Diet of Arctic char and brown trout in Northern Sweden -

Potential effects of burbot and lake area

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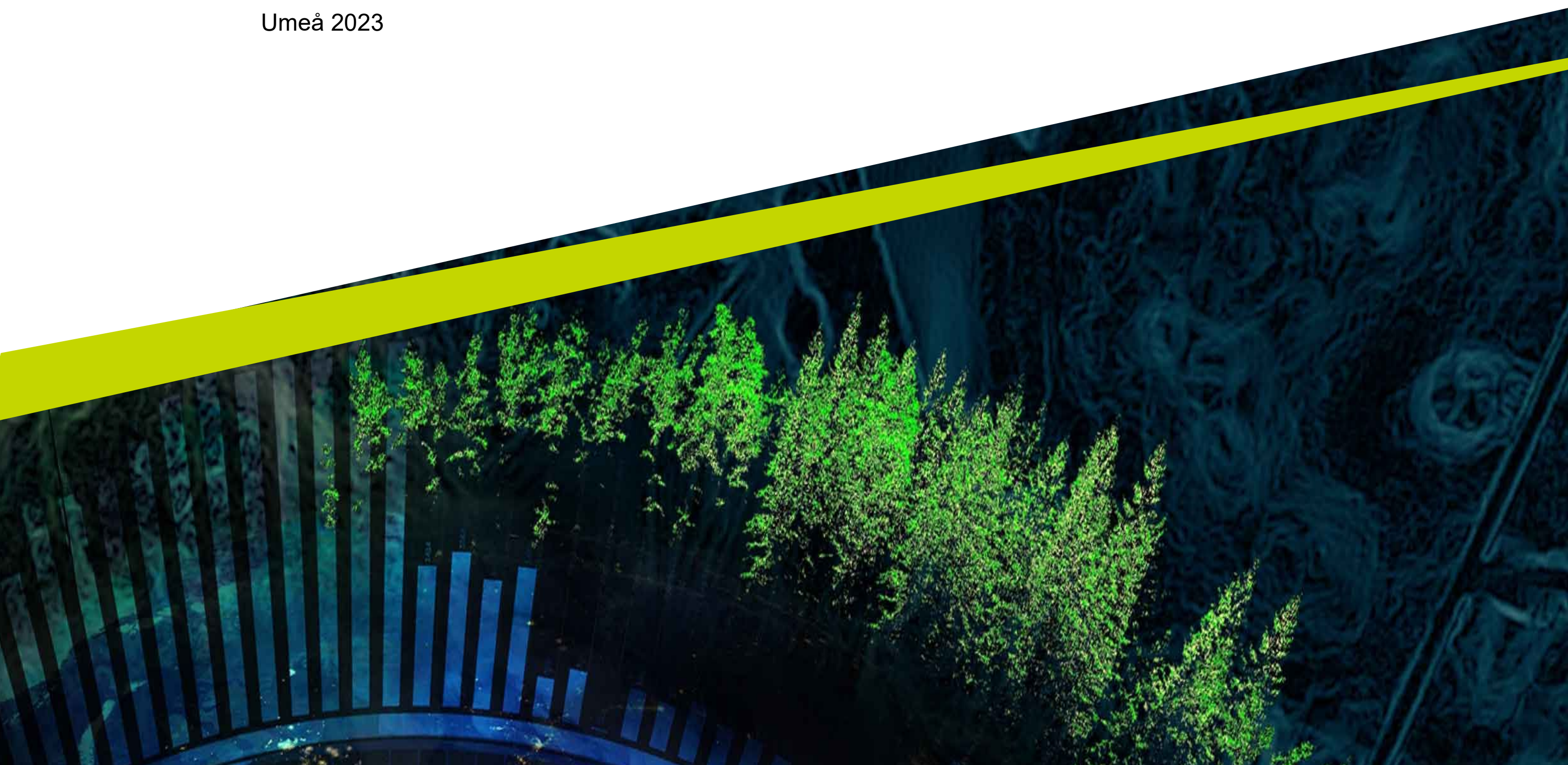

Diet of Arctic char and brown trout in northern Sweden *– Potential effects from burbot and lake area*
Fjällrödingens och brunöringens dieter i norra Sverige *– Potentiella effekter av lake och sjöstorlek*

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Abstract

To manage and conserve different fish species, it is important to know what factors affect the presence and performance of the species. Relatively few studies have focused on burbot and how they interact with other species. In this study I investigate how burbot may be affecting two common salmonids in the arctic and subarctic regions, Arctic char and brown trout. I do this by looking at how the salmonids diets change with- and without burbot presence, and if burbot seem to predate on small salmonids. Additionally, I will also investigate the impact of lake area, since it is an additional factor that can affect fish diets.

Eight lakes located in the subarctic region containing Arctic char and brown trout were sampled. Previous studies have found that Arctic char is sensitive to brown trout and burbot competition. The result in this study aligns with that since the Arctic char diet seemed to change more than the brown trout diet when interacting with burbot. Arctic char fed more in the littoral zone when burbot were present, as their diet consisted to a higher extent of large bottom-living invertebrates. But they also fed more on terrestrial insects, which can be found on the lake's surface. This could indicate that Arctic char get more opportunistic in their search for food. Arctic char unexpectedly seems to eat less pelagic zooplankton when burbot is present, but this could be due to them being more opportunistic. Brown trout diet did not seem to be affected by the presence of burbot.

Lake area was important for both Arctic char and brown trout diets. Arctic char seemed to eat more *Mysis* in bigger lakes, but *Mysis* was not found in all lakes which could be causing this difference. Brown trout seemed to eat more terrestrial insects in bigger lakes and more molluscs in smaller lakes. Burbot predation effects on salmonids seemed to be minor since no fish were found in the stomach content of the burbot in this study. However, only 9 larger individuals (>25cm) were examined, so no strong conclusions can be drawn.

This study indicates that both lake area and the relationship between burbot and Arctic char could influence fish communities in arctic/subarctic lakes and this needs to be investigated in greater detail to be able to manage and conserve fish communities in the future.

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Abbreviations

PSM	Predation sensitive macroinvertebrates.
PPT	Percentage points.
$n_{Arctic\ char}$	The amount of Arctic char caught.
$n_{Brown\ trout}$	The amount of brown trout caught.
n_{Burbot}	The amount of burbot caught.

1. Introduction

In fish management, it is crucial to know what factors affect certain species' growth and presence. In many arctic and subarctic lakes, Arctic char *(Salvelinus alpinus),* brown trout *(Salmo trutta)* and burbot *(Lota lota)* are the only species present. Hence, the interaction between these species is crucial for understanding the dynamics in arctic and subarctic lakes. There are few studies on burbot and there are knowledge gaps on the interaction of burbot with other species.

Arctic char is sensitive to interactions with other species and changing species interactions can be one of the biggest threats to Arctic char populations all over the world (Maitland 1995; Langeland et al 1991; Jansen et al 2002). Arctic char is restricted to cold waters and is the freshwater fish that is found the furthest north (Klemetsen et al. 2003). Because of this, Arctic char often live without competitors in high alpine lakes. However, in subarctic regions Arctic char often coexists with brown trout (Hesthagen et al. 1997). Burbot and Arctic char prefer cold water (≈11 degrees) and brown trout has a wider comfort temperature (7-19 degrees) (Degerman & Andersson 2019; Curry-Lindahl 1985; Wiklund & Ottosson 2020; From et al 1995; Brännäs & Wiklund 1992). Small Arctic char feed mostly on plankton and bottom-dwelling animals, and as they grow, they may become predatory and feed on small fish (Curry-Lindahl 1985; Wiklund & Ottosson 2020). Brown trout is a very adaptable species, and its diet can vary a lot depending on where they are located. For brown trout that live in smaller lakes/streams, the diet often consists of different invertebrates in the littoral zone and/or surface insects. As size increases, brown trout diet gets more piscivorous (Jansen et al 2002; Curry-Lindahl 1985; Wiklund & Ottosson 2020). The main diet of burbot consists of diurnal larvae, crustaceans, molluscs and shellfish, but fish and fish eggs are often included in the diet as well. As for other fish species, the larger the burbot, the larger the contribution of fish to the diet (Curry-Lindahl 1985; Wiklund & Ottosson 2020).

Arctic char and brown trout often seem to overlap in diet (Cavalli et al. 1998). Brown trout are often aggressive and when competing for the same resources, brown trout often push Arctic char towards feeding more in the pelagic zone (Cavalli et al. 1998). This could be causing Arctic char to mainly eat zooplankton since they are better at catching smaller prey and therefore utilize a greater part of the lake when there is competition in the littoral zone (Langeland et al. 1991; Jansen et al 2002; Eloranta et al. 2013).

Burbot is known to be a possible competitor for space and food with other small benthic living fish species, like the stone loach (Barbatula barbatula) (Fischer et al 2000). However, interactions between Arctic char and burbot are not well studied. Interaction effects are often hard to study and can depend on many factors such as lake morphology, season, and species composition (Langeland et al. 1991; Sandlund et al. 2010). Lake morphology can affect the amount of available habitat and the area of the profundal zone (Kristoffersen et al. 1994), which could affect the diet of different fish species. A Norwegian study shows that high burbot densities push Arctic char away from the benthic zone and into the pelagic zone (Knudsen et al. 2010). In the absence of high densities of burbot, Arctic char mainly forages in the benthic zone. In other words, there were clear shifts in Arctic char foraging and food selection when burbot was present in high densities. There also was a high predation pressure from the burbot on smaller Arctic char that lived close to the bottom (Knudsen et al. 2010). In addition, they also suggest that the fact that Arctic char ate zooplankton to a greater extent when burbot was present could lead to an increased risk of parasite-related infections. Over time, this could negatively affect the Arctic char stock (Knudsen et al. 2010). Another study concluded that one of the biggest effects that burbot had on Arctic char was that the younglings avoided water spaces where there was an odour from burbot. The interaction between brown trout and burbot has not been investigated before (Laakkonen 2007).

However, some studies suggest that brown trout is a bad competitor compared to other salmonid species (Fausch & White 1986; Hayes 1987). A study carried out in Northern America concluded that in competition with brook trout and coho salmon, the brown trout was less likely to outcompete these species for energetically profitable parts of the stream (Fausch & White 1986). Another study from Northern America studied the competition effect for spawning grounds between rainbow trout and brown trout (Hayes 1987). They found that introducing rainbow trout could be causing brown trout to get a 94% reduction in spawning success (Hayes 1987). But other studies suggest that brown trout is a stronger competitor than other salmonids (Stradmeyer et al. 2008). A study from Scotland on brown trout and Atlantic salmon juveniles states that brown trout juveniles were dominant when competing for pool refuges during periods of dewatering (Stradmeyer et al. 2008).

To be able to manage fish populations in arctic and subarctic lakes, it is of vital importance to know in greater detail how a common competitor like burbot is affecting other species.

1.1 Aim and hypotheses

The goal of the study is to investigate whether Arctic char and brown trout diets differ between lakes with- and without burbot present. I investigated this by studying the stomach content from Arctic char and brown trout caught in eight lakes in northern Sweden, which all contain Arctic char and brown trout, but only half of them contain burbot. I also studied the potential effect of lake size by using lakes ranging from 246 hectares to 10661 hectares. Additionally, I investigated if the burbot diet and if their stomach content contains smaller individuals of brown trout or Arctic char.

My hypotheses are:

- Arctic char will to a greater extent include pelagic and/or surface living invertebrates in their diet when burbot is present.
- The diet of brown trout will change less than the diet of Arctic char when burbot is present since they are a stronger competitor than Arctic char for the benthic zone.
- Arctic char will to a greater extent include pelagic living invertebrates in their diet in larger lakes since they will be more available, and Arctic char can utilize large parts of the water mass.
- The diet of burbot will include salmonid juveniles.

2. Material and Method

2.1 Lake description

A total of eight lakes were analysed in this study (Table 1). All lakes are in the county of Jämtland and Västerbotten in northern Sweden. *Mysis* presence is noted since *Mysis* is not native to subarctic and Arctic lakes in Sweden and is only introduced in some lakes as a supplementary food source (Lasenby et al. 1986).

Table 1: Morphometric and sampling information about the lakes. X indicates lakes that have Mysis present (Vatteninformation i Sverige 2021).

Lakes	**Fish species**	***Mysis* presence**	**Mesh size gillnets (mm)**	**Surface area (Hectares)**	**Depth (M)**	**Sample year**	**Amount of fish caught**
Nedre-Häbbersvattnet	Arctic char, Brown trout,Minnow		12,15,18,21,23,30,33, 45,55,66	246	30	2021	48 Arctic char, 30 brown trout
Öster-Noren	Burbot, Arctic char, Brown trout, Minnow		12,15,18,21,23,30,33,45,55,66	472	19	2022	9 Arctic char, 20 brown trout, 4 burbot
Ankarvattnet	Arctic char, Brown trout,Minnow	X	12,15,18,21,23,30,33, 45,55,66	934	75	2022	22 Arctic char, 17 brown trout
Åkersjön	Arctic char, Brown trout,Minnow		12,15,18,21,33,38,45,55,66,	1200	70	2022	19 Arctic char, 15 brown trout
Rengen	Burbot, Arctic char, Brown trout, Minnow		12,15,18,21,23,30,33, 45,55,66	2160	70	2020 & 2022	43 Arctic char, 5 brown trout, 4 burbot

Kultsjön	Burbot, Arctic char, Brown trout	X	12,15, 18, 21, 23, 30, 33, 45, 55, 66	5340	100	2022	22 Arctic char, 3 brown trout, 4 burbot
Torrön	Burbot, Arctic char, Brown trout, Minnow	X	12,15,18,21,23,30,33, 45,55,66	10300	100	2022	17 Arctic char, 10 brown trout, 4 burbot
Stora Blåsjön	Arctic char, Brown trout,Minnow	X	12,15,18, 21,30,33,45,55,66	10661	144	2022	9 Arctic char, 16 brown trout

2.2 Gillnet sampling

Gillnetting was performed to collect fish from the eight lakes. Using gillnets is known to be a well-functioning method to be able to estimate fish populations (Appelberg 1995). All gillnets were set during the summers of 2020, 2021, and/or 2022). Gillnets are size-selective, and the selectivity depends on the mesh sizes used. The nets used in this study varied in mesh size (12, 15, 18, 21, 23, 30, 33, 45, 55, 66 (mm)). In addition, multi-mesh gillnets were used to capture fish of different sizes to get a wide range of fish to analyse. The multi-mesh gillnets (NORDIC gillnets) are 30m long and 1,5m deep. NORDIC gillnets have 12 different panels with different mesh sizes (5, 6.25, 8, 10, 12.5, 15.5, 19.5, 24, 29, 35, 43, and 55 mm). Each panel is 2.5m long. The nets were distributed over the known depths of the lake.

2.3 Other sampling

As burbot rarely get caught in gillnets, Cages were used to catch burbot. A minor part of the data also comes from local people who caught and sent in fish to be analysed. This only covers a smaller amount of burbot in this report (5 individuals).

2.4 Laboratory work

In the lab there were initially several measurements taken from each fish:

- Length was measured in millimeters from the nose to the tip of the tail fin with the fin placed in a neutral position.
- Overall stomach content grouping was determined (weight of invertebrates, fish, and inedible items)

The stomach content was further examined for a subset of the fish in closer detail. From each of the eight lakes, between 30 and 89 individuals were selected - depending on the number of available fish from lake Nedre-Häbbers ($n_{Arctic\ char}$ = 48, $n_{Brown\ trout}$ = 30, n_{Burbot} = 0), Öster-Noren ($n_{Arctic\ char}$ = 9, $n_{Brown\ trout}$ = 20, n_{Burbot} = 4), Ankarvattnet ($n_{Arctic\ char}$ = 22, $n_{Brown\ trout}$ = 17, n_{Burbot} = 0), Åkersjön ($n_{Arctic\ char}$ = 19, $n_{Brown\ trout}$ = 15, n_{Burbot} = 0), Rengen ($n_{Arctic\ char}$ = 43, $n_{Brown\ trout}$ = 5, n_{Burbot} = 4), Kultsjön ($n_{Arctic\ char}$ = 22, $n_{Brown\ trout}$ = 3, n_{Burbot} = 4), Torrön ($n_{Arctic\ char}$ = 17, $n_{Brown\ trout}$ = 10, n_{Burbot} = 4), Stora Blåsjön ($n_{Arctic\ char}$ = 9, $n_{Brown\ trout}$ = 16, n_{Burbot} = 0) (Figure 1). The criteria to be selected was that the fish must be ranging over all sizes (<10cm - 30>cm). From lakes that had 40 or fewer individuals, all individuals were examined. Since there were so few burbots, all burbots were examined. This resulted in a total of 321 individuals (189 Arctic char, 116 brown trout, and 16 burbots), out of which 269 stomachs (170 Arctic char, 91 brown trout, and 8 burbots) contained prey items (the rest were empty). These stomachs were investigated and most of them contained invertebrates.

The water-living invertebrates were either identified to species level or a higher taxonomic order (Table 2), depending on how rare they were and how difficult it was to distinguish the different taxonomic orders. All terrestrial insects were pooled into one group. For each sample, the number of invertebrates was counted, and the lengths of the invertebrates were measured. For many samples, there were a lot of individuals from the same taxa and for these samples, 10 random individuals were selected and the mean length of these was used for the rest of the individuals in that sample. The biomass (dry) of the invertebrates was calculated from already available equations for length-weight relationships for each taxon (Benke et al 1999; Sage 1982; Johnston & Cunjak 1999). The invertebrates were categorized into 10 different groups: *Bythotrephes, Diptera, Eurycercus,* Pelagic zooplankton, *Gammarus,* Predation - sensitive macroinvertebrates (PSM), Terrestrial, Mollusks, Others, and *Mysis*. These groups were based on where in the lake they were present and how common they were. (Table 2)

Table 2: Overview of the groupings of insects and wherein the water mass they are present.

Groups:	**Invertebrate taxa**	**Benthic zone**	**Surface area**	**Pelagic zone**
Bythotrephes	*Bythotrephes*			x
Diptera	*Chironomidae*, Ceratopogonidae	X		
Eurycercus	*Eurycercus*	X		
Pelagic zooplankton	Bosmina, Daphnia, Copepoda			x
Gammarus	*Gammarus*	X		
Predation-sensitive macroinvertebrates (PSM)	*Ephemeroptera, Plecoptera, Tricoptera, Megaloptera, Coleoptera*	X		
Terrestrial	Terrestrial insects		x	
Molluscs	*Bivalvia, Gastropoda*	X		
Other	Fish eggs, Nematoda, Worm	X		
Mysis	*Mysis*	X		

2.5 Statistical analysis

All statistics were performed by using R (version 4.1.1). All significance levels were set to $p \leq 0.05$. The packages ggplot2, tidyverse, vegan, and other basic statistical functions in R were used (Wickham 2016; Oksanen et al. 2022). To assess the effect of burbot presence and lake area on the diet composition (based on stomach contents) of Arctic char and brown trout a permutational multivariate analysis of variance (permanova, adonis2, vegan package) was used (Oksanen et al. 2022). The null hypothesis that there was no significant difference between the diet composition for the different factors: species identity (Arctic char or brown trout, categorical), burbot presence (categorical), lake area (continuous), and body length (continuous) was tested. Further, the interaction effects between species identity and burbot presence, species identity and lake area as well as species identity and length of the species were tested. Burbot was not used as a category for the species factor due to the low sample size. A post hoc analysis was performed to confirm with more precision where the differences were for the significant factors from the permanova. The permanova was chosen to analyse the diet composition since the data was not normally distributed data, which for example a manova needs. Permanova is also less sensitive to multilinearity in the data, meaning that the input data groups do not have to be correlated, and it can handle many zeros in the data (Legendre, P & Anderson, M. J 1999; Anderson,M. J 2001).

A similarity percentage test (SIMPER, vegan package) was done to determine which prey groups were mostly affecting the significant difference for each factor (Appendix 1). A beta dispersal analysis was done to test if the variance for two or more groups (factors) differs significantly from each other (betadisper, vegan package). The beta dispersal analysis (Table 5) suggests that there is significance for the beta dispersal, meaning that the data is non-homogenous dispersed which is challenging one of the conditions that should be met to use permanova. However, recent studies indicated that permanova is relatively insensitive to heterogeneity in beta dispersal (Anderson, M & Walsh, D 2013).

To visualize the results, non-metric multidimensional scaling (NMDS) plots were made in R.

3. Results

3.1 Arctic char and brown trout diets in relation to burbot presence

The interaction between species and burbot presence significantly (p = 0.001) affected diet composition in the study (Table 3). The post hoc test shows that there were significant differences in diets for all combinations of interactions between the species and burbot presence, except for the difference between brown trout when burbot is present and not present (Table 4). The dispersion of the diet differed significantly (p= 0.001) between brown trout and Arctic char, with brown trout showing a higher variability in the diet compared to Arctic char (Figure 1, Table 5).

In lakes where burbot was absent, Arctic char stomach content consisted mainly of pelagic zooplankton (32.8%), *Eurycercus* (26.5%), and *Bytotrephes* (22.3%) (Figure 2-3). In lakes where burbot was present, the Arctic char stomach content consisted of a variety of invertebrate groups (Figures 2 & 4). The biggest differences being; more terrestrial insects (9.3 percentage points (PPT) increase), more PSM (8.6PPT increase) and less pelagic zooplankton (13.2 PPT decrease) included in the diet (Figure 3-4). The brown trout diet mainly consisted of terrestrial insects (34.9%) and molluscs (21.9%) in lakes without burbot (Figure 6). In lakes where burbot was present, brown trout mainly ate terrestrial insects (38.8%), molluscs (21.6%,) and PSM (11.5%) (Figure 5). The interaction between length and species did not have a significant effect (p = 0.764) on diet composition (Table 3).

The only group that was not present in the stomach content of both species was *Gammarus,* which was missing in all Arctic char stomachs (Figure 3-4). The taxa that were causing the main differences between the species are pelagic zooplankton (more in Arctic char), terrestrial insects (more in brown trout), PSM (more in brown trout), and *Bythotrephes* (more in Arctic char) (SIMPER analyses, Appendix 1).

*Table 3: Table showing the results for the permanova analysis of the diet proportions of Arctic char and brown trout, with the degrees of freedom (df), the sum of squares, the amount of variance that can be explained by the specific group,(R2) and the significance. * is showing an interaction between the two factors.*

Factors	Df	Sumofsqs	R2	F	Pr>F
Species*Burbot presence	1	2.316	0.023	7.601	0.001
Species*Lake area	1	0.863	0.009	2.831	0.031
Species*Length	1	0.134	0.0013	0.440	0.764

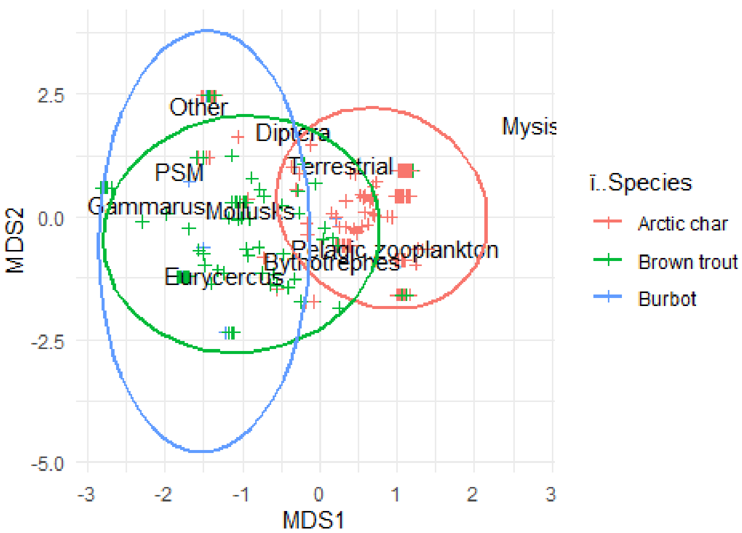

Figure 1:NMDS-plot for the diets of the three different species (Arctic char, brown trout, and burbot)

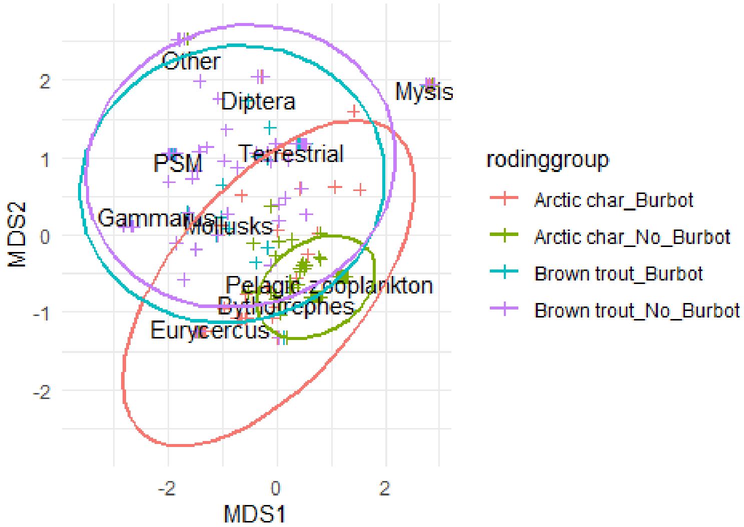

Figure 2:NMDS-plot for the diets in lakes with and without burbot for Arctic char and brown trout.

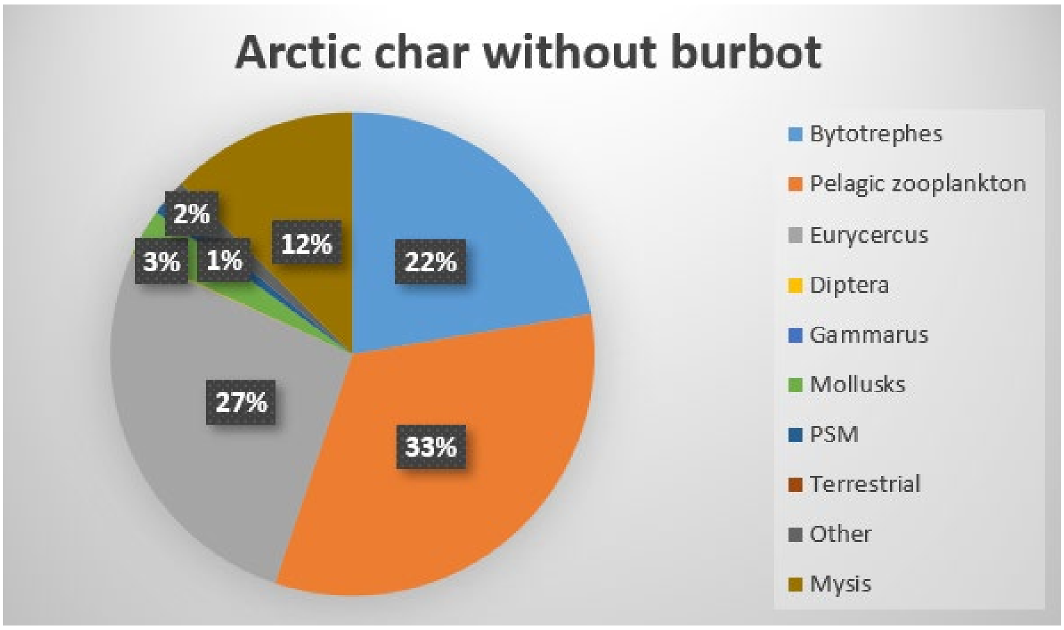

Figure 3: An overview of the diets of Arctic char in the different lakes where no burbot are present.

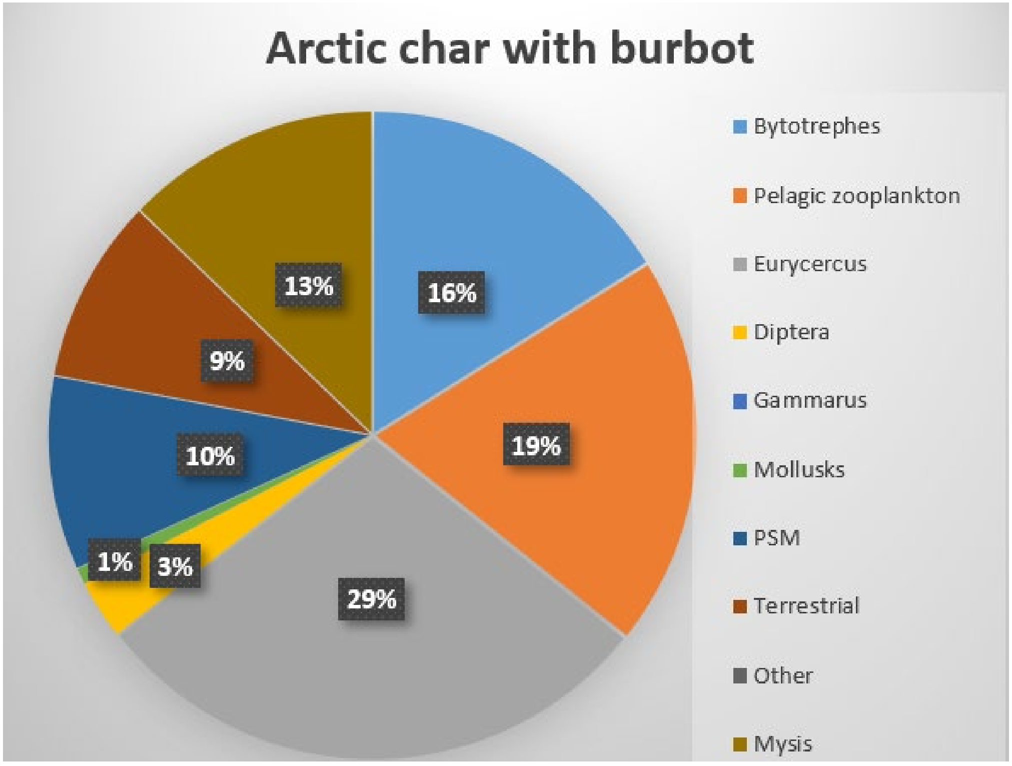

Figure 4: An overview of the diets of Arctic char in the different lakes where burbot are present.

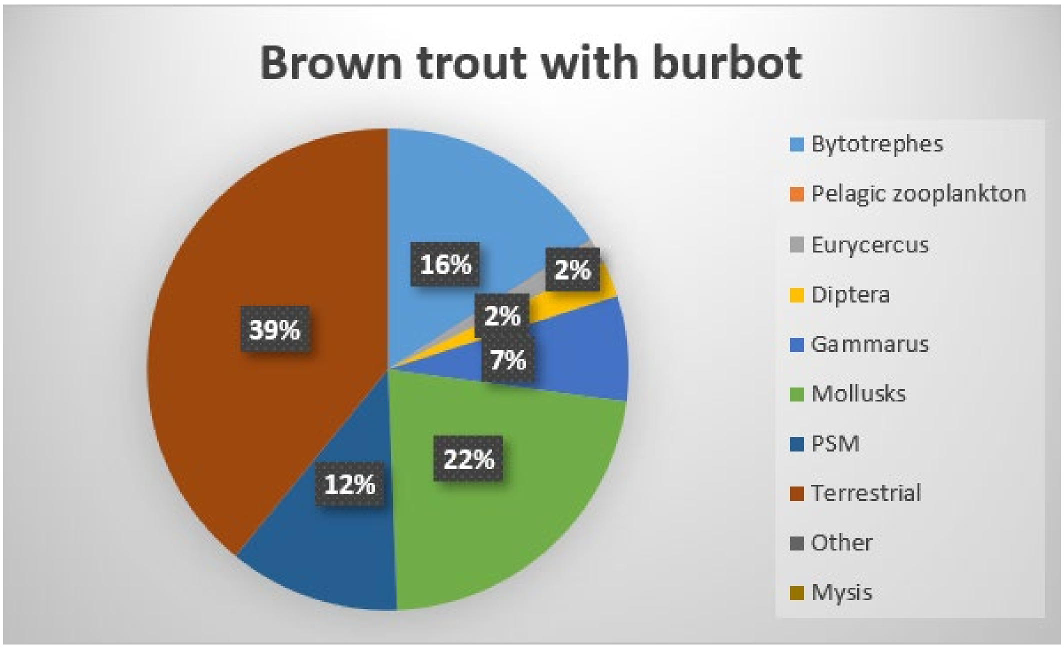

Figure 5: An overview of the diets of brown trout in the different lakes where burbot are present.

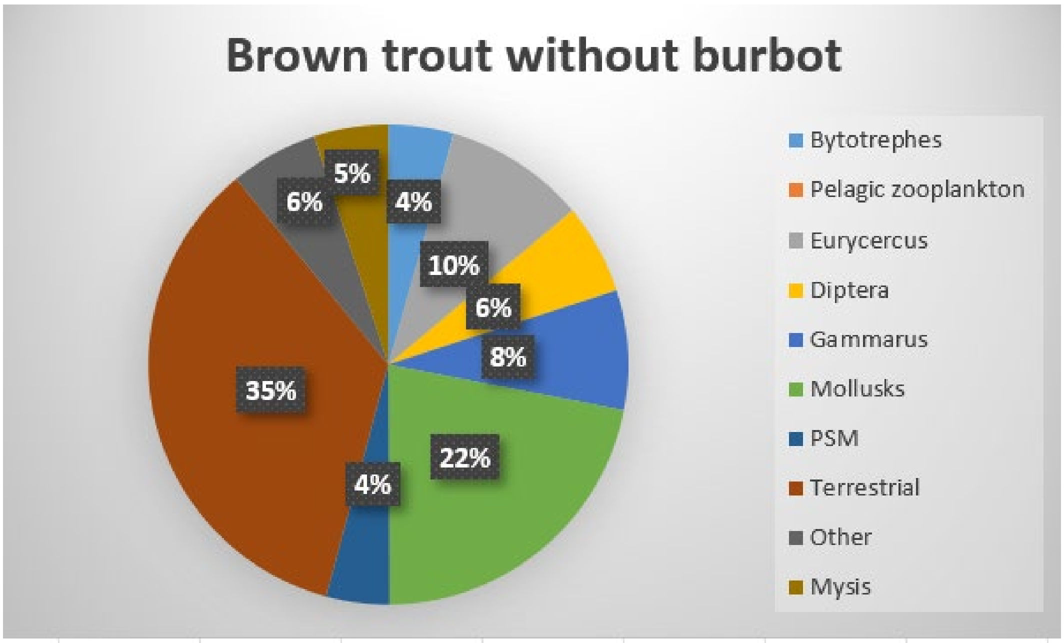

Figure 6: An overview of the diets of brown trout in the different lakes where no burbot are present.

*Table 4:Post-Hoc test for the significant factors interacting with Arctic char (R) and brown trout (O) * is showing an interaction between the two factors.*

Factors	**Df**	**SumofSqr**	**R2**	**F**	**Pr>F**
Species	1	13.408	0.134	39.908	0.001
Burbot presence	1	3.310	0.330	8.829	0.001
O_Burbot*O_No Burbot	1	0.282	0.0078	0.708	0.638
O_Burbot*R Burbot	1	3.454	0.0846	9.153	0.001
O_Burbot*R_No Burbot	1	7.411	0.214	32.614	0.001
O_No Burbot*R_Burbot	1	5.311	0.0913	13.759	0.001
O_No Burbot*R_No Burbot	1	13.511	0.240	49.893	0.001
R_No Burbot*R_Burbot	1	6.586	0.130	24.853	0.001

Table 5: Beta dispersal for burbot presence and species differences showing if the data is non-homogenous dispersed.

Factors	**Df**	**Sumofsqr**	**MeanSq**	**F**	**Pr>F**
Species	1	1.043	1.043	15.512	0.0001

Burbot presence	1	0.424	0.424	7.021	0.0086

3.2 Arctic char and brown trout diets in relation to the lake area

The interaction effect between fish species and the lake area was significant (p = 0.031), meaning that the fish diet between Arctic char and brown trout was dependent on the lake area (Table 3; Appendix 4). Arctic char and brown trout diets seem to overlap the same amount in smaller lakes and large lakes (Appendix 4). The most important factor creating a difference in Artic char diet between larger and smaller lakes was the amount of *Mysis*. The stomach content from larger lakes consisted of a large amount of *Mysis*, while the stomachs from smaller lakes contained no *Mysis* (Figure 7). For the Arctic char in the largest (Stora-Blåsjön) and third-largest lake (Kultsjön) *Mysis* constituted ~50% of the stomach content. The Arctic char in the second (Öster-Noren) and third smallest lakes (Ankarvattnet) is primarily eating *Eurycercus*. In the smallest lake (Nedre-Häbbersvattnet) and one of the middle-sized lakes (Rengen), the Arctic char was primarily eating pelagic zooplankton. In Åkersjön, Arctic char fed on *Bythotrephes* to a large extent (Figure 7). Brown trout was to a large extent feeding on terrestrial insects in four of the middle-sized lakes (Ankarvattnet, Åkersjön, Rengen & Kultsjön) and the largest lake (Stora-Blåsjön). In the smallest lakes (Nedre-Häbbersvattnet & Öster-Noren) and second-largest lake (Torrön), brown trout diet contained more molluscs (Figure 8). Notable is that the brown trout only ate *Mysis* in one lake, Stora Blåsjön.

The effect of burbot presence on Arctic char and brown trout diets seems to be different between small and large lakes (Appendix 2-3). Arctic char in small lakes seem to eat a more varied diet if burbot is present and brown trout seem to not be as affected (Appendix 3). In large lakes, there seems to be an effect of burbot presence on both Arctic char and brown trout. Arctic char seems to eat a more varied diet when burbot is present, while brown seems to eat a more varied diet when burbot is not present. (Appendix 3).

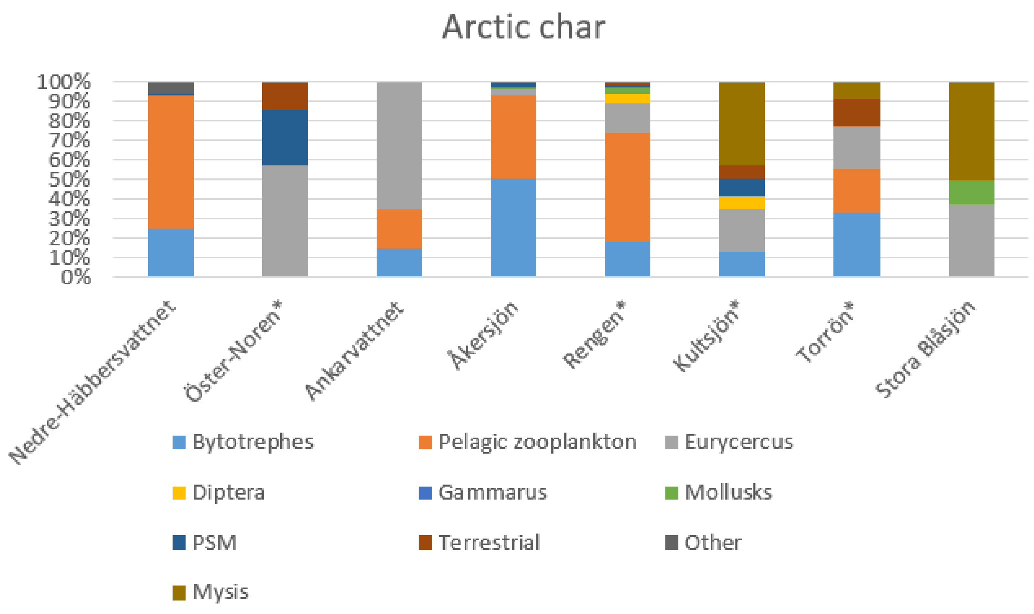

*Figure 7: Stomach content from Arctic char displayed with the smallest lake (Nedre Häbbersvattnet) on the left to the biggest lake (Stora Blåsjön) on the right. Lakes marked with * contain burbot.*

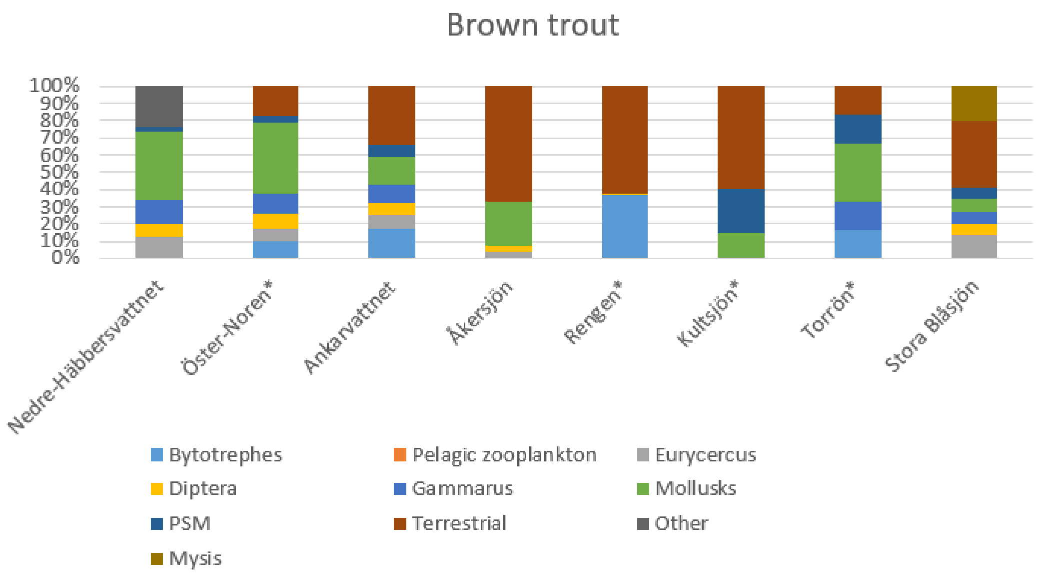

*Figure 8: Stomach content from brown trout displayed with the smallest lake (Nedre Häbbersvattnet) on the left to the biggest lake (Stora Blåsjön) on the right. Lakes marked with * contain burbot.*

3.2 Burbot stomach content and predation

There was no evidence that burbot feeds on small brown trout or Arctic char. No individuals of any species had fish parts in their stomachs. 16 burbot stomachs were investigated, where eight of them contained invertebrates and the other contained inedible items or were empty. The stomachs contained primarily *Mysis* (33.6%) and molluscs (30.2%) but also *Bythotrephes* (10.4%) and pelagic zooplankton (8.1%) (Figure 9). Burbot diet also overlapped more with brown trout than Arctic char (Figure 1). The stomachs came from the lakes Öster-Noren (4), Rengen (4), Torrön (4), and Kultsjön (4).

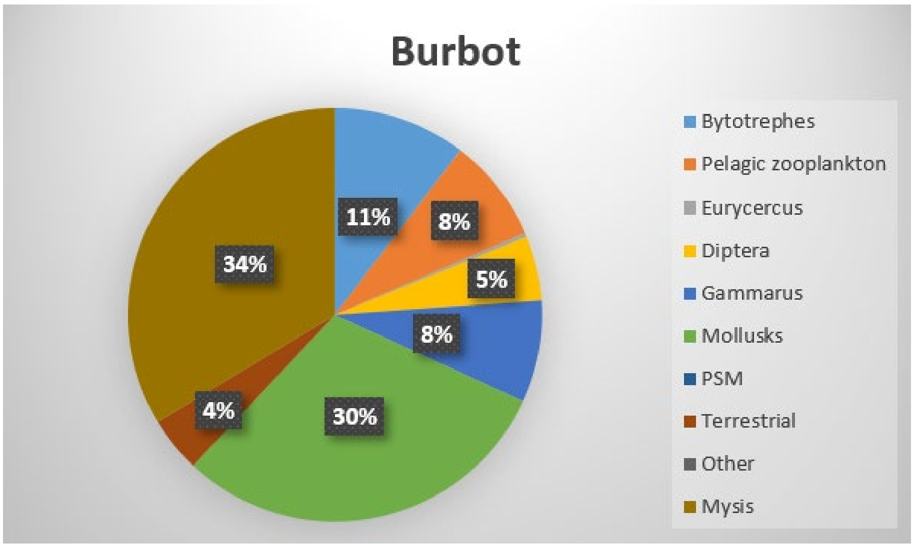

Figure 9: Stomach content from the burbot caught in the examined lakes.

4. Discussion

4.1 Diet in lakes with and without burbot

In lakes with burbot, Arctic char diet consisted of more predatory sensitive macroinvertebrates (PSM) and less pelagic zooplankton, compared to lakes where burbot was absent. Burbot could hence be causing Arctic char to feed more on PSM and less on pelagic zooplankton. This does not align with my hypothesis that the Arctic char would primarily feed on pelagic zooplankton and invertebrates found in the surface area with burbot present. Nor does it agree with previous studies that found Arctic char to be foraging more in the pelagic zone when burbot is present. (Knudsen et al. 2010)

A possible explanation for this could be that we have brown trout in all lakes, which according to other studies (Langeland et al. 1991; Jansen et al 2002) can make the Arctic char move their foraging to the pelagic regions. It could lessen the effect of burbot if Arctic char already is utilizing the pelagic to a larger degree. However, in three of the lakes (Öster-Noren, Kultsjön, and Stora Blåsjön) Arctic char was hardly feeding on pelagic zooplankton at all (although Bythotrephes was included in the diet). However, the previous study on burbot effect on Arctic char also had brown trout in all lakes so if this was affecting the effect burbot have on Arctic char, we should see the same pattern there (Knudsen et al. 2010)

Another possible explanation could be that there is not enough zooplankton in the lakes with burbot for Arctic char to feed on, which could be causing them to be more opportunistic in their food search. However, burbot is usually not considered to feed on zooplankton, so it is unlikely that it would be competition causing this pattern. But burbot in this study had eaten some *Bythotrephes*, which is a predatory zooplankton (analysed separately in this study). Another factor that could affect the habitat use of Arctic char is the predation risk in the pelagic. Small Arctic char and brown trout are known to take shelter in the profundal zone among rocks and other forms of structure (Klemetsen et al. 2003).

Arctic char seems to eat more terrestrial insects in the lakes where burbot are present, which could be an indication that they are focusing their foraging on non-littoral zones due to the interspecific competition from burbot. This is following my hypothesis. But, at the same time Arctic char are eating more of PSM, which is benthic living invertebrates, so it is hard to conclude something here. This could also be connected to what was discussed earlier, that Arctic char gets more opportunistic in their search for food and is therefore searching for food in all zones. A possible reason for could possibly be that burbot odor (Laakonen et al 2007) is stressing the Arctic char, which could cause an irrational search for feed. Another possible explanation here could be that the preferred diet for Arctic char that live in sympatry with other species is known to vary between lakes due to lake morphology, available habitat, and prey population densities (Skoglund et al 2013; Langeland et al 1991; Sandlund et al 2010).

Brown trout mainly consumed terrestrial insects, molluscs, and *Bythotrephes*, both in lakes with and without burbot present, and their diet was more varied than the diet of Arctic char. The fact that brown trout seem to eat more benthic invertebrates could be an indication of the competition between Arctic char and brown trout suggested in previous studies (Langeland et al. 1991; Jansen et al 2002).This could be forcing the Arctic char to feed in other profundal and pelagic zones due to high competition from brown trout in the littoral zone (Langeland et al. 1991; Jansen et al 2002). Brown trout did not seem to be affected by the presence of burbot, which aligns with my hypothesis, and earlier studies that brown trout is a relatively strong competitor for the benthic zone. But there are also studies showing that brown trout can be affected by other species, depending on which species they are competing with (Fausch & White 1986; Hayes 1987).

4.2 Lake area

The main effect of the lake area in this study seemed to be that Arctic char consumed more *Mysis* in large lakes. This relates to my hypothesis that Arctic char would utilize more pelagic living invertebrates in larger lakes. While *Mysis* are not pelagic living invertebrates, they do feed on pelagic zooplankton and are considered to acquire a lot of their energy from the pelagic habitat (Johannson et al 2011). A lack of mysids in some lakes could also be influencing the result**.**

For brown trout, the biggest difference connected to the lake area was that brown trout were feeding more on terrestrial insects in the larger lakes, and more on molluscs in smaller lakes. The fact that brown trout were feeding on more terrestrial insects in larger lakes could be an indication that brown trout live more in the pelagic/surface zone in larger lakes. A possible reason for this could be that there is less food available for the brown trout in the benthic zone in larger lakes, due to a lack of sunlight which decreases the production of benthic algae, bottom-dwelling insects, and crustaceans. Brown trout are known to prefer the littoral zone and invertebrates that live in the littoral zone, such as PSM, molluscs, and *Diptera*. (Jansen et al 2002; Curry-Lindahl 1985; Wiklund & Ottosson 2020). In larger lakes, the littoral zone constitutes a smaller part of the lake which could make the competition for the littoral zone higher, in turn causing brown trout to expand their search for food to the surface area.

I did not perform post hoc tests to disentangle the interaction effect between the lake area and the presence of burbot but based on figures (Figure 7-8; Appendix 4) it seems like the lake area caused the Arctic char to eat a more varied diet if burbot is present. This effect seems to be biggest in small lakes. On the other hand, brown trout seemed to be eating a bit more terrestrial insects in lakes where burbot was present, and in larger lakes especially. The width of the brown trout´s diet seems to change only in large lakes, where the diet was more varied when burbot was not present. A possible reason for this could be the interspecific competition from burbot, which is causing the brown trout to mainly feed in the surface zone for terrestrial insects and not eat in other zones to such a high extent. It is also plausible that there is some biotic factor affecting this, for example, a major hatch of a terrestrial insect that the brown trout prefer over water-living invertebrates.

Arctic char also seems to be eating a more varied diet in large lakes (Appendix 4). This could be because of several reasons but one could be that three of the four largest lakes have burbot, which could be driving this change. It is also possible that it is the interspecific competition that is causing this. Since brown trout seem to eat more terrestrial insects, hence competing for food in the surface zone, and burbot seem to inhabit the benthic zone, this could cause the Arctic char to be more pressured by brown trout and burbot and hence the level of stress might increase. Which, as stated above, could be causing them to be more opportunistic.

It might also be that abiotic factors and lake area alone do not affect Arctic char in any substantial way as argued in earlier studies (Hein et al. 2012). It could rather be that species interactions are important, and the effect of interactions between species could be tightly linked to the area of the lake. In this study, there was a wide range of lake areas, ranging from 246 to 10661 hectares, but the dataset was small, and more lakes needs to be investigated to resolve the complex question concerning how species interactions and lake characteristics interact.

4.3 Burbot stomach content and predation

There were no indications that burbot was feeding on small brown trout or Arctic char since no stomach content from burbot contained any fish parts. Nor did any salmonid stomachs have burbot in them. However, I only had a few samples from burbot (16 individuals) from four lakes compared to the number of samples from Arctic char and brown trout (305 individuals) in this study, which could have influenced the result. All burbot were relatively big (≥17.1cm) and at least individuals over 25 cm (9 individuals) should be able to prey on smaller fish. Another factor that made it more difficult to examine burbot stomach content was that half of the burbot stomachs were empty (8 empty stomachs). This could be because the burbot were caught in the summer and they are known to be less active during the summer months (Wiklund & Ottosson 2020: Curry-Lindahl 1985). This is mainly due to warmer water temperatures and spawning making them more active in the winter (Wiklund & Ottosson 2020: Curry-Lindahl 1985). To further investigate the predation effect of burbot on salmonids the way of collecting the data should be evaluated to better fit the lifestyle of the burbot. Fishing with baited hooks or cages in the winter could be a better approach.

4.4 Limitations

Limitations of the study are that it is based on only eight lakes (4 with- and 4 without burbot) which is a small dataset. This could influence the results since individual lake differences could be interpreted as differences due to other factors (burbot presence or lake area). This also becomes a limitation since we only have three lakes with *Mysis*. *Mysis* seem to affect the Arctic char and burbot in quite a substantial way by being a large part of the diets in lakes where *Mysis* is present, which could make these species more prone to eating in the benthic area in lakes with *Mysis*. All the lakes containing *Mysis* are also large, therefore the lake area effect seen in this study could be an effect of *Mysis* instead. Worth mentioning is that in two of the three lakes with *Mysis* it looks like a substantial part of the diet consists of *Mysis* for Arctic char, but in the third lake (Ankarvattnet) no *Mysis* was found in the stomach content from Arctic char. Nearly no *Mysis* was found in brown trout stomachs. This indicates that the effect of the *Mysis* must be investigated further. However, more research is needed to understand the interaction between species in subarctic lakes and which factors could be affecting fish populations.

In this thesis, there are also few samples of burbot (reasons mentioned earlier in the discussion). This part should probably more be seen as a part to learn from (fishing techniques, possible seasonal variations) for further studies on burbot.

Another limitation of this study is that all the data is collected in summer. This was briefly touched upon in the discussion but could have influenced the outcome of this study. Burbot are known to be more active in the winter and Arctic char are probably as well if compared to many other species (due to the water temperature being high in the summer). Brown trout could be more active in the summer, as they eat mainly invertebrates which are plentiful in the summer, and they also have a wider comfort zone regarding water temperature. The level of activity of the fish could influence what they are eating and the chance of them getting caught in a gillnet, which could influence the results of this study.

6. Conclusions

As previously stated, it is important to keep in mind that the ecology and community composition in lakes could have many different explanations (Hein et al 2012). This is what makes it hard to evaluate the effects of single factors and to know exactly in which way for example interaction effects will affect our northern species.

But the analysis based on the eight lakes that were investigated in this study, points in the direction that burbot may affect the diet of Arctic char populations. It seems as if Arctic char is the biggest loser among the salmonids due to their sensitivity to interspecific competition (Maitland 1995; Langeland et al. 1991; Jansen et al 2002). Brown trout did not seem to be affected by the presence of burbot. However, additional studies are needed to disentangle the importance of lake area and burbot interactions with both Arctic char and brown trout. This study indicates that the lake area might be an important factor for the interspecific competition but a bigger dataset over a longer time is needed to evaluate the effects in more detail. This study also concludes that the interaction effects between burbot and brown trout seem to be minor but more detailed studies regarding the effects of the interaction between these species are needed to fully understand this. Other questions surrounding the effect of burbot on Arctic char also must be investigated further, possibly by looking at lakes with only Arctic char and burbot to exclude the possible effect of other species.

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Popular science summary

To be able to help and protect fish species, we need to know what their favourite food is and where they live. Very few people know how burbot interact with other species. In this paper, I investigate how burbot may be affecting two common species in the arctic and subarctic regions, Arctic char, and brown trout. I do this by looking at how the fish diets change with- and without burbot presence, and if burbot seem to predate on small fish. Additionally, the lake area effect will also be investigated since it is an additional factor that can affect fish diets.

Eight lakes located in the north of Sweden that contains Arctic char and brown trout were sampled. Previous studies have found Arctic char to be sensitive to competition from both brown trout and burbot since Arctic char does not like to be around other species. The result in this paper also shows that the Arctic char diet seemed to change more than the brown trout diet when interacting with burbot. Arctic char seemed to eat more on the bottom of the lake when burbot were present. But they also eat surface living insects. This could indicate that the Arctic char gets more stressed, which makes them disorientated so they might have a hard time deciding what to eat. The Arctic char also seems to eat less pelagic zooplankton, which is a tiny insect that lives in the middle of the water mass and is so small that you can hardly see it with your own eyes, when burbot are present. This was unexpected, but it could be due to them being more stressed and disoriented. Brown trout diet did not seem to be as affected by the burbot.

The size of the lake was important for both Arctic char and brown trout diets. Arctic char seemed to eat more of a big predatory insect that is called *Mysis* in bigger lakes. But *Mysis* is quite unusual and not native to Sweden which means that they do not live in all lakes in this paper. This could be causing affecting the result. Brown trout seemed to eat more surface-living insects in bigger lakes and more bottom-living insects in smaller lakes. Burbot did not eat any fish in this study, but only 9 larger individuals were caught and examined.

There is a lot of further studies needed to be able to see if the Arctic char and the brown trout are affected by burbot, and by other fish species.

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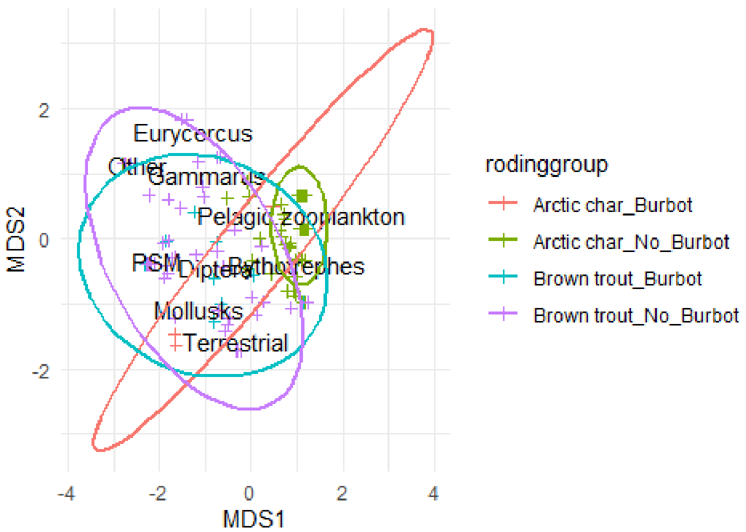
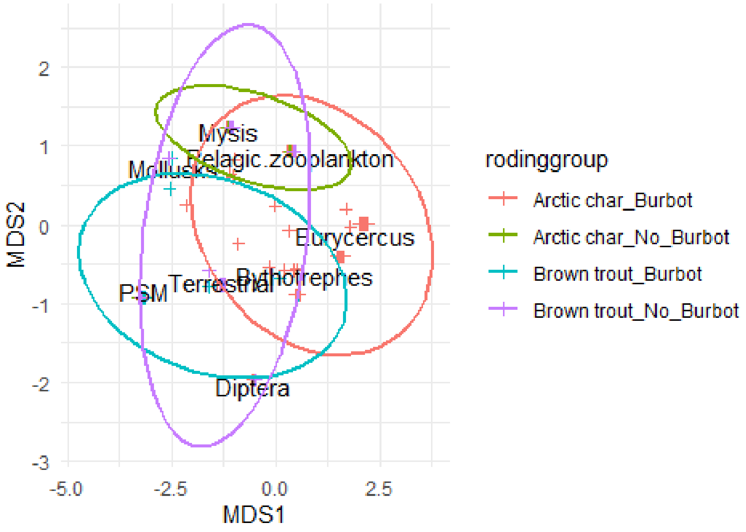
9. Appendix

Appendix 1: Simper analysis for which insect groups influence the significant differences for species and burbot presence in the permanova.

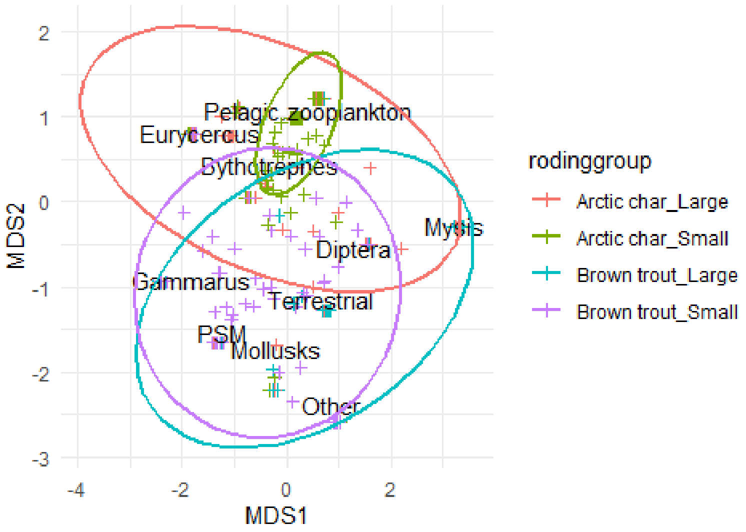
Factors	Pelagic zooplankton	Terrestrial	*Eurycercus*	PSM	*Bythotrephes*
Species	0.230	0.383	0.769	0.527	0.664
Burbot presence	0.241	0.667	0.400	0.774	0.551



Appendix 2: NMDS-plot for the four smallest lakes with diets from Arctic char (R) and brown trout (O) showing the difference in diets with- and without the presence of burbot.



Appendix 3: NMDS-plot for the four largest lakes with diets from Arctic char (R) and brown trout (O) showing the difference in diets with- and without the presence of burbot.



Appendix 4: NMDS-plot for the diets of Arctic char (R) and brown trout (O) in large and small lakes.

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