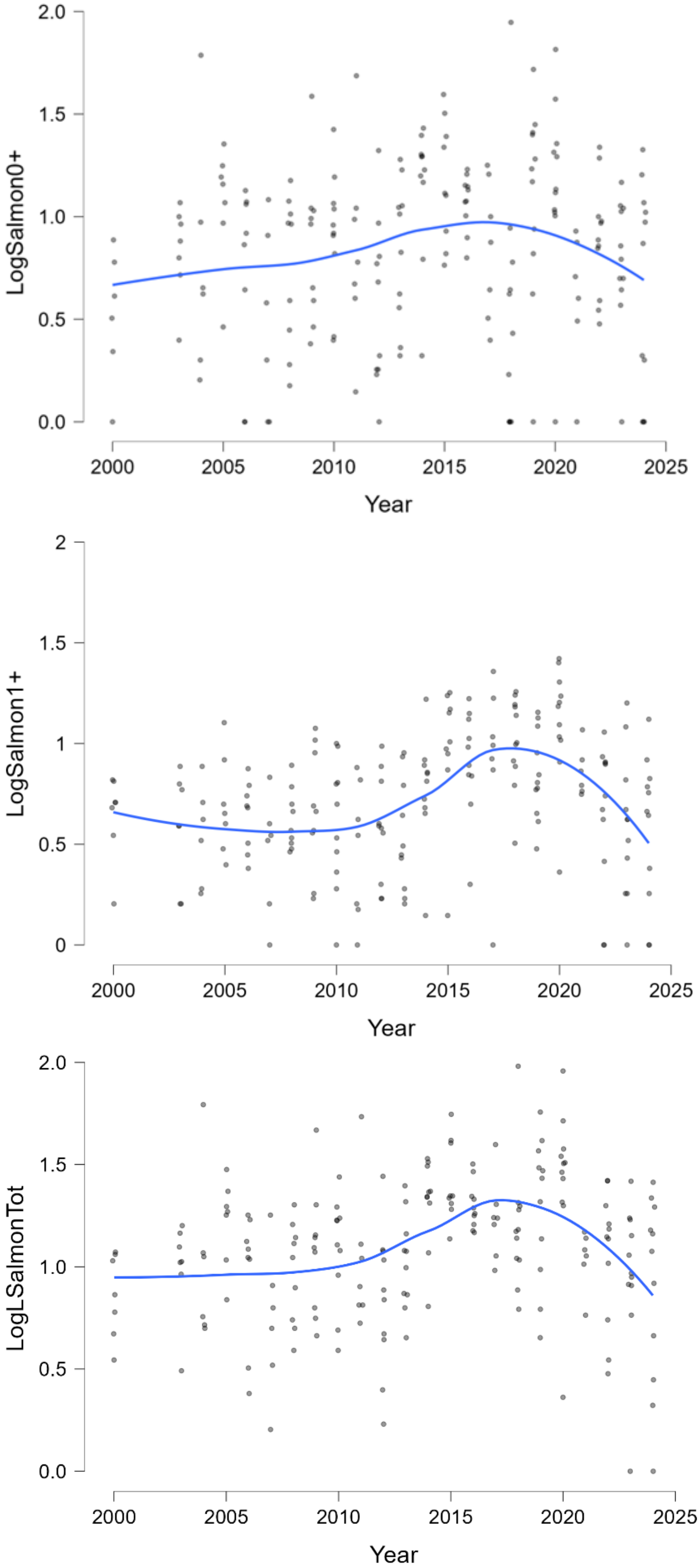

Figure 6: Plots showing abundance of salmon over time, with log(density+1) on the y-axel and years on the x-axel. The top plot illustrates yearlings over time, middle plot older than yearlings over time and the bottom plot both yearlings and older combined over time.

3.2.2 Linear mixed model

Table 4: ANOVA analyses on density of trout between three different periods of time. Effect = factor, df = degrees of freedom, F = F-statistic for the model, p = p-value.

Effect	df	F	P
Time period	2, 10.60	1.190	0.342

Table 5: Recalculated estimated marginal means from log(density+1) to number of individuals. Estimate = average density, SE standard error of the estimate, 95% CI = upper and lower margins for 95% confidence intervals of the estimate.

			95% CI	
Time period	Estimate	SE	Lower	Upper
1.Before	13,134	0.041	10.093	15.555
2.During	19,578	0.105	12.588	30.785
3.After	12,749	0.090	8.834	18.66

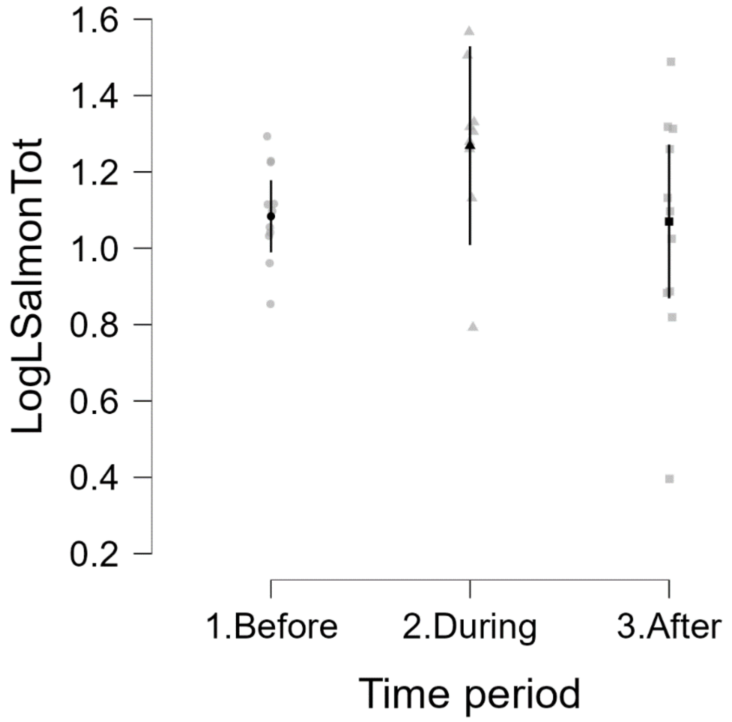

Figure 7: Linear mixed model showing estimated densities of salmon before, after and during restoration with site as grouping factor. The graph shows estimated marginal means for each category, with error bars showing 95 % confidence interval. Data are shown transformed, using log(density+1).

4. Discussion

4.1 Summary of results

No significant differences, in neither trout nor salmon densities, were detected between the before- and after time-periods, although the trend points towards a decrease or no change in abundance of the species since the restoration project started in 2016. When looking at the trout and salmon trend plots (Figure 4 and 6), the trend is relatively steadily decreasing from the restoration period with some variety. The trout yearlings show no change since restoration. This means that the trend plots point towards restoration measures having a non-positive impact on either population. A possible negative impact is not supported by statistical significance. A study by Richer et. al. (2019) has also showed negative or non-significant results when looking at short-term effects of restoration. A proposed possible explanation was related to the new habitat qualities and sampling sites. The restoration had created more heterogeneous habitat with patches of lower quality and higher quality than what had previously been available in the river. Sites that previously had bad habitat quality were targeted and made better through restorations. Sampling sites on the other hand, were selected to gather data from different habitat qualities. The sampling site selection combined with creation of a more heterogeneous environment was believed to impact the results, which also could be the case in this project. These factors are important to keep in mind, and that they can influence the result. Factors including disease, broadening of the river channel, habitat quality, time.

4.2 Factors that can affect the result

4.2.1 Disease

Disease prevalence may affect the general population trends in rivers. Salmon and trout populations varies from year to year and between different rivers (Dannewitz et al. 2019). Different diseases can affect condition, spawning, survival in younger fish and survival in older fish. Described in this section is some of the more common diseases on salmon and trout in the northern Swedish river systems and in the Baltic Sea that possibly could have an impact on the results.

One of the more common disease causing agents is fungal infection (Brockmark & Carlstrand 2017), which develops into skin diseases when the immune system is supressed, e.g. during spawning or in high temperatures (Brockmark & Carlstrand 2017). Fungal infection can lead to a decrease in fitness, decreased chances of reaching the spawning grounds and in some cases death. This is a common disease, regularly affecting most populations in most rivers, to various degrees. In years with especially high occurrence of fungal infections, the number of spawners can be significantly affected. Between the years 2014 and 2020 many reports of dying salmonids with skin conditions caused by fungal infections were made (ICES 2024). This is a possible explanation of the decline in salmonids in Lögdeälven over the recent years. Hypothetically, fewer salmon in good condition reach their spawning areas, leading to lowered production hatchlings and therefore less juvenile salmon the upcoming years.

Herpesvirus and iridovirus are other common disease agents that cause wounds or abnormalities on the skin (Brockmark & Carlstrand 2017). It is hard to spot the difference between these virus infections and fungi infections due to the similarity of symptoms and result in fish with the same lowered condition. Hypothesized effects would be the same as for fungal infections. According to Ask (2019), salmon in Lögdeälven were not heavily effected by either fungal infections or other diseases which decrease the likelihood of it having an effect on the result (Asker 2019).

Thiamine (vitamin B1) deficiency syndrome (M74) is believed to have an impact on reproducing salmon and trout (ICES 2024) in the Baltic sea. The fish cannot produce thiamine by themselves, but rely on getting it through their food (Brockmark & Carlstrand 2017). The amount of M74 afflicted fish varies over years and between rivers, in 2017/18 the amount was higher than most previous years. This could be a contributing factor to why the positive trend that is seen in Figure 4 drops around 2018, i.e. an effect of M74 on juvenile production.

If the brown trout and salmon populations were affected by disease or fungi, their juvenile density in the river would possibly decrease naturally. Given that the results show a negative trend but no significant decrease, it is possible that the restoration could have had a positive effect on density and counteracted the effect of disease and fungi to some degree. However, this reasoning remains speculative.

4.2.2 Broadening the river channel

Environmental factors related to the restoration measure must be taken in consideration. The river channel is locally re-shaped by the restoration measures, both in the route it flows and in depth and width. When adding substrate and broadening the river channel, more area will be wetted, and this may affect the electrofishing result. When electrofishing, a specific survey area is fished, but the results are often extrapolated to produce an estimated density of a larger river area. However, this method may not always give the correct results reflecting the whole river. Given that the river channel has been broadened in some places, and the newly restored habitat patches are of high quality, then the fish have more high-quality areas to live in. Before larger numbers of fish have "filled-up" the available habitat, the results from electrofishing may indicate lowered densities compared to before restoration measures were implemented. In other words, the same number of fish on a larger area will lead to lower estimates of densities, but this does not necessarily mean less fish in the river. This could be a contributing factor and possibly lead to electrofishing results indicating a more negative result than what the real situation is.

Another problematic scenario related to electrofishing is presented in Figure 8. Here, the electrofishing site is located in an already good habitat with a high density of fish before restoration (to the left). After restoration the electrofishing site is once again located inside the good habitat with the same density of fish (given that little or no restoration was needed in the already good habitat), but the good habitat area has now been increased, in effect covering the whole river channel (to the right). The density estimate resulting from electrofishing will hypothetically, be the same both before and after restoration even though the after-restoration illustration has a higher number of fish in the river channel.

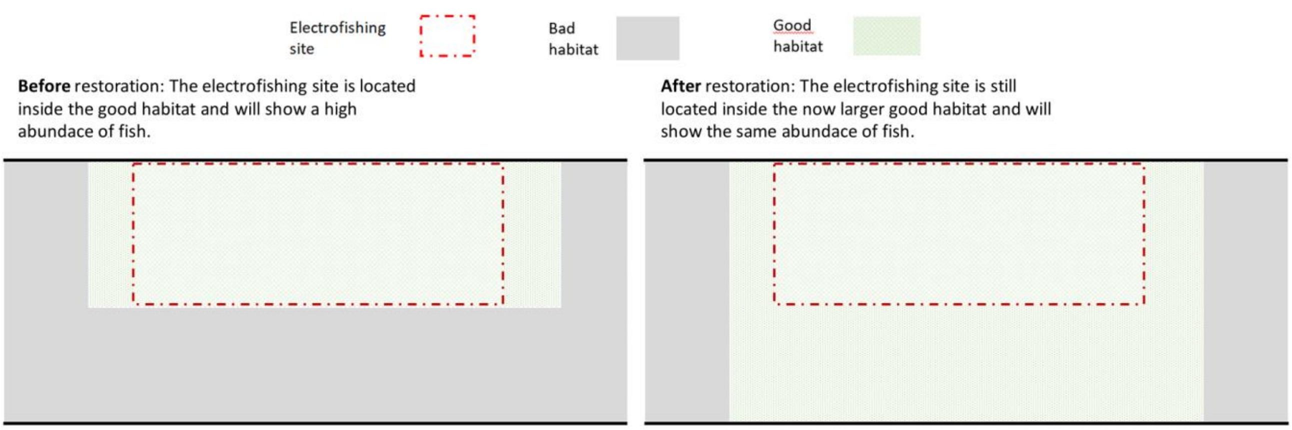

Figure 8: Example showing a possible complication with electrofishing as a method to analyse before and after restoration.

With respect to present study of Lögdeälven, many of the electrofishing sites were chosen because of the high abundance of salmon and trout yearlings (i.e. relatively high quality habitats) to follow up on the effects of limning, or to follow the general trend in salmon abundance. Since these sites presumably were of high (or at least decent) quality already before restoration, they might not be representative of the pre-restoration state of the river as a whole.

The presented possible problems related to electrofishing methodology might be an indication that the way restoration evaluation results are obtained and analysed, may have to be revised to better assess changes in fish abundance in water bodies that have been morphologically changed.

4.2.3 Time

Post-restoration recovery time is an important factor in monitoring restoration projects. This study looks at the short-term effects (3-8 years) of restoration and it might not reflect the final effect of the project. A study from Finland monitoring the long-term effects of restoration on trout, concluded that monitoring should at least cover 10 years after restoration (Louhi et al. 2016). Monitoring over a shorter period is at risk of being obscured by other factors and natural fluctuations. The Finnish results initially showed a decrease in trout, but over time the effects switched direction to a positive result (Louhi et al. 2016). The monitoring of trout in this study started in 1999; in 2002 a drought period occurred which was believed to have a negative impact on the trout populations, leading to the initial decrease. An analysis on a longer monitoring period of restoration effects in Lögdeälven might show different results compared to the results in this study.

4.2.4 Other

There are more factors that potentially could have an impact on the result. For example, changes in resource competition between different species could affect densities of the different species (i.e. as one species is favoured, another may decrease due to increased competition pressure). Another possible factor is alterations in methodology over time, for instance change of electrofishing equipment, might be related to different fish capture efficiency. A third factor is systematic changes in climate factors affecting either the fish community or the electrofishing surveys, such as temperature, drought or unusually high water levels.

4.3 Conclusion

Due to lack of significant results, no strict conclusion can be drawn on whether or not restoration had an impact on salmon and trout densities in Lögdeälven. My prediction was that juvenile densities and total densities would increase in the after-restoration time-period, compared to the before-restoration time-period. This however, has not been supported in my work. A negative or no trend is observed in salmon and brown trout densities, which indicates a possible decrease in abundance during the short time-period after restoration. Many factors could possibly have affected the results outside of restoration measures, for instance disease, habitat quality and electrofishing site selection. Natural- or random fluctuation may have major effects on analyses evaluating short time-periods such as this. An analysis investigating the long-term effects is needed to be able to draw a conclusion about the final effects of restoration. It is also possible that an evaluation of monitoring methodology is needed, to be able to assess whether the collected data is suitable for this type of analysis evaluating changes before and after restoration.

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