Magisteruppsats

Master's Program in Applied Environmental Science 60 hp

Lake brownification seems negatively to affect perch (*Perca fluviatitis*) reproductive organs (quota) in southern Sweden.

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Master thesis

Applied Environmental Science

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Abstract

The objective of this thesis is to do a scientific examination on how lake brownification affects the perch fish community of smaller lakes in the vicinity of Lake Bolmen in Southern, Sweden.

Specifically, the question of how brown water lakes affect the perch body size, diet, and its reproduction organs is addressed.

The data collection of brown water lake and body size, (length, weight, height) and gonadic somatic index took place in the two selected lakes, one dark brown and one light coloured water. The data collected was examined by using correlation/Pearson and spearman tests in SPSS.

The results show that climate change, land use and iron (Fe) deposition in lakes and streams which increases brownish colour, can be corrected with changes of perch body size (length, weight, and height), diet, but most important, the reproductive organs, as it is investigated in this research.

Keywords: Brownification, Climate Change, Perch fish, Gonadic somatic index, Fecundity.

Sammanfattning

Syftet med denna magisteruppsats var att göra en vetenskaplig undersökning av hur brunifiering av sjöar påverkar abborrfisksamhället i mindre sjöar i närheten av sjön Bolmen i södra Sverige.

Specifikt behandlas frågan om hur bruna vattensjöar påverkar abborrens kroppsstorlek, kost och dess reproduktionsorgan.

Datainsamlingen av brunvattensjö och kroppsstorlek, (längd, vikt, höjd) och gonadiskt somatiskt index ägde rum i de två utvalda sjöarna, en mörkbrunt och en ljusfärgad sjö. Data som samlades in undersöktes med hjälp av korrelations-/Pearson- och spearman-tester i SPSS.

Resultaten visar att klimatförändringar, markanvändning och avsättning av järn (Fe) i sjöar och vattendrag ökar den brunaktiga färgen vilket orsakade förändringar av fiskens kroppsstorlek (längd, vikt och höjd), kost samt reproduktionsorgan hos abborre, vilka undersöktes i denna studie. **Nyckelord: Brownifiering, Klimatförändringar, Abborre, Gonadal somatiskt index, Fruktsamhet**

Introducion:

Lake brownification can be referred to as the changes in biogeochemical actions that consist of a reasonable amount of dissolved organic carbon (DOC) and have severe deleterious effect on ecosystem freshwater lakes and rivers (Ask et al.,2009, Finstad, Helland, Ugedal, Hesthagen & Hessen,2014; Jeppesen et al.,2012; Vasconcelos et al.,2016). This activity causes browning or brown colouration in many ecosystems' freshwater lakes and streams (Evan et al.,2006). Browning hinders or limits the visual capacity of perch Perca fluviatilis in many lakes and streams, this can lead to reduction in body size and feeding activities and reproduction organs (Kritzberg & Ekström,2012).

Diverse research shows many reasons for lake brownification, such that many lakes and rivers in the northern hemisphere have become brownish during the past three decades. All is due to several activities done by altered land use, climate change, the rising concentration of terrestrial dissolved organic carbon (Köhler et al.,2013; Weyhenmey et al.,2014; Van Dorst et al.,2018).

Brownification of rivers is related to an increase of precipitation and changes of land use that can lead to the increment of dissolved organic carbon coloration (Williamson et al.,2015). In addition, another important driver responsible for strong changes in aquatic ecosystem is alteration made through man's activities in water transparency (Revenga et al.,2014) such as eutrophication and therefore caused by the elevation of loading sediment (Schindler et al.,2008; Wood et al., 1997).

Iron concentration also increased dissolved organic carbon, another important factor responsible for brown water that leaches through the soil to lakes and rivers. The concentration of iron (Fe) matches-up or tally with the water quality in Swedish rivers and lakes (Kreuzberg & Ekström,2012). High iron concentration may cause discomfort and disorder in fish, and flakes in the gills which may be attributed into respiratory disorder and end up causing death (Bury et al 2019). The iron is also accumulated in the livers and muscles and thus causes permanent disorder in the fish liver (Jezierska and Witeska 2016; El-Moselhy et al., 2014). Climate warming is also an important driver that is responsible for increase in temperature, humic content, and brown coloration in the boreal forest rivers. There are also diverse effects or impacts on so many aquatic species such as fish and it is scientifically evidence that brownification can reduce the fertilisation and production of perch species (Kritzberg et al et al.,2017).

There are a number of brown lakes located in the boreal regions that are formed because of the higher amount of organic carbon that is deposited in the regions, and it is transported to water bodies in streams and lakes. This higher number of organic carbons that are stored as peat is considered as one-third of the world's terrestrial lagoon (Bradshaw and Warkentin, 2015). This deposition of organic carbon in lakes and rivers is not a conducive environment for most aquatic species such as perch etc. This further changes the species community and composition structures (Hayden et al.,2017, Ranåker et al.,2014). The initial production reduces at a rise in watercolour which leads to lowering the overall food web production and combined with fish weight or biomass, fatty acids, and algae (Karlsson, et al.2009). Browning often promotes phytoplankton species that have fatty acids, abundance of species composition, bacteria, the influence, and the relationship between the copepods and that of Cladocera. These species further constitute food for perch at an early age.

Previous research carried out on the ecosystem of freshwater gives the important processes in brown water, for example affects fish community and reproduction, and recreational facility (Van Dorst et al.,2018). There are two fundamental reasons which show that brownification can affect the generalised growth of perch and the vast community of perch.

The first fundamental reason is that brown water accelerates bacterial fecundity which can be incorporated in the food web and a shift in humic ecosystems, that is moving from autotrophic system to many heterotrophic food web communities. In both situations bacterial production increased and there is a tendency for an increase in humic dissolved organic carbon, humic lakes-oriented environment (Jansson et al.,2000). This is connected to the smaller sizes of organisms at the bottom of the heterotrophic food web. In this event of the bacterial system, transfer is essential before the energy is transferred to the fish. Regarding the energy transfer, little efficiency of energy can provide energy for those in the higher consumer levels (Jansson et al.,2000). Furthermore, browning induces light limitation and thus has a negative effect on aquatic ecosystems.

Moreover, it reduces photosynthesis, and it further reduces algal fecundity and food provision at trophic scale (Ask et al.,2009). In this vein, it is a fact that browning coloration has a strong impact on the trophic level energy transfer, and this can affect the lake bottom community composition and the bottom-up processes in the trophic level of energy (Van Dorst et al.,2020).

The second fundamental reason is light limitation that browning water has an impact on aquatic ecosystems and negatively effects on foraging consumers such as perch or it diminishes the visibility of perch. This happens at the bottom of brown water, a declining vision of the perch at the bottom of the water makes it unable to detect food, and hunt prey and small perch, ages 1-2years, feed on mayfly larvae, mosquito larvae etc. This condition causes serious impact on foraging with piscivorous fish since they depend on hunting or rummage around (Ranåker et al.,2014). With consistent impact on foraging, behaviour altitudes, selecting their prey, anti-predatory behaviour and reaction and several prey fishes escape or flee (Ranåker et al.,2014, Ranåker et al.,2012).

The perch fishes that dwell in brown water are seriously reliant on food vision, to see and catch food which may not change its food web and at the scene of trophic level (Ranåker et al.,2014) and sediment record indicates browning at moderate level promotes fish production. This is applicable as terrestrially derived organic matter acts on energy and nutritional food elements (Finstad et al.,2004). Moderate browning can also reduce harmful UV radiation from sunlight (Williamson et al.,1994).

The Eurasian perch is the most common fish species in several Swedish lakes and within the aquatic environment (Artdatabanken,2020a) Perch feeds on various organisms in their life history, going through ontogenetic niche shifts. This commences from their feeding stage on zooplankton and proceed to macroinvertebrates and attain to the fish eaten stage, that is within the ages of three and above (Estlander et al.,2012).

There is a competition between perch and Roach (Rutilus rutilus) this is wherein the roach feeds on all water species in the lakes that are within the feeding habitats and similar food substances and thus shift between food web in most lakes (Ardatabanken ,2020b). These two species compete for the same food resources especially during their minor planktivorous stages (Persson ,1990).

This food competition is attributable to niche shifting in several brown lakes that moves from planktivory to benthic prey in the preliminary age which can be attributed to reduced growth rate from an increase within a specific competition or contest (Persson and Greenberg, 1990).

Decreased feeding can also be attributed to the impact of the browning environment of perch, which is due to the rapid and consistent dark water and the limitation to search for prey and the essence of hunting prey (Estlander et al.,2012). It has been scientifically proven that the body size of perch can also be affected negatively in brown water lake, and it is due to the efficiency and elongated food chain that has been happening in several brown aquatic environments (Kankaala et al.,2019). Previous studies have further elaborated that the population growth of perch shifting mechanism to that of a better or good percentage of the offspring in small individual brown water lake environments is better (Rask et al.,2014; Van Dorst et al.,2019).

In sum, perch which is regarded as a visual hunter in brown lakes can out-compete other fishes such as roaches, since they dive deep in the bottom of brown lake (Estlander et al.,2012). This will be the level of hunting that the perch do better than the roach.

The brown water lake coupled with climate change and land use, severely or emphatically affect aquatic ecosystems or habitats. Previous researchers (eg.Rask et al.,2012) stated that brownification of water reduces light limitation to the bottom of lakes and streams and thus has a negative effect on aquatic organisms such as perch fish growth, size, age, length, and weight, in lakes, rivers, and streams. The limitation of light to the underground zone in lakes, rivers caused by browning in pelagic food web can be emphasised by the changes in resources availability and composition in various lakes. In considering the foregoing, I would refer to brownification of water in lakes and streams as an aquatic-terrestrial habitat which is also a global phenomenon.

This study is focused on three listed objectives;

(a) Does brownification and water chemistry (pH, turbidity, temperature, dissolved oxygen, and conductivity/salinity.) changes the size of perch in Southern, Sweden?
(b) Does brownification affect the diets and the reproduction of perch?

The hypothesis of the research was stated in two folds;

(i) If brownification must reduce hunting ability and food availability, I therefore hypothesis that bigger fishes having large gonad mass in light coloured water than brown water.
(ii) I, further expect that there are possible differences because of reduced body size and diet/food web in brown and light-coloured water.

Materials & Methods:

Study area & Sampling site.

This study of perch fish living in brown water and light-coloured lake was conducted in two studied lakes, Rackaregölen (Brown) and Stora Slätten (light coloured) lakes Fig. 1; located closely to Lake Bolmen, which is the tenth biggest lake in Småland, Gotland south, Sweden.

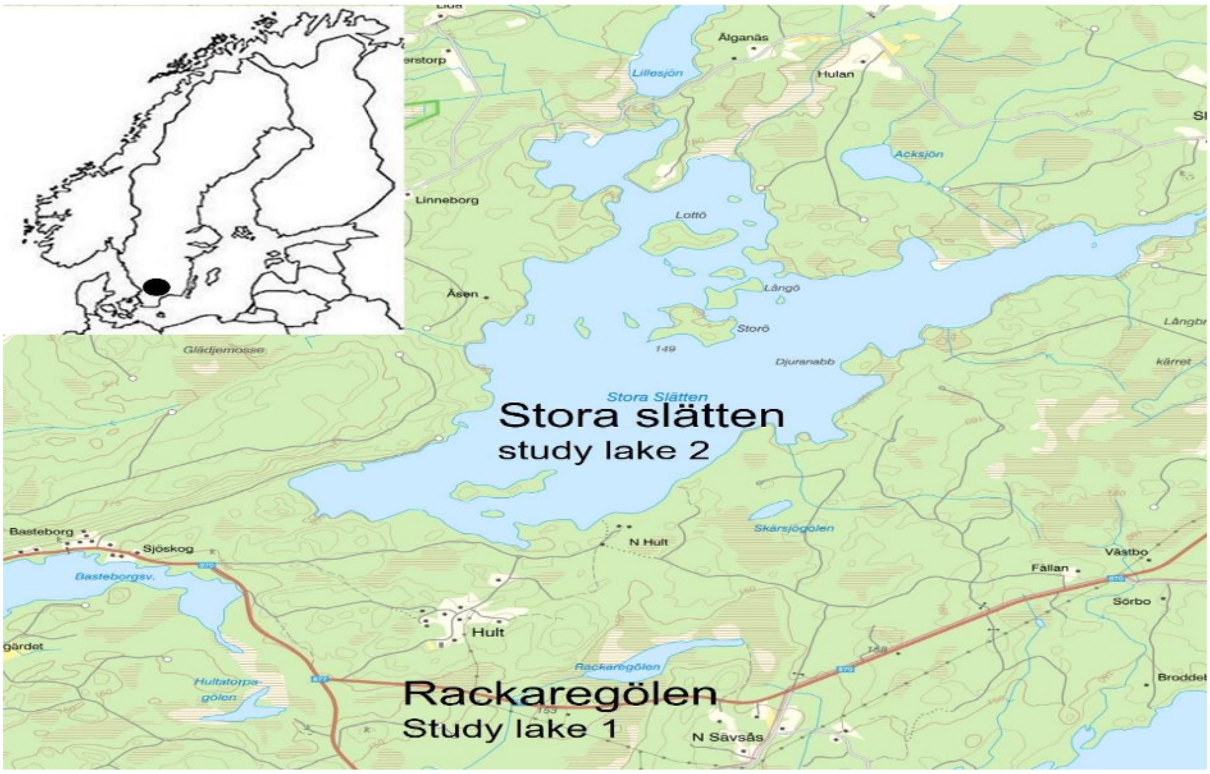


Fig.1: Map showing study area Rackaregölen and Stora Slätten at Bolmen Lake in South, Sweden from Lantmäteriet.

Methods

The landowners, is theTiraholm at Lake Bolmen, gave the necessary permission and authorities for a comprehensive data collection such as, the brown water, light coloured water, and the perch species in both lakes. The authorization was specially meant to catch fishes by using nets. The clarity of the lakes was identified using secchi disk depth instruments that are normally used to describe the transparency of water and the amount of DOC in water. The secchi disk, which is used to measures how deep is the lake or stream, was depth 2.0m and1.5m depth in the Rackaregölen and Stora Slätten lakes respectively and was recorded (Tab 2).

I carried out a field experiment that was first conducted in the small brownish lake, known as Rackaregölen lake (Fig.1). The watercolour was collected, and the fishing boat was used, and I went as far as where I laid the fishing nets and measured, and it was recorded. The perch fish collection was done by placing the longnets in the lake in the evening hours at 16:00 hours and the longnets was collected in the early morning hours at 9:00. A total number of perch fishes 13 (Tab.3), was collected and among these fishes in Lake Rackaregölen eight (8), was females and five (5) males (Tab.3). Each fish was weighed on the laboratory scale at Lake Bolmen, placed in a plastic bag closed on ice cubes and transported to Halmstad university laboratory for further analysis. I did the same procedure in the second lake, Stora Slätten Lake (Fig.1), this lake is larger and lightly coloured and not much of dissolved organic carbon (DOC). The water colour was collected, and the pH was measured/weigh including turbidity, & perch fishes at Lake Bolmen Laboratory. In the second lake the longnets was also put down in Stora Slätten Lake during the evening hours at 16:00 and collected in the morning hours at 9:00. A total number of twelve (12) perch fishes was caught by the longnet and nine (9) males and three (3) females perch fishes were collected and transported for weighing at Lake Bolmen laboratory.

The perch fishes and the water samples were also transported to lake Bolmen Laboratory for initial scientific findings. The preliminary weight of each perch fish was done at Lake Bolmen before fish was transported on ice cubes to Halmstad university Environmental laboratory for more findings pertaining the objectives of the thesis. The following investigations was determined; the age, sex identification of the reproductive organs that is the testis in the male and ovaries in the female, lengths, heights, Gonadic somatic index (GSI) known as the quota in this experiment ,stomach contents, this includes the types/number of food eaten by the perch; such as mosquito's larva, beetle fly larva, mayfly's larva's, crustacean larva etc., that the skeletons were found in the intestinal layers of the perch caught.

The gill cover or operculum was used in determining the age of the fish. The operculum was removed from each perch and heated over a Bunsen burner in 2ml distilled water in a test tube. The operculum was cleaned from coagulated soft tissue and the age was determined under the microscope by counting the number of summer growth zones. The specimens were all from the age span of 0-3 winters summers. Sex was determined by inspecting the gonads (reproduction organs) which are located towards the top of the gut cavity. Females have orange ovaries and whitish testis in the males. The length of the perch was measured from the pointed head of the mouth closed to the tail fin that is compressed when the fish was lying by the side. This measurement was conducted together with the height of the perch and the height was measured from the base of the dorsal fin down to the base of the pelvic fin. The perch gonads were collected from each fish caught and weighed on each perch samples, that is the ovaries in the females and the testis in the males.

I correlated the weight upon the length to compare the size of the perch in Rackaregölen as well as in Stora Slätten lakes and similarly correlated the height and quota to compare the impact on the reproductive tissues of the perch in brown and light coloured water. This was done to show the effect done on the gonad tissues (testis and ovaries) the reproduction organs of perch in the two lakes. Since there are impacts on bigger fishes having larger gonad mass in brown water than in light coloured water, there is every potential that reproduction was not good in light coloured water lake and females in brown lake had good reproduction organs in this work.

In deriving the graphs by statistical analysis for both Rackaregölen and Stora Slätten lakes, the following was done: -

I correlated the length upon the weight, which was given as the body size (length, weight, and height) of perch. Therefore, the lenght upon weight was statistically analysed. In Rackaregölen lake, the males and the female's groups were correlated by using spearman's and pearsons correlation. In Stora Slätten, the males and females were correlated by using the spearman's in both groups respectively. I compared the body size (length, weight & height) of perches caught in the two studied lakes; Rackaregölen and Stora Slätten.

In examination of the reproductive tissues of perch at Rackaregölen lake and compared it to Stora Slätten lake. The quota of the perch fish in Rackaregölen and Stora Slätten was correlated by using both Pearson and spearman on both males and females' group. I made comparison also between the studied lake; Rackaregölen and Stora Slätten respectively. The height upon the quota was compared.

All correlation were made in IBM SPSS 26

The perch fishes are calculated according to gender and total was achieved in a table 3.

I compared the food consumed, total number of consumed foods by each perch males & females in Rackaregölen and Stora Slätten lakes and visualized the food results by using the pie-charts.

Results.

Body Size (weight, length & height) perch

The results of this thesis can be stated, though perch sample sizes caught in both lakes were small in number (25, Tab.3), there was comparison carried out between the two studied lakes of perch. In the first phase at Rackaregölen males' group was correlated and the results shows, the body size (length upon the weight) (Fig.2), in the scattered plot, as p=value 0.001, r^2 – 0.999 the males show positive significant correlation. In the females, the correlation between the females' group, body size shows that there was no significant value between the females, body size (length and weight) in Rackaregölen shows, as p value = 0.154, r^2 value 0.269 (Fig.3).

At Stora Slätten lake, the number of perch males' group body size (length upon weight) in this lake was correlated using spearman's and there shows as significant p-value = 0.001 & r^2-value =0.900. This implies that the correlation is significant in the males' length upon weight in Stora Slätten Lake (Fig.4). Correlating the body size (length upon weight) of the female, this shows no significant as p-value =0.375, r^2value 0.691 (Fig.5). The comparison between the two studied lakes on the body size of the two genders was stated as follow; Rackaregölen males (Fig.2) to Stora Slätten-males (Fig.4), Rackaregölen females (Fig.3) to Stora Slätten females (Fig.5).

The Reproductive organs.

The results of the reproduction organ was carried out as the height upon the reproductive organs (Quota). I examined the male's height upon quota shows, with a p=value of 0.833 and a r^2value of 0.017 (Fig.6). The diagram of males in Rackaregölen lake and show that there was no significant value, but the scatter plot also show that the quota is not increasing with fish hight. In female group at Rackaregölen the female `height upon the females' reproductive organ `Quota was a significance as its shows p-value =0.001, & r^2value= 0.816 (Fig.7). Also, here the quota did not increase with fish height.

In Stora slätten the male's height upon the male's reproductive organ`Quota` was correlated by using pearsons which shows there was no significant value as p-value =0.670 & r^2-value =0.056 (Fig.8).

In Stora Slätten lake also the female's height upon the female's reproductive organ `Quota' was correlated by pearsons, which show that the p-value is 0.455 and r^2 value=0.571 (Fig.9). I also compared the height upon the quota in the two studied lakes and came out to analysed as follows: Rackaregölen Males (Fig.6) to Stora Slätten Males (Fig.8), and Rackaregölen Females (Fig.7) to Stora Slätten Females (Fig.9).

There was few trends and few significant correlations in Stora Slätten, further investigation was done by calculating the correlation coefficient (CC) for each graph. The body size (weight, length, and height) and the gonad (Quota) was analysed (Tab.1). The CC, I compared the weight versus the length in Rackaregölen & Stora Slätten lakes in both males and the females (Tab.1). This shows that there was less weight and height gained in brown (Rackaregölen) lake during the growth stage of the perch fish compared to cases in the fish. The coefficient correlation hence show; y=8.38 +0.17^{xx} and y=10.51+0.09^{xx} males and females (Tab.1).

In light coloured lake, Stora Slätten, where the body size is proportionally heavier. I also compared the CC which was much better compared to the brown lake, and this was given as y=2.85-1.3.69^{xx} males and the females as y=14.3+3.69^{xx} (Tab.1). Further investigation at Rackaregölen, concluded that bigger specimen was proportionally a smaller number of gonads (Lower quota) than those in Stora Slätten (Tab.1).

The trend lines and the CCs indicate that males in Rackaregölen are proportionally heavier when they grow bigger and when compared to the males in Stora slätten (Figs.2-5), also the females in Rackaregölen grows less compared to females in Stora slätten.

Trend lines also indicates that the males in Rackaregölen have proportionally bigger gonads when they are smaller than when they larger in size, while in Stora slätten have larger gonads when there are of same sizes. This pattern is seen in females (Figs.6-9).

<u>Food/Diet Consumed by perch in the two lakes.</u>

Visually, comparing stomach content at Rackaregölen the males consumed food were, crustaceans, beetle flies, midges, and mosquito's larva (Fig.10a). The females in Rackaregölen lake consumed food were, midges, beetles flies, mayflies, mosquitoes' larvae, and crustacean larvae (Fig.10b).

The males in Stora Slätten consumed food content are crustaceans, midges, beetles flies, mosquito's larvae, and mayflies (Fig.10c). The females in Stora Slätten, the stomach contents had consumed foods are mosquito larvae, mayflies, crustaceans, midges, and the beetle flies (Fig.10d).

Table 1. Correlation Coefficient (CC) at Rackaregölen and Stora Slätten Lakes

Lakes /Gender	Correlation Coefficient Equation
Rackaregölen	
Body size (Weight, length, Height)	
Males	y=8.38+0.17*ˣ
Females	y=10.51+0.09*ˣ
Reproductive organs (Quota)	
Males	y=2.85-1.27*ˣ
Females	y=3.23+0.85*ˣ
Stora Slätten	
Body size (weight, length, Height)	
Males	y=6.7+0.14*ˣ
Females	y=11.85+0.07*ˣ
Reproductive organs (Quota)	
Males	y=1.51+22.07*ˣ
Females	y=3.79+33.6*ˣ

Table 2: Water chemistry Data on Rackaregölen and Stora slätten Lake.

Water Chemistry Data	**Rackaregölen Lake- Brown water**	**Stora Slätten Lake-Slight clear water**
Area (ha)	1,5	2,8
Maximum depth (m)	2,5	1,5
pH	4,87	6,20
Turbidity (Nephelometric Turbidity Units) NTU	57,2	40,01
UV radiation (mW/m^2)	338	287,26
Colour (ms /cm-1)	410 (0,598)	436 (0,359)
Dissolved oxygenated (DO) (mg/L).	98,4%	98,6%

Males In Rackaregölen Lake

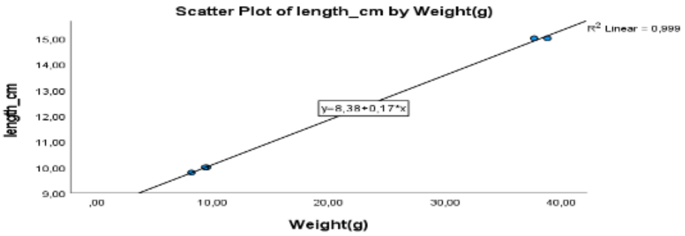


Fig.2 Scattered plot of males in Rackaregölen Lake.

Females in Stora Slätten Lake.

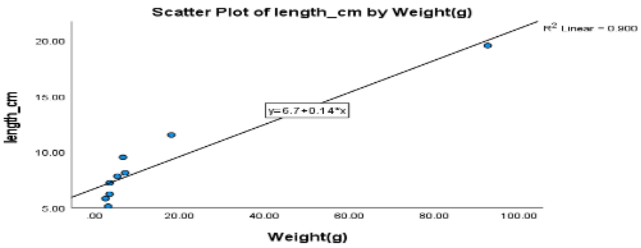


Fig.4 Scattered plot of females, Stora Slätten Lake

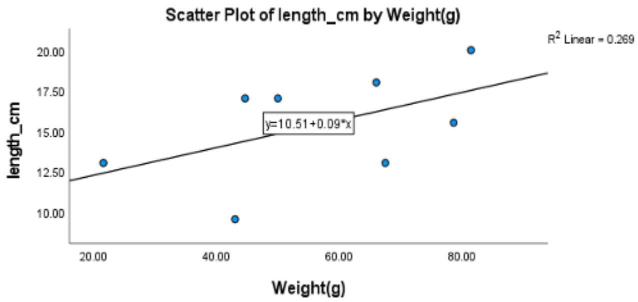


Fig.3 Scattered plot females Rackaregölen Lake.

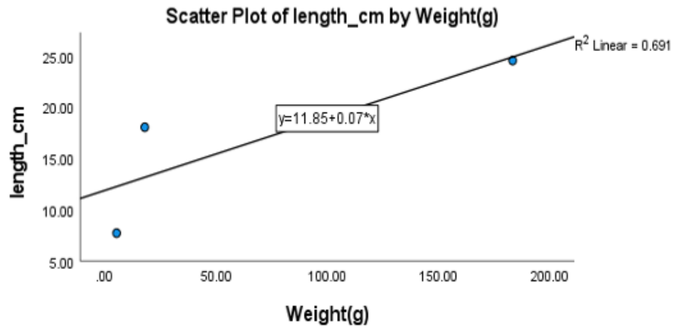


Fig.5 Scattered plot Females Stora Slätten Lake.

Height by Quota Males Rackaregölen

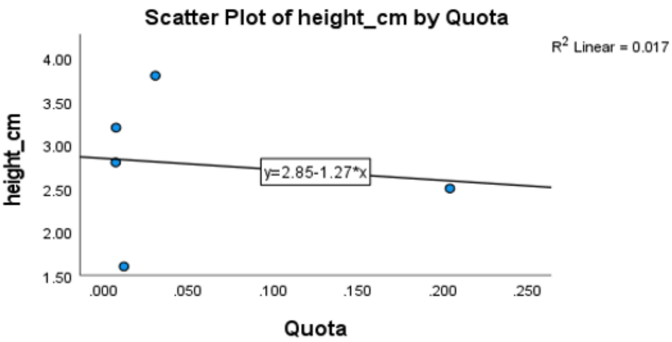


Fig.6. Scattered plot Quota Males Rackaregölen Lake.

Height by Quota Males Stora Slätten

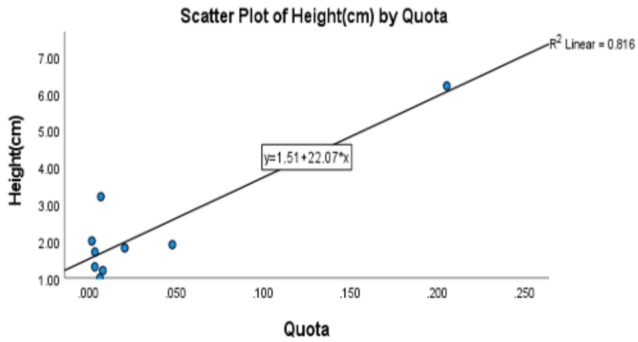


Fig.7. Scattered plot Quota Males Stora Slätten Lake

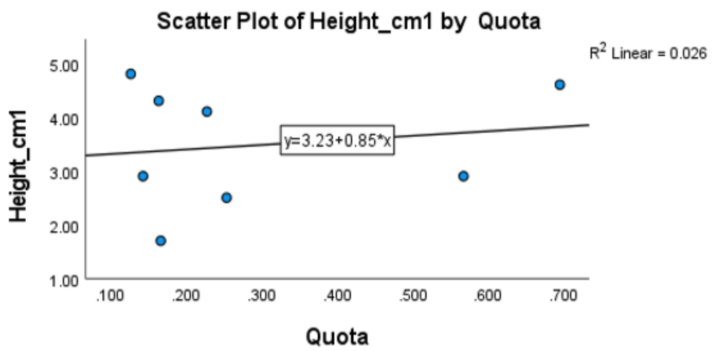


Fig.8. Scattered plot Quota Female Rackaregölen Lake

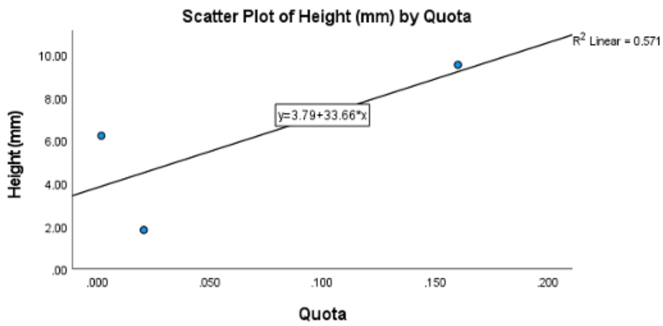
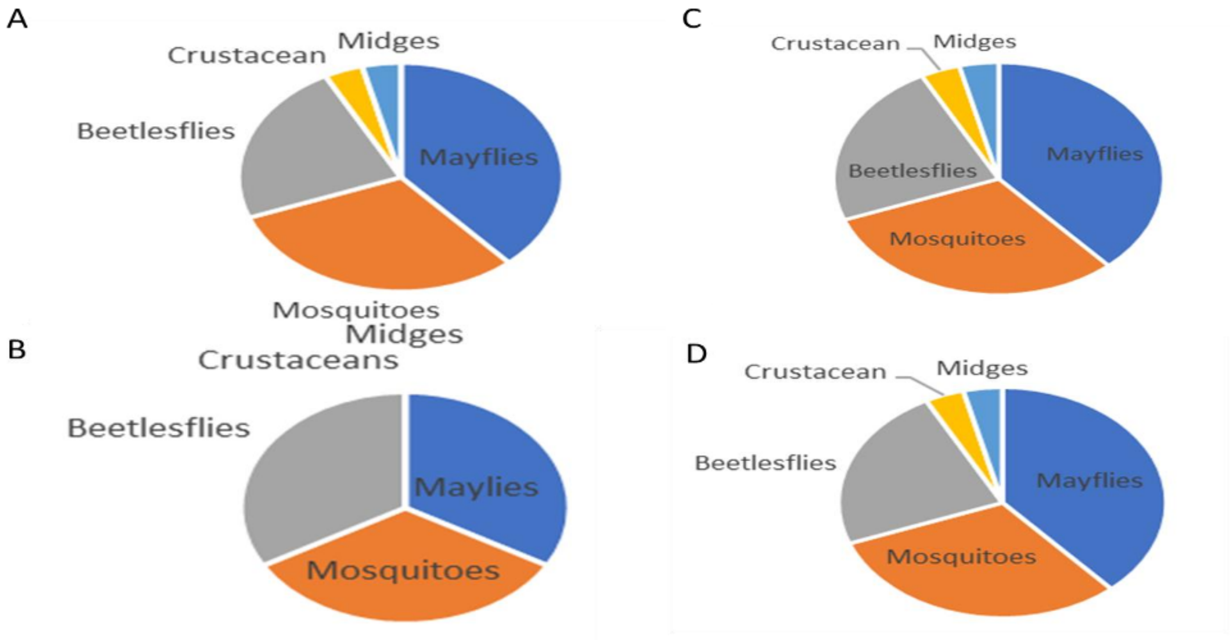


Fig.9.Scattered plot Quota Female Stora Slätten Lake



a = Rackaregölen Lake female b= Rackaregölen males

c= Stora Slätten Lake, female d=Stora slätten, males.

Fig.10. Stomach content of perch in Rackaregölen and Stora slätten Lakes.

Table 3: Age of Perch fishes on the studied lakes

Age	Number of Perch	Lake
1	10	Rackaregölen & Stora Slätten
2	12	"
3	3	"
Total	25	-------.

Discussion:

The result of this thesis gave evidence that fish in a dark brown lake have reduced body size (length, weight, & height) as well as a decreased gonadic somatic index (GSI).

The body size was the length upon the weight of the males in Rackaregölen lake and it was significant (Fig.2). The body size (length, weight & height) of males of perch in relations to the age span of 0+-3 summer winter years (Tab.3) in brown lake was affected in Southern, Sweden. The body size was decrease and reduced due to browning of the lake and the findings agreed with the objective of the thesis. This state that browning affects the body size of perch, and this will cause the lack of diets and photosynthesis not to occurs in the aquatic environment. Browning has stronger effects on body size especially for young and older perch (2-3 yr. Tab.3). As this was evidence or manifested in this research. The growth was also reduced due to the browning of the lake. Browning has stronger effects on the body size of perch, especially for juveniles and old perch and it has been stated in previous studies (van Dorst et al.,2020). However, the effect is normally proved in young and older perch that proved to be alike. It is essentials to think about the growth of juvenile and survival of perch fish community. It is strongly believed that if the juvenile in the population is reduced drastically due to browning, the tendency of fitness, the ability for then to compete and survival of each species will be reduced which will cause the juveniles or the young prone to predators for a long period of time (Chick & Van Avyle, 2000, Jönsson et al.,2012). Similar analysis was also done on the females' body size in Rackaregölen, (brown lake). The female body size didn´t show no significant changes as the p-value was negative (Fig.3). This shows that in brown lake, there seems to have negative p-value on the female body size. The reason for the effect of the negative trend, was due to the number of small sample size caught in the brown lake (Tab.3). This might also be the reason as in previous studies there was effect of browning on both sex (Hayden et al.,2017).

I did similar statistical analysis in Stora Slätten, this lake which is light coloured than Rackaregölen lake. There was significant of p-value=0.001 r^2 value= 0.900 on males (Fig.4). The females' group shows significant value. The body size (weight, length, and height) rate of juvenile (0+-1yr) coupled with the population of perch in a brownish aquatic environment is important as they will grow actively while feeding on benthic macroinvertebrates. It is further researched that if the growth of juvenile is reduced, they will be subjected to predation (Chick & Van den Avyle,2000.,2012). Previous studies (Jönsson et al.,2012) clarified that most of juvenile planktivorous perch (0+-1+ yr.) reduces apparently because of continual browning of lake and light limitation and problems of food chains will be absent in brown lake, and there was starvation in the ecosystem (Horppila et al.,2010; Kankaala et al.,2019; Rask et al.,2014). In this situation older perch becomes cannibalistic which impact the survival rates of the juveniles and youngers perches. The older perches consumed the juveniles and younger perches, and they are also impacted seriously in the recruitment processes (Persson et al.,2002). In another circumstances, this would be possible for discussion, as a results of these factors, stunted growth, threaten by other fish predators and finally mortality. It is also evidence that continues browning adversely affect feeding capacity of perch and the older perch feeds on benthic invertebrates such as dragonflies' larvae, stoneflies larvae, and beetle flies' larvae (Bergman & Greenberg, 1994). I did not do much investigation on light limitation on the lakes at Rackaregölen, as well as in Stora Slätten.

The body size (length, weight & height) males perch, reduced in the brown lake and this can further lead to light limitation that have strong tendency on the feeding of perch (Van Dorst et al.,2015). In diverse research It is measured that browning influences light limitation and have effect on the ecosystem organisms such as perch. These further decreases the vision and foraging and growth of perch. I observed the stomach content on each perch caught in the lakes and found out that there was enough foods or diets in the two lakes. Since diets/foods are responsible for growth and survival and even though browning negatively affects the feeding ability of perca fluviatile (Thorson et al.,2017).

It´s important to concentrate on the reproduction mechanism of perch in a brown lake environment, fish living in a brown ecosystem should have the ability to reproduce off- springs but this was problematic and thus affects reproduction organs, the gonadic somatic index (GSI). The quota as it is labelled in my project was affected and therefore it answered the second objective of the project. The dissolved organic carbon (DOC), climate change, Fe (iron) solution leeching through the soil into lakes and rivers etc, all these factors' attributes to brownification of lakes and rivers and impacted the ecosystem organisms. In brown lakes, it was obvious that perch response to these environmental factors that are dependent and decreases the water transparency and thereby increases the means temperatures. This is impacted on feeding rate on the female perch related to the male in a brown lake. Water transparency decreases negatively on both sexes of perch significantly. In this scenario, the female body size reduces or is more impacted and reproduction or the gonadosomatic index is highly affected on both sexes of perch species (Estlander et al.,2015). In my project I conducted studies on the gonadic somatic index (GSI) on the perch to have evidence that the brown lake has effect on the gonads. In Rackaregölen lake I correlated the gonad, named as the quota and height, the male's group was compared. It was evidence that there was no significance as p-value was negative (Fig.6). This simply shows that the reproduction organs are not affected apart from the females in brown lake (fig.7), this was because brown lake have the tendency to decrease the reproduction organs. The female's quota was correlated and didn´t have no significant in light coloured lake. I, therefore concluded that the chances of female reproduction in brown lake seems to have negatively influence on the reproductive organs.

In Stora Slätten, light coloured lake was also correlated on the males' group, this shows no significant value and there seems to have no significant effect on the gonad to reproduce offspring (Fig.8). The Female group was analysed, and there is no significant difference among the females in Stora Slätten lake and this maybe due to the number of specimens collected which was only three perch fishes caught and very small (Tab.3).

I visually compared the stomach content in Rackaregölen and Stora Slätten on males and females to see the different types of food or diet consumed by each perch caught. The diet of perch is said to be different and hard since they suffer from competitions or interspecific competitions from other fishes such as ruffe (Gymnocephalus cernuus) at an adult stage, the invertebrates and other fishes make it competitive (Bergman & Greenberg, 1994) The brownish lake can also cause the eyes of the perch not to notice food in its surroundings. This can also result into depression of the perch and makes food materials shortage. This eventually decreases and reduces the body growth of 1+ perch (Pearson et al.,2000). I further compared the perch fishes caught in the two studied lakes; Rackaregölen and Stora Slätten. The males body size in Rackaregölen and those in Stora Slätten (Fig.2 to Fig.4) was compared. It was evidence that the males body sizes of perches in the two lakes had a positive significant value. This implies that there were no differences between the brown lake and the slightly brown lake in term of body size reduction or decreased. I also did similar analysis for the females' body sizes in both lakes, Rackaregölen and Stora Slätten (Fig.3 to Fig.5). It is evidence that there is negative significance of both females' body sizes between the two studied lakes. This is evidence that the body size decrease as the water get browner, this claim was supported by lot of freshwater ecologists, such as Van Dorst et al. (2020), & Estlander et al. (2015).

The correction coefficient are just trends and non-significant but worth further studies in scientific research. The correlation coefficient (CC) from figures (2-9) were coordinated for more investigations on the body sizes and the gonadic somatic index which is known as the quotas in this project. The body size (length, weight, and weight) had showed several ranges in the results (Fig.2-5, CC2-5) and there is disturbance on the body size in Rackaregölen as well as Stora Slätten. This causes the perch fish seems to function normally, such as movement, feeding, and growth. Lot of scientific researchers (Mount ,1973, Craig & Baksi,1977, Lee & Gerking,1981) have showed that fishes body size reduces in brown lakes and streams environments but there was little amount of evidence in my investigation. On the reproductive areas the gonads (quota) were also correlated coefficient (CC) in figures. The gonads (quotas) did show some evidence that seems to be negative and positive in this project as both testis and ovaries functions smoothly and spawning and reproduction was a little reduced in the brown water (Fig.5-9, CC6-9). The perch populations in previous studies, investigated that especially the female shows negavity to spawn and reproduced was unfavourable in brown coloured environment (Tsai and Gibson,1971 & Svatora (1977). This can be manifested in severe brown lake condition were dissolved organic carbon is at its maximum in water (Le Cren,1965). The comparison, I did was also between the reproduction organs, named as quota, and the height. It was evidence that the male's height upon quota in the two lakes (Fig.6 and Fig.8) had negative p-value. This mean there is no differences between the two lakes. I also compare the female's height upon the quota in the two studied lakes. In Rackaregölen the female's height upon the quota had a positive p-value (Fig.7) and in Stora Slätten the female's height upon the quota had a negative p-value (Fig.9). This is because there was only three samples of females' perch fish caught and collected at Stora Slätten lake. I did found evidence of positive on the females' quotas and seems to be decreased on the females in my experiment, the reproductive organs of perch decrease and reduces when the water gets browner. The decrease of perch population maybe due to decreased water transparency, which is generated from dissolved organic carbon, (Finstad AJ, Helland IP, Ugedal. O. 2013).

The Age of the perch fishes was calculated on the number of summer winters growth of age span 0-3yr (Tab.3). The food types were observed to see the types of food consumed by each perch caught in my studied lakes. Basically, the diet of perch mostly consists of zooplankton. This happens when the perch is in the juvenile stage and later its shift from feeding on macroinvertebrates, that are benthic invertebrates and as it grows about cc.15-17cm it begins to feed on fishes. The feeding on macroinvertebrates shift to the fish feed on fish, when the perch is approximately 3+. The perch fish feeds when the fish length is approximately 17.5cm and above (Allen 1935; Persson et al.,1991). The fish feeding arises with the fish size of cc.18cm, and this can be that the perch is piscivorous and is full adult size (person et al.,1991). When these steps fail the normal growth becomes delay or stunted (Holmgren & Appelberg (2001). In this view, further research was not necessary taken on how diet and feeding affect the perch, but the stomach content or diets in the stomach (Fig.10) was observed to verify the food types in the stomach of each perch caught in the two (2) studied lakes (Fig.1). In my paper, I differentiated the food types in each perch stomach observed, the diet found were crustacean, midges, mayflies, mosquito larvae, beetleflies cuticles (Fig.10).

In this thesis the diet/ food can be stated that juvenile, young and adult perch feeds on zooplankton, macroinvertebrate and fry and fingerlings (fish).

I further analysed the effect of brown lake and impact on perch fish between the two studied lake within the vicinity of Lake Bolmen, Southern, Sweden. The watercolour was measured by using the disc secchi forei ule scale, even though there are different methods of measurement and several of the methods don´t have a standard measurement (The American Society of Limnology and Oceanography, 1992). This research was analysis by looking at the water chemistry and dissolved organic carbon as the main drivers that are responsible for the brownification of lakes in the southern Sweden.

Table 2 shows a comprehensive analysis on the water chemistry on the two studied lakes.

The acidic content or the pH at Rackaregölen lake was strong compared to Stora Slätten lake (Tab.2). This pH is said to be acidic but show little on the perch specimens caught. It was researched by several freshwater ecologists (eg. Thorson et al.,2017) that most acidic water environment fishes consume a lot of energy than in neutral environment, this was done to maintain the ionic balance in the lakes and rivers (Lee et al.,1983). There are some delays in growth in some perch fish and it is due to the higher amount of acidic potential (Rodgers, 1984., Kwain & Rose ,1985., Tain & Payson 1986). In this research, there was no further research with the evident that the pH was lower in some areas, but this didn´t affect the perch on the body size and gonads. Browning lakes and rivers is a concept of deterioration and light limitation at the bottom, and it creates negative impact on the ecosystem services.

The amount of light penetration is limited in most brown lake and less in light coloured lake (Fig.1) in the two studied lakes there was evidence of climate change, iron deposition, dissolved organic carbon concentration leeched through soils which was researched by various freshwater ecologists. I did correlate between the length-age in DOC which I thought that it would be stronger, but the samples perch caught was little in the two studied lakes. Therefore, there was little amount of evidence in this project which was part of the research question. The amount of DOC in various lakes are coordinated and detected (Kritzberg & Ekström (2012). This describes water colour to have higher water turbidity of brownish colour at Rackaregölen and not much in lightly coloured in Stora slätten. Therefore, there are differences between Rackaregölen which is regarded as brown lake and Stora Slätten as lightly coloured lake.

Global warming and land-use (eg, to postures, crop production and urbanization) practices are the main drivers and have stronger impacts on perch and ecosystem. They can be attributed to less transparent, and warmer freshwater. This causes the smaller body sizes in lot of fish species such as perch (Hayden, et al.,2017).

Based on various studies that I have done (van Dorset et al.,2015) on fish living in brown lake and streams there are many negatively impacts on nutritional quality of fishes such as perch that are good for the consumption to human-beings and they also transfer fatty acids to mankind (Taipale et al.,2016). The stunted ability of fish to grow and the competition to search for food are among the many problems faced in brown water.

The concentration of iron which has increases the dissolved organic carbon (DOC) is said to caused discomfort and disorder in fish and flakes in the gills and will result to acute respiratory problems of the fish (Bury et al.,2019). Iron been at normal level in water, is not lethal in any aquatic species but higher amount of iron does not easily dissolve in water and fishes and other aquatic spices cannot process the higher concentrations found in water (Jezierska and Witeska,2016). There was evidence that states that there was higher amount of iron concentrations in the dissolved organic carbon in brown lake of this project.

The recreational value or activities in fishing, like games etc, played by fishes is quite relevant and important, if there is continues browning of the lakes, this would greatly impact the recreational activities and tourist visit, fishing industry or fishing stocks and yield production will be reduced.

The environmental goals of Sweden states, that Swedish lakes should have improved ecological status as well as the biodiversity, should be conserved (Sverige's Miljömål 2020). I am with the opinion that browning of lakes and streams is a threat to the this aim and that is creating obstacles that should be controlled or reduced.

The evidence in these studies found out that there is reduced body size (length, weight, height) and gonadic somatic index (GSI)in brown lake (Rackaregölen) and decreased GSI in the males in light coloured lake, Stora Slätten. When there is high increased of browning in the lake, this could have seriously impacted on the community structure, gonad, and body size (length, weight, height) structure of perch fish as well as impacted on other species in compounded processes. This will affect the gonads in both the females and the males perch, and it will cause extinction of the entire fish species.

Browning effect on perch fish community needs to be further investigated, besides this study requires the addition of information on the impacts of brownification and coupled with further investigation on mortality rate of perch fish species including transfers on perch fish community composition in the humic boreal lakes in Southern Sweden.

Conclusion:

In conclusion, this study offers a clear demonstration to address how lake brownification, climate change, land-use activities are the main drivers responsible for the browning of lakes and rivers that drains dissolved organic carbon (DOC), and how it reduced the body size (length, weight, height) of perch and affect the gonadic somatic index (GSI) for reproduction of off springs. This eventually seems to be impacted on the perch in the ecosystem and causes mortality and extinction of perch in the natural environment. If lakes and rivers continue to become brown, there will be more disaster in the ecosystem.

In my research, there is great effect of browning on perch fish, and it's met the required objectives of the thesis.

On the other hand, the diet and reproduction of the perch is mostly affected, due to the lake browning, and difficulty for the fish to see or visualize its diet and consume and this will be resulted to perch retardation in growth. This will also affect the reproduction of the perch species. The gonadic somatic index (GSI) of the sexes is seems to be negatively active to carry out sexual activities. There was an effect on the GSI in perch fish in browning lake on my thesis.

According to the results of this thesis lake brownification seems to negatively affect the body size (weight, length & height) on perch and in another analysis the brown water influences the reproduction organs of the perch.

I believed that hundreds of perch populations may be affected in Lake Bolmen which is entirely brown with larger number of perch. I, therefore, conclude that on my thesis lake brownification have influences on perch (perca fluviatilis) in Southern, Sweden.

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