Rapport de stage individuel

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Variation in age to length relationship in Arctic charr (*Salvelinus alpinus*) from Lake Leynavatn, Faroe Islands

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Finally, I would like to thank my academic tutor Michel BACCHI for accepting this role and for his time in evaluating my report.

Table of acronyms

AC	Arctic Charr
BT	Brown Trout
DEVO	Developmental [processes]
ECO	Ecological [processes]
EVO	Evolutionary [processes]
FWC	Florida Fish and Wildlife Conservation Commission
K	Condition Factor
PhD	Philosophiae Doctor [doctorate student]
SD	Standard Deviation
SSD	Sexual Size Dimorphism

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I. Introduction

Climate change is a worldwide issue and the resulting global warming poses many problematics, particularly at higher latitudes. Today, the most vulnerable ecosystems are the Arctic and subarctic aquatic environments (Godiksen et al., 2012, and Laske et al., 2019), where rapid changes in biodiversity and ecosystem functioning have been observed, such as warming waters, increased biological invasions and anthropogenic pressures. Species that inhabit such areas are therefore facing multiple pressures with few alternatives to mitigate those changes: adapt quickly, escape/disperse to more suitable habitats or disappear.

Many processes and their interactions can allow species to evolve and adapt and all have a common basis: **genetics**. For instance, **natural selection** is based on random genetic mutation which may give advantages to an individual who will be more likely to reproduce and to pass on its genes to future generations, which eventually leads to the appearance of new species. But, according to Skúlason et al. (2019), natural selection is only the result of the influence of ecology changes over evolutionary processes. Indeed, the ECO-EVO-DEVO framework (figure 1) aims to acknowledge the interactions between the **ecological**, **evolutionary** and **developmental** processes in shaping the observed phenotype(s). It also provides an initial response to the presence of several morphs/ecotypes of one species in sympatry, especially where two or more spatially distinct habitats are available (Malmquist et al., 2002b).

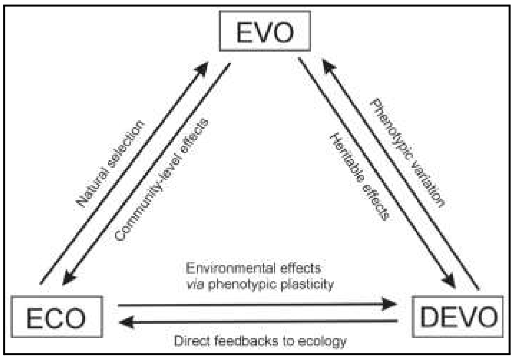

Figure 1: The ECO-EVO-DEVO framework (from Skúlason et al., 2019)

Fish are **ectothermic** organisms, meaning they have a physiologically optimal range of temperatures. Thus, **water temperature** is considered to be the most pervasive environmental factor affecting fish growth, and the magnitude of associated climatic effects on aquatic ecosystems is expected to depend on local catchment characteristics and lake geomorphology, including lake altitudinal and longitudinal position (Godiksen et al., 2012). Because of their geographical isolation in the North Atlantic Ocean, and because of the rugged terrain, the **Faroe Islands** are gifted with a unique animal and plant life in the context of ecology, diversity and evolution, making the Faroese lakes well-suited for biogeographical studies (Bloch, 2002 and Jeppesen et al., 2002).

Arctic charr (*Salvelinus alpinus*) is the most northerly freshwater fish. In some northern latitudes, it is the only species in the freshwater fish community (NatureScot, 2020). Therefore, it is particularly sensitive to water temperature variations. Moreover, its position at the top of the arctic and subarctic freshwater food chain make the Arctic charr to concentrate the changes of each of the species it dominates and so the rapid ecological changes caused by global warming. That is why the Hólar University has begun to study the morphological changes of Faroese Arctic charr populations due to global warming over a 20-years period, and the evolution of its interactions with its main competing species: the Brown trout (*Salmo trutta*).

A. Presentation of the host organisation

The Hólar University is a famous historical school founded in 1106 by Bishop Jón Ögmundsson, making it on+e of the oldest universities in Europe today (figure 2). It is a specialised higher education institution offering undergraduate and postgraduate education in three disciplines: Aquaculture & Fish Biology, Equine Studies and Tourism Studies. There are about 200 students in this school located in the northern part of Iceland, in the vicinity of Sauðárkrókur (figure 3).

Figure 2: Hólar University during winter (@Global Admissions, s.d.)

Figure 3: Location of Hólar in Iceland (@Carte du monde, s.d.)

The Aquaculture & Fish Biology department - in which my internship took place - aims to develop and **promote sustainable aquaculture** while **conducting research on arctic aquatic species**. To do so, the fishing company FISK lends a laboratory to the university, located in the port of Sauðárkrókur (30 minutes drive from Hólar) and where most of the experiments and researches take place. Students of all nationalities come here to participate in the research as trainees for short periods or as PhD students for longer periods (holaraquatic.is, s.d.).

In total, the permanent Aquaculture & Fish Biology staff is composed of 17 people including (figure 4):

- 8 academic staff: professor, associate professor and assistant professor
- 6 technical and support staff: project manager, station manager and technical manager
- 3 postdoctoral researchers

In addition, there are about 16 PhD students and some interns.

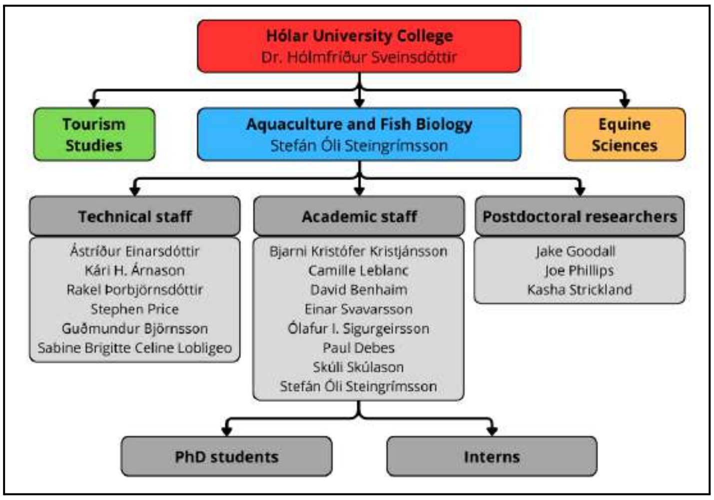

Figure 4: Aquaculture & Fish Biology department flowchart (@S. Dehove, 2023)

B. Context

1. The Arctic charr and the Brown trout

Arctic charr (*Salvelinus alpinus*) and Brown trout (*Salmo trutta*) are the only two native species of the salmonid fishes *Salmonidae* found in the Faroese freshwaters (Malmquist et al., 2002b). It may be difficult to differentiate the two species. Two morphological traits can be used to do so: first, Arctic charr have **white stripes** at the end of the pelvic and anal fins and red dots on the belly, whereas both are absent in the trout (figure 5).

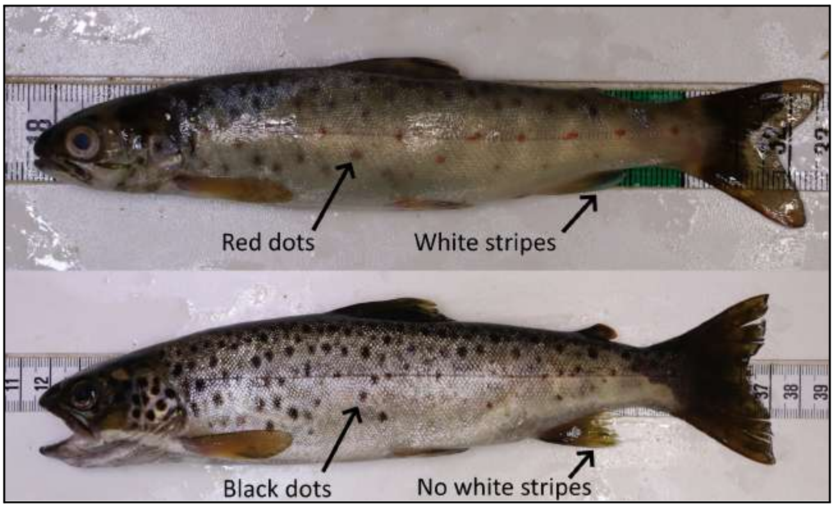

Figure 5: Top: Arctic charr ; Bottom: Brown trout (@Aquatic and Fish Department, 2022)

Arctic charr (AC) is often found in ancient Northern glacial regions of Europe and America, such as Russia, Scandinavia, Iceland, Greenland, Canada and Alaska, where it lives in cold rivers and lakes (4-16°C, optimal 9°C (Larsson, 2005)), up to 70 m deep. It commonly measures 20-40 cm long and can grow up to 107 cm, 15 kg and 30-40 years old (FishBase, 2023, and DORIS, 2023). Over 50.000 charr populations have been recorded around the world. Brown trout (BT) can be found in both cold and warmer waters as its optimal temperature is 16°C (Larsson, 2005). It is indigenous to Europe, North Africa and western Asia and has been introduced in the late 19th century in many other places (Klemetsen et al., 2003). It commonly measures 20-35 cm and can grow up to 100 cm, over 7 kg and 13 years old (FishBase, 2023, and DORIS, 2023).

The two species have some similarities: first, the spawning takes place in freshwaters during fall and winter and the fish mature at 3-6 years old depending on food resources available for their growth. Second, some populations are annually migrating to the sea during summer to feed more (**anadromous** populations) while others remain in freshwaters (**potadromous** populations). The size and weight of the fish are highly correlated to this factor (Eliott & Eliott, 2010). Third, each species shows a high degree of **polymorphism** (Malmquist et al., 2002b).

Although they have similarities, in nature, Brown trout feed more on smaller fish and are much more **aggressive** and **territorial** compared to Arctic charr (Svenning et al., 2022), but require much higher oxygen levels (Eliott and Eliott, 2010)

2. The Faroese subarctic lakes

The Faroe Islands are an archipelago of 1400 km² located in the North Atlantic ocean, midway between Scotland and Iceland, and is part of the Kingdom of Denmark. They are the remnants of volcanic eruptions that occurred almost 60 million years ago, causing the topography to be very steep: today, the 18 elongated islands are divided by narrow fjords and sounds and the highest location is 882 m high. This geology allowed formation of 2500 lakes formed through erosion by ancient glaciers in valleys, inland lagoons or tectonic origin (Mortensen, 2002).

Studies on these lakes first began in 2000 with the NORLAKE project (see part II.A) which focused on 5 representative lakes of the Faroese lowlands. In 2022, the FishFAR project, led by the Aquaculture & Fish Biology department and Faroese biology scientists, focused on 3 of these 5 lakes, partially due to time constraints. Each has specific particularities (Mortensen, 2002) (figure 6):

- Saksunarvatn: northernmost of the three, its deepest part coincides with the weakness zone caused by a dike crossing the lake.
- Toftavatn: eastmost lake, it has an asymmetrical basin with a shallow and narrow northern section and a wider and deeper southern section reaching 7 m below the sea level.
- Leynavatn: located at the crossing of two large valleys (figure 7), this is the only lake where Arctic charr can be naturally found in the Faroes Islands.

In contrast to the Arctic charr, Brown trout can be found in these three lakes as in many other lakes in the Faroese, where it was introduced a long time ago.

Figure 6: Location of the three Faroese lakes in this study (@Google Maps, 2023)

Figure 7: Lake Leynavatn in the middle of the steep relief (@Óli Gardshop, s.d.)

These lakes are rather small but deep compared to their area (table 1) and their concave basin formed due to glacier excavations is such that the size of littoral benthic habitat is very small relative to the pelagic habitat (Malmquist et al., 2002a).

Table 1: Geographical characteristics of the Faroese lakes (modified from Jeppesen et al., 2002)

Lake	Lake area (km²)	Mean depth (m)	Max depth (m)	Watershed (km²)
Leynavatn	0,18	13,7	33	16,6
Saksunarvatn	0,08	6,5	17	12,3
Toftavatn	0,52	5,8	22	3,6

Moreover, Jeppesen et al. (2002) demonstrated that thanks to the still well preserved wild state of the islands, the lakes were **oligotrophic** in early 2000's as they were protected from anthropogenic pollutants. However, no study has since been carried out to check whether this statement holds true in 2022.

3. Lakes functioning, fish population, interspecific competition and potential effect of climate change

6 native fish species can be found within the Faroese freshwater systems (Malmquist et al., 2002b): the European eel (*Anguilla anguilla*), Arctic charr (*Salvelinus alpinus*), Atlantic Salmon *(Salmo salar*), Brown trout (*Salmo trutta*), Nine-spined stickleback (*Pungitius pungitius*) and Three-spined stickleback (*Gasterosteus aculeatus*). However, these species are not native to all the Faroese lakes: some have been introduced from one lake to another for fishing purposes.

The fact that Arctic charr is only naturally found only in lake Leynavatn in the Faroe can be explained by a combination of geographic and thermal factors (Jeppesen et al., 2002 and Malmquist et al., 2002b). During summer, the mean surface temperatures of the lakes reaches 14-16,5°C in both pelagic and littoral zones. The strong wind easily stirs the water in shallow lakes which become thermally homogenised. In contrast, in deeper lakes such as Leynavatn, the deepest water layer called **hypolimnion** (figure 8) rarely exceeds 9°C, offering Arctic charrs a thermal niche all year around.

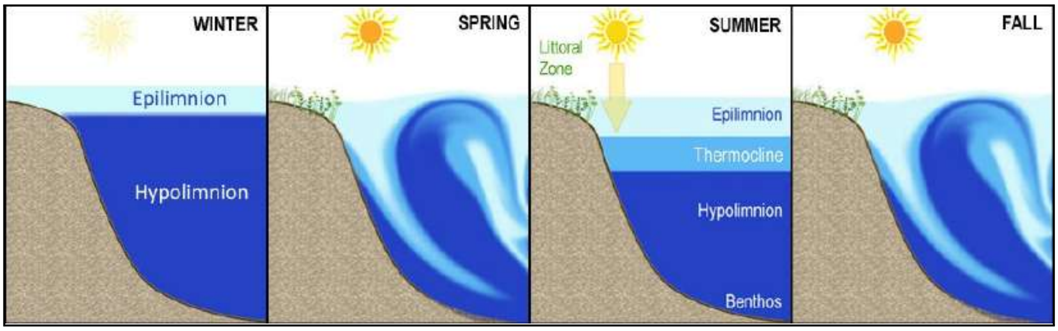

Figure 8: The evolution of thermal layers in lakes through the seasons (@RMBEL, s.d.)

Moreover, Arctic charr in Leynavatn are considered **resident** (potadromous population) whereas Brown trout are found in the outlet river connecting the lake to the sea, they are therefore considered anadromous (Malmquist et al., 2002b). The **sympatry** between the two salmonid species induces a **competition** for habitats and food in Leynavatn. In fact, AC tends to feed on a variety of food from both the littoral benthic and the pelagic habitats, whereas BT mostly exploits the littoral benthic habitat and feeds on surface insects and zoobenthos. The aggressive behaviour of BT can push AC out of the littoral zone and deeper into the pelagic zone, depriving them from a non-negligible source of food (Ulvan et al., 2012). The same author argues that, to compensate, AC has a growth efficiency twice as much as BT, but it proved to be disadvantageous in low-food resources places such as Leynavatn. In the end, only old and large AC can compete with BT in the rich-food pelagic zone, while younger and smaller AC hide in the lower-risk but lower-food epibenthic area (L'Abbé-Lund et al., 1993).

As a result, AC in Leynavatn have evolved apart from any other AC population: they are now **monomorphic** and characterised by **slow growth**, **short asymptotic length** (21 cm) and relatively **short lifespan** (8 years). In contrast, Leynavatn AC have been released in other Faroese lakes with unrestricted food resources and have shown signs of much faster growth rates and larger asymptotic length reaching about 50 cm (Malmquist et al., 2002b).

Furthermore, climate change seems to have an impact on fish populations and morphology. For instance, the predominance of BT over AC is accentuated: according to Svenning et al. (2022), temperature increases are associated with reduced catches of AC and increased catches of BT across all nordic regions, meaning BT is **displacing** AC and in some cases **replacing** it. In fact, an increased temperature leads to an increased metabolism rate and so an increase in food demand (Kristensen et al., 2006). In food restricted habitats such as small coldwater lakes where fish growth is seasonally restricted, the effect of rapid change in temperature combined with changes in fish composition (species change but also number of juveniles/adults) may have rapid consequences on each species' habitats, life history, and morphology. . Then, Reid et al. (2019) claim that it induces **reductions in body size** in freshwater species. However, water temperature changes do not seem to modify the feeding behaviour of any of the two salmonids (Ulvan et al., 2012).

4. Otoliths and fish ageing

Otoliths, also called earstones, are hard calcium-carbonate structures found inside all bony animal skulls, more precisely inside the ear canals, just below the rear of the brain. They allow the organism to **perceive linear acceleration**, both horizontally and vertically, and are involved in the detection of sound and the **process of hearing**. All fish have three pairs of otoliths (figure 9):

- the sagittae (largest of the 3)
- the lapilli
- the asteriscii

Their shape and proportional size differs according to the species (figure 10), which means they can be used to identify species and prey size eaten by birds and mammals when found in their stomachs.

Figure 9: The three pairs of otoliths (@Gov. of Canada, 2018)

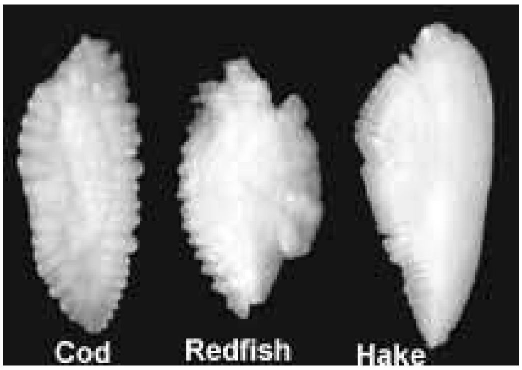

Figure 10: Different otoliths shapes along various species (@Gov. of Canada, 2018)

When put under a reflected light, thin otoliths reveal a succession of thick white opaque and thin dark translucent zones, respectively representing periods of slower and faster growth, similar to the rings found in trees (figure 11). In fact, the increment rate varies with individual fish growth - and indirectly its diet -, often less in winter and more in summer (FWC, s.d.). Then, by counting the number of dark rings called **annulus**, it is possible to estimate the age of the fish. Sagittae otoliths are commonly used in this process as they are the larger pair of otoliths and therefore easier to find inside next to the fish skull (Gov. of Canada, 2018).

Figure 11: The number of otolith rings correlated to the fork length and age (@Nunavik Ice, s.d.)

But, in order to properly estimate its age, the method must be validated to prove that one annuli is equal to one year of growth, and this for every species studied. To do so, it is possible to use fish from aquaculture since their age is already known and count the rings on the otoliths. However, Steven E. Campana (2001) demonstrated that artificial environments may lead to abnormal growth patterns. That is why the "**marginal increment analysis**" method is frequently used: the marginal increment is the measurement from the last annulus to the margin (= edge of the otolith). As it cycles down only once a year, it means that one annulus was deposited every year (FWC, s.d.).

In the end, otoliths can prove useful to estimate noy only the age of individuals but also growth rates, maximum age, age at maturity, mortality rate, overall population structures etc.

C. Research question and hypotheses

The age to length relationship is a crucial factor to properly study fish population's evolutions over long periods of time, as it is easily influenced by environmental changes and thus reflects the fish adaptations to these changes.

Indeed, the maturity of fish is correlated with their size and the number of eggs laid is correlated with their weight (Crawford et al., 2006), which indicates that if a fish population cannot grow as much as it normally would because of a disturbance in the food chain, the entire reproductive cycle is threatened. Moreover, it is proved that Sexual Size Dimorphism (SSD) is highly correlated to water temperature (Árnason et al., 2022), showing that climate change is a real threat to freshwater fish populations. Thus, if Arctic charr growth is proved to be negatively affected by global warming, it may threaten fish populations whose reproduction will not be efficient enough to sustain the species in the long term.

A previous study (Kristensen et al., 2006) has worked on the coupling between annual growth rates and fluctuations in annual mean temperatures and precipitations in West Greenland, using climate data between 1990 and 2004. It showed significant changes in temporal patterns of growth: it was **retarded** for one population but **stimulated** for another. The difference is supposed to be due to local differences in fish demand, food supply and parasitic load. But, since then, climate change effects have been accentuated or even worsened. For this reason, it is interesting to conduct a new study on this subject to determine whether these changes in pattern growth have increased or have stabilised (as a result of the species' adaptation).

Fish data and samples from Leynavatn, Saksunarvatn and Toftavatn lakes were collected in 2000 (part II.1) and can be used for comparison with the 2022 FishFAR data. Consequently, it is legitimate to ask whether **the relationship between age and length of Arctic charr and Brown trout in Faroese lakes has changed over a period of 20 years?** Two predictions were made, which I will try to answer by ageing the fish using the otolith method:

1. Brown trout is better adapted to warmer water than Arctic charr (Larsson, 2005). Thus, as water temperature in Faroese lakes has likely increased over the last 20 years, Brown trout will be favoured compared to Arctic charr when found in sympatry.
    - I expect to see **less** and **smaller** Arctic charr than 20 years ago, **maybe younger**.
    - I expect to see **more** and **larger** Brown trout than 20 years ago, **maybe older**.
    - I expect to observe a different age to length relationship compared to 20 years ago for both species.

2. As water temperature in Faroese lakes has likely increased over the last 20 years, Brown trout may also perform better when found in allopatry. Then, depending on food availability:
    - I expect to see **more** and **larger** Brown trout than 20 years ago, **maybe older**.
    - I expect Brown trout to **grow faster** than 20 years ago.
    - I expect to observe a different age to length relationship compared to 20 years ago

II. Materials and methods

A. Data collecting: the FishFAR project

The FishFAR project studies the **temporal changes in feeding ecology and life histories of Arctic charr and Brown trout in Faroese lakes**, in collaboration with Hólar University, University of Copenhagen, Icelandic Museum of Natural History and Faroe Islands National Museum, and is under the supervision of Agnes-Katharina Kreiling, Camille Leblanc and Bjarni K. Kristjánsson. It aims to identify effects of climate change on community structure and trophic ecology of fishes by comparing food resources, fish diet and fish morphology across the 3 subarctic lakes Leynavatn, Saksunarvatn and Toftavatn (part I.B.2), as they represent contrasting combination of fish populations.

The Research Council of Faroe Islands funded the project with a 18 millions ISK grant (≃ 135.000€). The project took place during summer 2022 (August 5-11), over 4000 measurements (water temperature, depth…) and samples were collected using multi-mesh gillnets (figure 12) layed overnight for 12 hours. In the end, 4 standardised multi-mesh gillnets of XX m² each were used in each lake, with mesh sizes of 10, 12.5, 15.5, 19, 24, 29, 35 and 48 mm. The fish caught were photographed, gendered, measured, dissected and stored in 95% ethanol (figure 13). The data are then to be compared to those obtained in summer 2000 during the NORLAKE project, which collected samples and measurements in the same 3 lakes. In total, the FishFAR project is exempted to last until 2025.

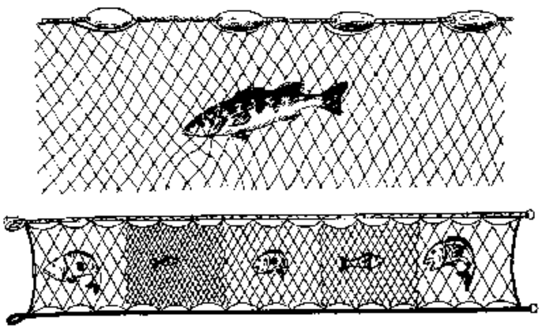

Figure 12: A multi-mesh gillnet (@Aquitec, s.d.)

Figure 13: Fish samples stored in 95% ethanol (@S. Dehove, 2023)

The aim of collecting biological data such as fork length and weight is that they can be used to assert the fish robustness/well-being by looking at Fulton's **condition factor K**, using the formula proposed by Htun-Han in 1978:

$$K = \frac{100 \times W}{L^3}$$ with L the fork-length (cm) and W the weight (g) of the fish.

The condition factor "*is influenced by age of fish, sex, season, stage of maturation, type of food consumed, amount of fat reserve and degree of muscular development*" (Barnham and Baxter, 1998). It allows us to compare the condition of individual fish within a population, individual fish from different populations, and two or more populations from different localities, as is the case in this study. A fish with a K-value above 1 is considered to be in good shape.

The **catch per unit effort (CPUE)** is an indirect measure of the abundance of a target species. It allows an easy reading for any reader and is then used widely in many different sectors.

Out of the 303 fish caught during the FishFAR project (part III.A), 167 were selected from the three lakes, among which 104 are from Leynavatn (67 AC and 37 BT). All were selected depending on the results of the ageing using scales proceded by Krista Veijonen, PhD student at the Aquaculture & Fish Biology department. About 70% of the BT have been aged via this method, but no AC as their scales were too fragile. All of the fish that could not be aged were automatically included along with some which were aged successfully to assert the comparison of the scales and otoliths ageing methods.

B. Otolith removal protocol

There are two methods to remove otoliths from a fish skull, each with its advantages and disadvantages. The required tools are gloves, a cutting board, a sharp knife, thin tweezers, plastic tubes, and 95% ethanol. If needed, it can also be useful to use a light, a magnifier and a hood to avoid bad smells from the fish and/or the ethanol.

First, the most common method consists in cutting off the top of the skull (figure 14). It allows access to the brain and to look for the otoliths located on each side of it (figure 15).

However, the Arctic charr otoliths are small, and it can be difficult for an inexperienced operator to find them, as it is not possible to directly see the otoliths with this method.

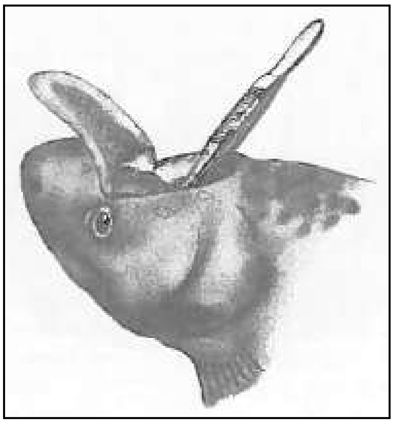

Figure 14: Cutting off the top of the fish skull (@Nunavik Ice, s.d.)

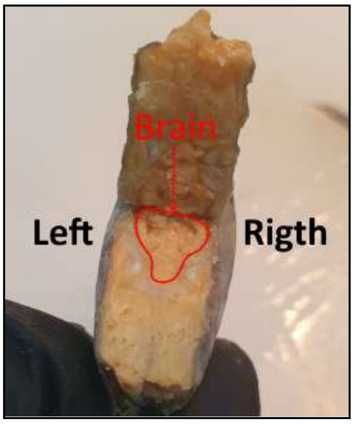

Figure 15: The fish brain from above (@S. Dehove, 2023)

The second method consists in cutting the back of the head, just behind the brain (figure 16). It allows direct access to the otoliths which are then easy to find as they are visible unlike the first method (figure 17).

However, it is difficult to cut the very right spot: if the first cut isn't close enough to the brain, the second cut can be very messy.

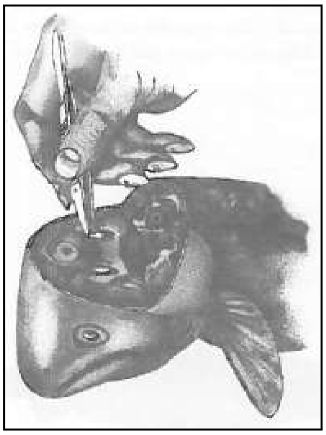

Figure 16: Cutting the back of the fish head (@Nunavik Ice, s.d.)

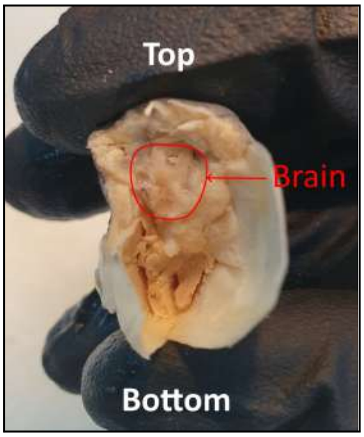

Figure 17: The fish brain from the back (@S. Dehove, 2023)

Whatever method is used, the otoliths are then cleaned of all residual tissue using ethanol and stored in plastic tubes with a label corresponding to the fish number. The tube is left opened for some time until the alcohol evaporates and then closed to avoid any otolith loss in case the tube falls. Finally, the number of otoliths found and any particular comment about the fish and/or the otoliths are written on a pre-prepared sheet (appendix 1).

C. Otolith photographing protocol

Once collected and cleaned, the otoliths were not readable yet. So they were soaked in 95% ethanol for 20 to 24 hours to dissolve the most external limestone layer and increase the clarity of the annuli. If immersion time exceeded ～28 hours, the readability sharply decreased as the annuli become too transparent. Each otolith pair was then placed in a petri dish filled with ethanol and photographed one by one using a Leika M165C stereomicroscope at a resolution of 1024 x 728 pixels, 2.0 magnification and a Leica MC170 HD camera (figure 18). A graph paper was placed underneath the petri dish so that the otoliths could later be measured by computer (part II.E). For each pair, three pictures were taken: left and right otoliths together, left otolith alone and right otolith alone. While taking photos, I also tried to count the annuli directly with the microscope.

Figure 18: The Leica M165C stereomicroscope (@S. Dehove, 2023)

D. Otolith and fish ageing protocol

Next, images were digitally enhanced with ImageJ® software through an unsharp mask filter using a radius of 20 pixels and mask weight of 0,6 (Tsinganis, 2016). When needed, brightness and contrast parameters were also adjusted manually. Figures 19 to 22 show the evolution of the image through the ImageJ® treatment and the ageing.

Figure 19: Raw otolith picture (@S. Dehove, 2023)

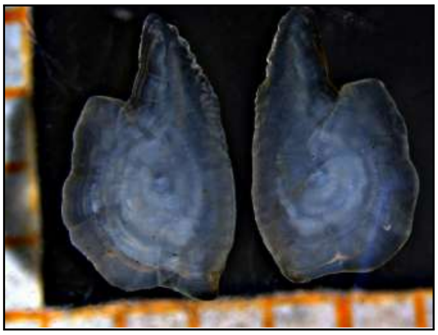

Figure 20: Picture with unsharp mask filter (@S. Dehove, 2023)

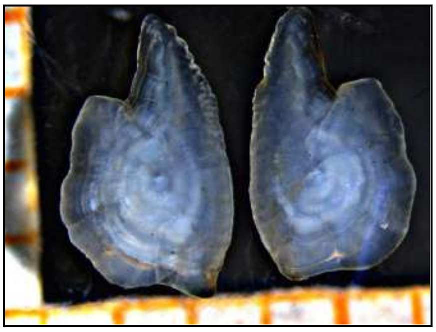

Figure 21: Picture with unsharp mask and brightness/contrast adjusted (@S. Dehove, 2023)

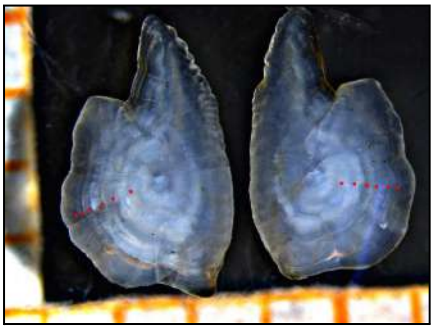

Figure 22: Aged otoliths (1 red dot = 1 year) (@S. Dehove, 2023)

In total, each otolith was aged three times

- Once under the microscope (see part II.C)
- Once using the pictures treated with ImageJ®
- Once using the pictures treated with ImageJ®, anonymised and randomised

The third reading was carried out to reduce the risk of any influence that might bias the results, that is why only images with a single otolith were used during this ageing stage, so that otoliths from the same pair were aged separately.

Finally, the age of the fish was assumed as follows:

- If 2 otoliths were found, at least 4 out of the 6 ageings had to produce the same result to assume the final age of the fish.
- If only 1 otolith was found, at least 2 out of the 3 ageings had to produce the same result to assume the final age of the fish.
- Otherwise, no conclusion was made.

III. Results

A. Fish population and biological data

In total, 303 fish were captured during summer 2022 including 67 Arctic charr and 234 Brown trout (table 2) along with 2 American eels in Saksunarvatn and 29 threespine sticklebacks in Toftavatn. 93% of the AC and BT were gendered successfully. In addition, 5 BT were found in the nets with the head missing and could consequently not be gendered. The 2022 CPUE was calculated using the formula described in part II.A, resulting in a CPUE of 5.4 for AC and 7.0 for BT in Leynavatn, 6.4 in Saksurnavatn and 5.0 in Toftavatn.

Table 2: Number of fish caught and sex ratio in 2022 (@S. Dehove, 2023)

Sex (number/%)	Leynavatn Arctic charr	Leynavatn Brown trout	Saksunarvatn Brown trout	Toftavatn Brown trout
Male	32 (48%)	50 (59%)	22 (30%)	28 (37%)
Female	32 (48%)	32 (38%)	44 (60%)	39 (51%)
Undetermined	3 (4%)	3 (3%)	7 (10%)	9 (12%)
TOTAL	67 (100%)	85 (100%)	73 (100%)	76 (100%)

When comparing this table to the 2000 data (table 3), it is very noticeable that much less fish were gendered: only 34% in total. 3 BT were found with the head missing in the net. The 2000 CPUE was also much lower in every lake, with 3.4 for AC and 1.3 for BT in Leynavatn, 5.0 in Saksurnavatn and 2.2 in Toftavatn.

Table 3: Number of fish caught and sex ratio in 2000 (@S. Dehove, 2023)

Sex (number/%)	Leynavatn Arctic charr	Leynavatn Brown trout	Saksunarvatn Brown trout	Toftavatn Brown trout
Male	22 (16%)	16 (32%)	30 (15%)	19 (48%)
Female	28 (20%)	23 (46%)	6 (3%)	21 (52%)
Undetermined	88 (64%)	11 (22%)	169 (82%)	0 (0%)
TOTAL	138 (100%)	50 (100%)	205 (100%)	40 (100%)

Once the fishing process completed, biological data such as fork length and body weight were registered following the data collection protocol described in part II.A (figures 23 and 24).

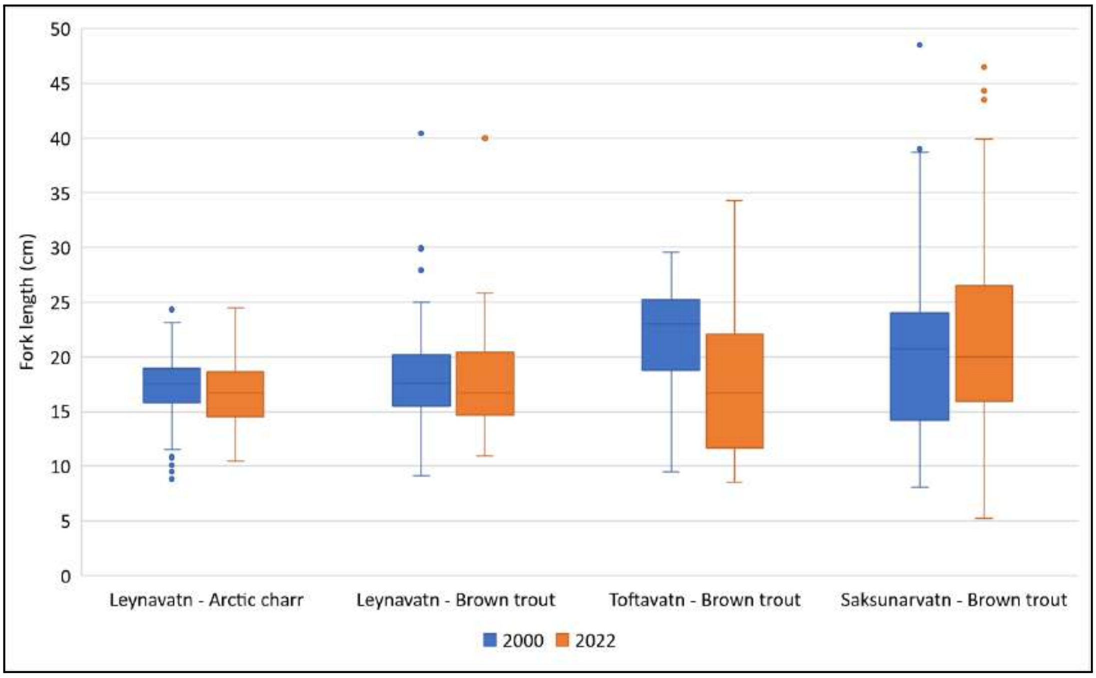

Figure 23: Fork length data (@S. Dehove, 2023)

Figure 23 shows that both AC and BT fork length range is generally greater in 2022 than in 2000. Mean and standard deviation were 17.3 ± 3.0 cm in 2000 and 16.6 ± 2.8 cm in 2022 for AC in Leynavatn, 18.0 ± 4.0 cm in 2000 and 17.7 ± 4.7 cm in 2022 for BT in Leynavatn, 21.4 ± 5.2 cm in 2000 and 17.8 ± 6.7 cm in 2022 for BT in Toftavatn and 19.8 ± 6.8 cm in 2000 and 22.3 ± 8.8 cm in 2022 for BT in Saksunarvatn.

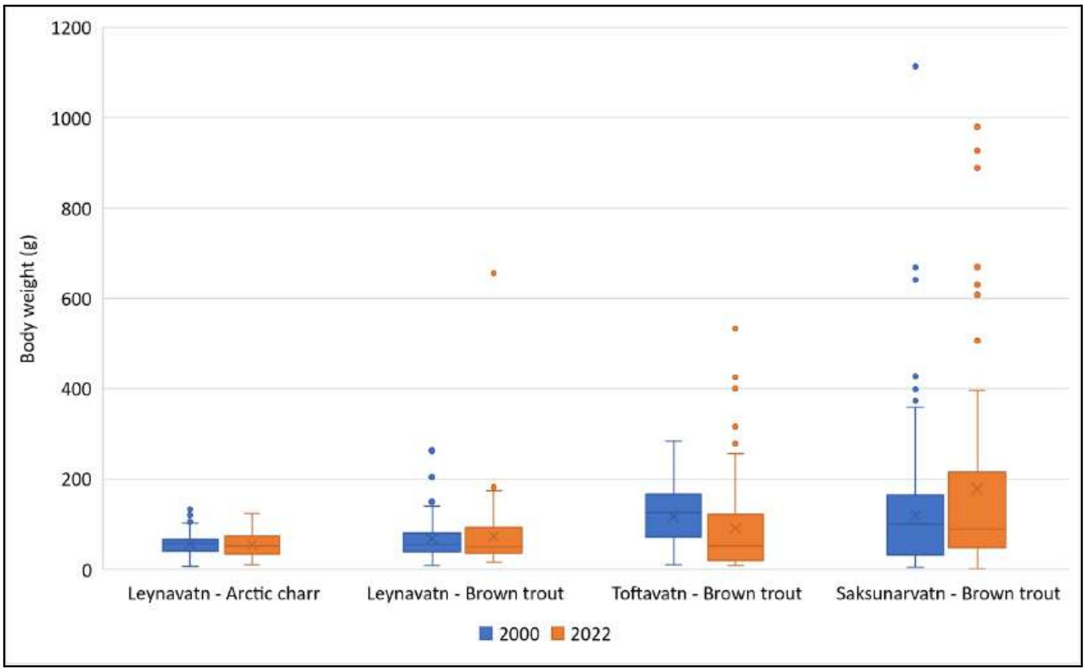

Figure 24: Body weight data (@S. Dehove, 2023)

On one hand, figure 24 shows that body weight range is greater for all lakes and species in 2022 but BT in Toftavatn. On the other hand, there are many more out-of-the-norm fish in that lake. Mean and standard deviation were 56.1 ± 24.4 g in 2000 and 54.2 ± 25.2 g in 2022 for AC in Leynavatn, 68.4 ± 47.2 in 2000 and 73.5 ± 79.9 g in 2022 for BT in Leynavatn, 116.9 ± 63.4 g in 2000 and 91.2 ± 104.9 g in 2022 for BT in Toftavatn, and 119.6 ± 122.2 g in 2000 and 179.5 ± 219.3 g in 2022 for BT in Saksunarvatn.

However, these two biological data alone are not enough to assert the robustness or well-being of the fish, that is why Fulton's condition factor was calculated for all the fish caught, except those which were either not gendered or decapitated in the net (figure 25).

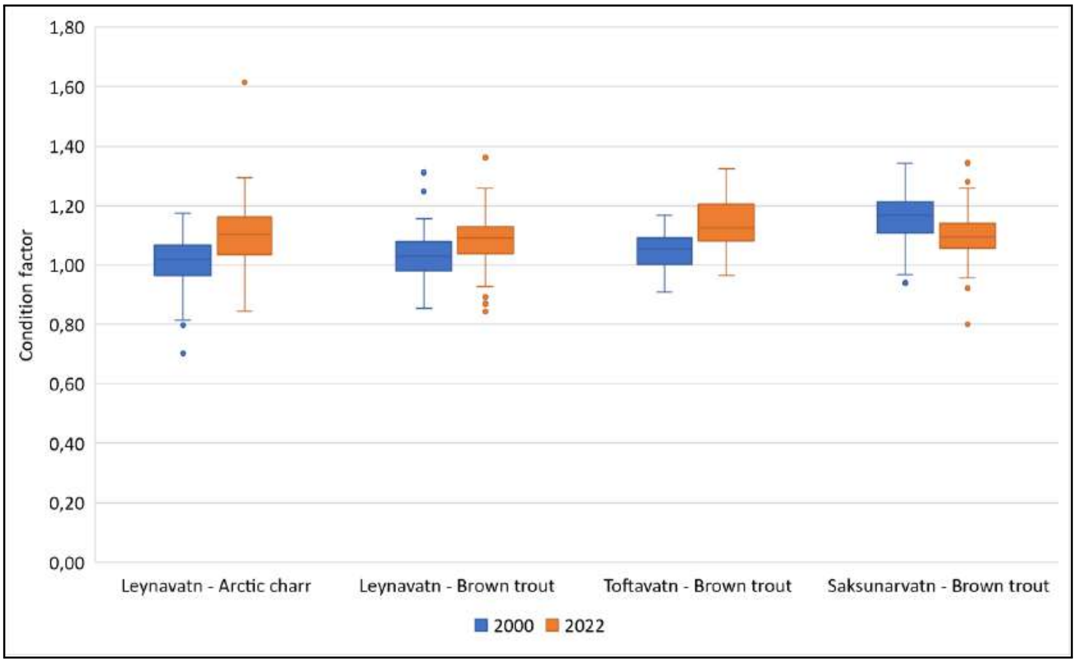

Figure 25: Condition factor data (@S. Dehove, 2023)

Figure 25 shows that the median condition factor is higher than 1 in every lake, and that it has increased since 2000 but in Saksunarvatn, proving the fish of the two species are physically doing well. Moreover AC have the lowest K-value mean and the highest standard deviation. Mean and standard deviation were 1.01 ± 0.08 in 2000 and 1.11 ± 0.11 in 2022 for AC in Leynavatn, 1.04 ± 0.09 in 2000 and 1.08 ± 0.08 in 2022 for BT in Leynavatn, 1.05 ± 0.06 in 2000 and 1.13 ± 0.11 for BT in Toftavatn, and 1.16 ± 0.08 in 2000 and 1.10 ± 0.08 for BT in Saksunarvatn.

B. Age to length relationship

Before starting the ageing process, I trained with otoliths that were aged with great certainty from a previous study working on Arctic charr from Norway. However, Faroese AC's otoliths revealed to be much thicker, thus they were harder to age, which forced me to adapt the initial ageing protocol to the one described in part II.D. Because of the time I spent figuring it out, I was unable to age fish from the three Faroese lakes and concentrated on ageing AC first (figures 26 and 27) and Leynavatn BT second (figure 28).

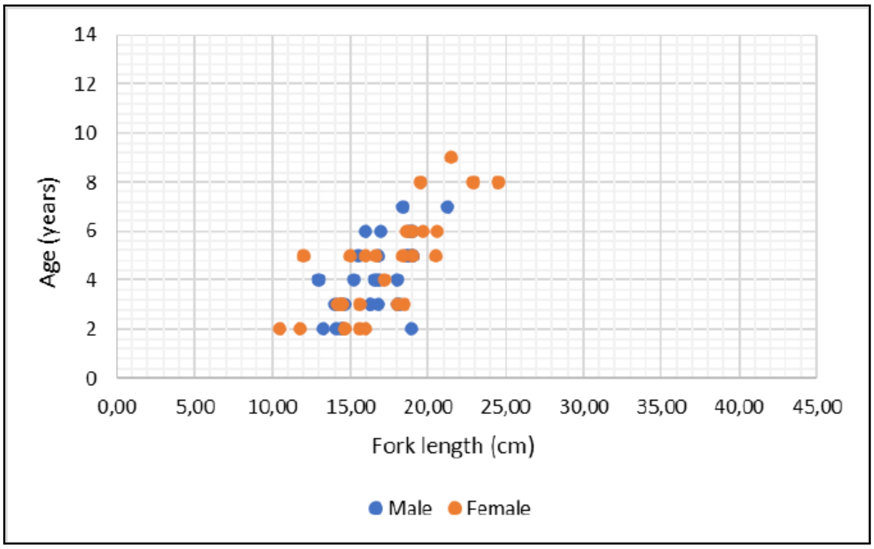

Figure 26: Arctic charr age to length relationship in 2022 (@S. Dehove, 2023)

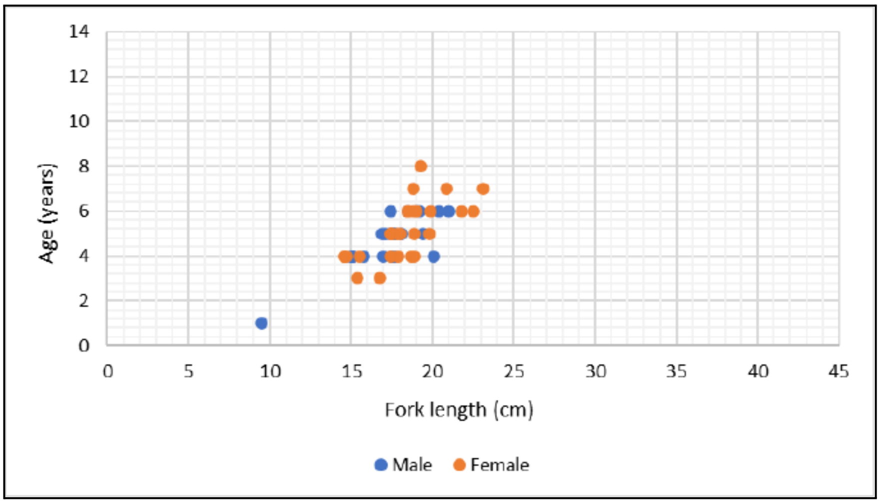

Figure 27: Arctic charr age to length relationship in 2000 (@S. Dehove, 2023)

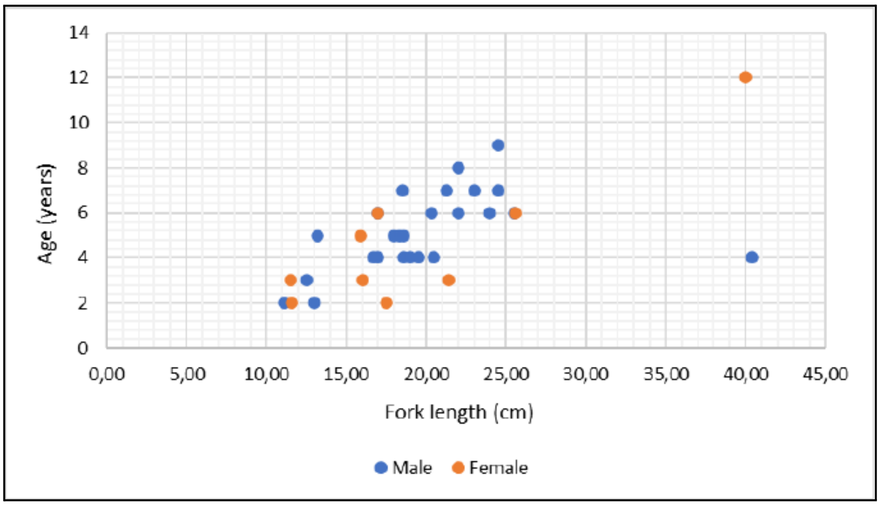

Figure 28: Brown trout age to length relationship (@S. Dehove, 2023)

All three figures seem to show a relationship between age and fork length for both species and both sex. Only one male Brown trout individual seems to be out of the norm, probably estimated younger than it really is: because of its age, its otoliths may have been too thick and may have distorted the age reading. However, figures 26 and 27 do not show any significant difference in the age to length relationship over the years for AC.

C. Changes in the relationship between age and length over time

As every other physiological condition, the age to length relationship can vary over time. That is why comparing this relationship between 2000 and 2022 is necessary for AC in Leynavatn (figure 28).

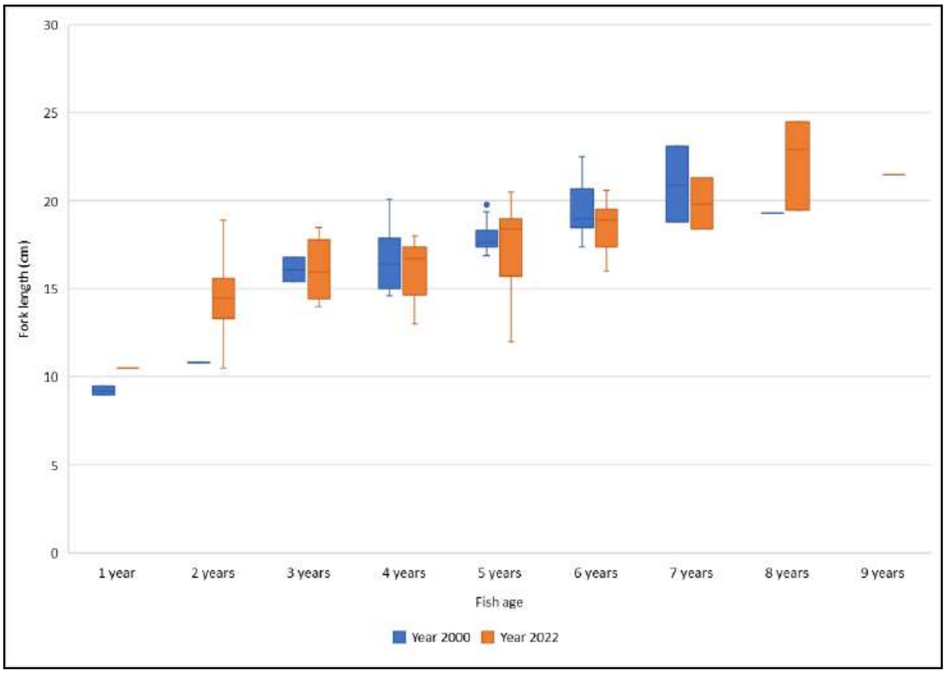

Figure 28: Comparison of Arctic charr age to length relationship (@S. Dehove, 2023)

No significant difference can be observed between 2000 and 2022 in figure 28, despite the difference in terms of number of fish for each age.

IV. Discussion

A. Discussion on the results

The Arctic charr population in Leynavatn has a very equitable sex ratio both in 2000 and 2022 while for Brown trout, more females were caught in this lake the two years. In Saksunarvatn and Toftavatn, more males BT were captured in 2022 while it was mostly equitable in 2000. Nevertheless, these imbalances are not very significant.

From 2000 to 2022, the **CPUE has increased for the two species in every lake**, showing the fish populations have increased over the years. The most interesting increase is the shift between AC CPUE and BT CPUE in Leynavatn: AC CPUE was higher in 2000 but is now lower in 2022. This shift shows that BT, which was introduced in the lake, is taking over AC in terms of fish population. Still, more AC were captured in 2022, showing that this species is not being eliminated by BT in this lake, but **cohabits with its competitor**.

At the same time, AC condition factor has increased along with the fish population while fork length and body weight have decreased. This can allow us to assert that **AC are more numerous and smaller but are doing relatively better than in 2000**. Even though BT are more numerous, a bit bigger and a bit larger in Leynavatn, their condition factor is similar: the two populations seem to have reached a good **balance**.

In the two other lakes, Toftavatn's BT's condition factor has greatly increased since 2000 while it decreased in Saksunarvatn. In fact, Saksunarvatn's BT have the greatest mean and standard deviation for both fork length and body weight, which highlights the **heterogeneity** of this population.

The age to length relationship could be used for comparison for AC only, as no BT was aged in 2000. Only one AC was aged at 9 years old, just one year older than the oldest AC aged in 2000. Thus, it is not possible to say that the AC population is either younger or older in 2022.

It is then possible to answer the two predictions made earlier (part I.C):
The 1st prediction was "*Brown trout is better adapted to warmer water than Arctic charr (Larsson, 2005). Thus, as water temperature in Faroese lakes has likely increased over the past 20 years, Brown trout will be favoured compared to Arctic charr when found in sympatry.*"

- **Yes, I can observe smaller Arctic charr than 20 years ago, but they are more numerous and it is not possible to conclude about the fish population's age.**
- **Yes, I can observe more and larger Brown trout than 20 years ago when found in sympatry, but it is not possible to conclude about the fish population's age.**
- **The age to length relationship is very similar for Arctic charr in 2000 and 2022 (figures 26 and 27) but it is not possible to conclude for Brown trout.**

The 2nd prediction was: "*As water temperature in Faroese lakes has likely increased over the last 20 years, Brown trout may also perform better when found in allopatry. Then, depending on food availability:*"

- **Yes, I can observe more and larger Brown trout than 20 years ago when found in allopatry, but it is not possible to conclude about the fish population's age.**
- **It is not possible to conclude about the Brown trout growth rate.**
- **It is not possible to conclude about the age to length relationship.**

B. Discussion on the methods

As described by Tsinganis (2016), errors in the ageing process generally take two forms:

- Errors that affect **accuracy**: the choice of the first annuli is a determining factor and has to be consistent within all ageings. In this study, the first annuli was considered to be the closest one to the middle of the otolith, but this was a choice of mine. Consequently, all age determinations were potentially wrong by a margin of +/- 1 year.
- Errors that affect **precision**: otoliths in this study seemed to be much thicker than some used for ageing training that came from lakes in Iceland, therefore they were harder to read.

In order to avoid as much as possible these two types or errors, another person doing the exact same manipulations as me would have been necessary, without any communication with each other, so that we could have compared our results in the end.

The 2000 data was not very detailed, mostly because very few fish were aged. It would have been possible to get better/more results if more fish were aged in 2000.

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VI. Appendices

Appendix 1: Data sheets used during the otolith removal, photographing and ageing.

Fish number	Species	Lake	Sex	Fork length (cm)	Weight (g)	Condition factor	Number of otoliths found	Otolith length (mm)		Magnification	Picture number of otoliths (FISHFAR-...)			Age of the fish (microscope)		Age of the fish (pictures) 1ST READING		Age of the fish (pictures) RANDOMISED		Final age of the fish	Age obtained with scales	Comments
								1	2		ALL	1	2	1	2	1	2	1	2			
FAR22-001	BT	TOF	F	28,00	237	1,08															4	
FAR22-012	BT	TOF	F	29,50	278	1,083															4	
FAR22-023	BT	TOF	F	20,10	86	1,059															3	
FAR22-024	BT	TOF	F	23,10	131	1,063															4	
FAR22-025	BT	TOF	F	20,00	89	1,113															4	
FAR22-027	BT	TOF	F	16,20	44	1,035															2	
FAR22-028	BT	TOF	F	25,00	166	1,062															4	
FAR22-032	BT	TOF	F	22,00	119	1,118															4	
FAR22-033	BT	TOF	F	21,20	101	1,06															4	
FAR22-036	BT	TOF	F	16,80	52	1,097															4	
FAR22-041	BT	TOF	F	27,00	199	1,011															4	
FAR22-049	BT	TOF	F	17,30	51	0,985															1	
FAR22-073	BT	TOF	F	34,00	425	1,081															6	
FAR22-074	BT	TOF	F	32,00	401	1,224															5	
FAR22-075	BT	TOF	F	34,30	534	1,323															6	
FAR22-010	BT	TOF	M	11,60	17	1,089	X	X	X	X	X	X	X	X	X	X	X	X	X	X	2	decapitated = no otoliths
FAR22-011	BT	TOF	M	26,80	195	1,013															4	
FAR22-013	BT	TOF	M	20,70	97	1,094															2	
FAR22-016	BT	TOF	M	15,60	16	0,421															3	
FAR22-022	BT	TOF	M	20,50	99	1,149															3	
FAR22-026	BT	TOF	M	25,70	166	0,978															5	
FAR22-042	BT	TOF	M	22,30	128	1,154															3	
FAR22-058	BT	TOF	M	24,50	171	1,163															3	
FAR22-062	BT	TOF	M	17,60	59	1,082															3	
FAR22-076	BT	TOF	M	19,00	81	1,181															3	
FAR22-034	BT	TOF	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	decapitated = no otoliths
FAR22-035	BT	TOF	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	decapitated = no otoliths
FAR22-048	BT	TOF	X	16,50	51	1,135															1	
FAR22-053	BT	TOF	X	13,00	25	1,138															2	
FAR22-077	BT	SAK	F	39,60	669	1,077															6	silvery, salmon, sea trout ?
FAR22-080	BT	SAK	F	30,60	385	1,344															6	
FAR22-081	BT	SAK	F	36,50	389	0,8															X	silvery
FAR22-082	BT	SAK	F	46,50	980	0,975															X	
FAR22-083	BT	SAK	F	29,00	266	1,091															7	
FAR22-089	BT	SAK	F	12,50	18	0,922															1	
FAR22-090	BT	SAK	F	17,00	56	1,14															4	

TOF = Toftavatn / LEY = Leynavatn / SAK = Saksunarvatn / ITR = Impossible To Read / X = Missing data / AC = Arctic charr / BT = Brown trout / Operator: Simon Dehove 05/23-07/23Page 1/5

FAR22-091	BT	SAK	F	36,00	507	1,087															X	
FAR22-092	BT	SAK	F	11,50	18	1,184															1	
FAR22-093	BT	SAK	F	22,90	138	1,149															X	
FAR22-094	BT	SAK	F	32,50	386	1,124															6	
FAR22-095	BT	SAK	F	10,80	14	1,111	2														1	
FAR22-096	BT	SAK	F	22,70	133	1,137	2														4	
FAR22-097	BT	SAK	F	29,30	276	1,097															6	
FAR22-100	BT	SAK	F	32,80	397	1,125															8	
FAR22-102	BT	SAK	F	25,40	161	0,982	2														4	
FAR22-113	BT	SAK	F	29,40	264	1,039	2														X	
FAR22-129	BT	SAK	F	17,70	62	1,118	2														X	
FAR22-136	BT	SAK	F	26,00	197	1,121															X	
FAR22-138	BT	SAK	F	16,40	47	1,066															X	
FAR22-140	BT	SAK	F	24,50	172	1,17															4	
FAR22-143	BT	SAK	F	19,20	77	1,088															X	
FAR22-144	BT	SAK	F	22,40	121	1,077															X	
FAR22-085	BT	SAK	M	25,80	212	1,234															5	
FAR22-098	BT	SAK	M	30,80	318	1,088	2														5	
FAR22-099	BT	SAK	M	21,50	125	1,258	2														X	
FAR22-101	BT	SAK	M	25,00	159	1,018	2														4	
FAR22-103	BT	SAK	M	16,5	51	1,135	2														X	
FAR22-120	BT	SAK	M	13,00	2	0,091	2														1	not on the initial list
FAR22-134	BT	SAK	M	19,30	82	1,141															X	
FAR22-139	BT	SAK	M	43,50	890	1,081															X	
FAR22-088	BT	SAK	X	13,00	21	0,956	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	decapitated = no otoliths
FAR22-108	BT	SAK	X	13,6	27	1,073															X	
FAR22-149	BT	SAK	X	5,20	1,58	1,124															X	
FAR22-168	AC	LEY	F	11,80	18	1,096	1			2.0	X	013	X	2	X	2	X	2	X	2	X	
FAR22-170	AC	LEY	F	18,00	60	1,029	2			2.0	115	116	117	6	7	5	5	6	6		X	
FAR22-178	AC	LEY	F	14,60	32	1,028	1			2.0	X	089	X	2	X	2	X	2	X	2	X	
FAR22-188	AC	LEY	F	18,60	74	1,15	2			2.0	028	029	030	7	7	6	6	6	6	6	X	
FAR22-191	AC	LEY	F	16,00	43	1,05	2			2.0	143	144	145	6	ITR	5	5	5	5	5	X	
FAR22-199	AC	LEY	F	10,50	13	1,123	2			2.0	058	059	060	2	2	2	2	2	2	2	X	
FAR22-203	AC	LEY	F	19,70	84	1,099	2			2.0	061	062	063	ITR	ITR	6	6	6	6	6	X	
FAR22-206	AC	LEY	F	19,50	83	1,119	2			2.0	093	094	095	8/9	8	8	8	8	7	8	X	Difficult to read
FAR22-209	AC	LEY	F	14,20	32	1,118	2			2.0	010	011	012	3	3	3	3	-	-	3	X	
FAR22-211	AC	LEY	F	12,00	19	1,1	2			2.0	055	056	057	3	3	5	5	5	5	5	X	
FAR22-213	AC	LEY	F	18,50	74	1,169	2			2.0	085	086	087	3	3	3	3	6	3	3	X	
FAR22-217	AC	LEY	F	24,50	124	0,843	2			2.0	155	156	157	11	8/9	8	8	8	8	8	X	Very large otoliths, difficult to read
FAR22-218	AC	LEY	F	22,90	124	1,033	2			2.0	109	110	111	8	ITR	8	ITR	8	7	8	X	Difficult to read
FAR22-219	AC	LEY	F	21,50	97	0,976	2			2.0	067	068	069	ITR	ITR	9	9	9	9	9	X	

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FAR22-220	AC	LEY	F	20,60	89	1,018	2			2.0	136	137	138	ITR	ITR	6	6	6	6	6	X	
FAR22-232	AC	LEY	F	20,50	100	1,161	1			2.0	X	099	X	7	X	5	X	5	X	5	X	
FAR22-234	AC	LEY	F	19	68	0,991	2			2.0	140	141	142	6	6	6	6	7	7	6	X	
FAR22-247	AC	LEY	F	14,50	32	1,05	2			2.0	176	177	178	2	2	3	3	3	3	3	X	
FAR22-249	AC	LEY	F	14,50	31	1,017	2			2.0	082	083	084	3	3	3	3	-	-	3	X	
FAR22-250	AC	LEY	F	18,40	64	1,027	2			2.0	118	119	120	5	5	5	5	ITR	5	5	X	
FAR22-252	AC	LEY	F	15,00	40	1,185	2			2.0	046	047	048	4/5	5	ITR	5	5	5	5	X	
FAR22-253	AC	LEY	F	19,00	76	1,108	2			2.0	040	041	042	5	5	6	5	6	5	5	X	
FAR22-258	AC	LEY	F	16,70	50	1,074	2			2.0	167	168	169	6	5	5	5	5	5	5	X	
FAR22-266	AC	LEY	F	15,60	39	1,027	2			2.0	001	002	003	2	2	2	2	-	-	2	X	
FAR22-268	AC	LEY	F	18,00	68	1,166	2			2.0	052	053	054	3	ITR	3	3	3	4	3	X	
FAR22-269	AC	LEY	F		29		2			2.0	158	159	160	5	5	4	4	4	4	4	X	
FAR22-271	AC	LEY	F	14,40	33	1,105	2			2.0	014	015	016	3	3	2	2	3	3	3	X	
FAR22-273	AC	LEY	F	16,00	43	1,05	2			2.0	034	035	036	ITR	ITR	2	2	4	2	2	X	
FAR22-278	AC	LEY	F	15,60	42	1,106	2			2.0	173	174	175	3	3	3	3	-	-	3	X	
FAR22-281	AC	LEY	F	15,5	42	1,128	2			2.0	025	026	027	4	3	4	2	4	3		X	
FAR22-284	AC	LEY	F	17,20	57	1,12	2			2.0	076	077	078	5	4	4	3	4	4	4	X	
FAR22-287	AC	LEY	F	14,60	35	1,125	1			2.0	X	020	X	2	X	2	X	-	X	2	X	
FAR22-177	AC	LEY	M	14,40	30	1,005	2			2.0	090	091	092	3	2	3	3	3	3	3	X	
FAR22-192	AC	LEY	M	18,70	78	1,193	2			2.0	124	125	126	4	4	5	5	5	5	5	X	
FAR22-193	AC	LEY	M	19,00	78	1,137	2			2.0	161	162	163	6	5	5	5	6	5	5	X	
FAR22-195	AC	LEY	M	18,00	72	1,235	2			2.0	164	165	166	6	4	4	4	6	4	4	X	
FAR22-197	AC	LEY	M	14,5	32	1,05	1			2.0	X	024	X	2	X	2	X	-	X	2	X	
FAR22-204	AC	LEY	M	17,00	60	1,221	2			2.0	133	134	135	ITR	6	ITR	5	ITR	6	6	X	Weird shape for otolith 1
FAR22-205	AC	LEY	M	16,30	54	1,247	2			2.0	004	005	006	3	3	3	3	5	3	3	X	
FAR22-207	AC	LEY	M	16,80	51	1,076	2			2.0	064	065	066	4/5	4	5	5	5	5	5	X	
FAR22-208	AC	LEY	M	15,50	44	1,182	2			2.0	112	113	114	5	5	5	5	5	5	5	X	
FAR22-214	AC	LEY	M	18,00	60	1,029	2			2.0	121	122	123	3	4	3	3	3	5	3	X	
FAR22-221	AC	LEY	M	21,30	89	0,921	2			2.0	127	128	129	7	7	6	6	7	7	7	X	Very large otoliths
FAR22-229	AC	LEY	M	18,80	72	1,084	1			2.0	X	139	X	ITR	X	6	X	6	X	6	X	
FAR22-230	AC	LEY	M	18,40	76	1,22	2			2.0	149	150	151	7	8	7	7	7	7	7	X	Otolith 2 broken
FAR22-235	AC	LEY	M	18,9	70	1,037	2			2.0	073	074	075	2	2	2	2	-	-	2	X	
FAR22-236	AC	LEY	M	18,60	68	1,057	2			2.0	130	131	132	6	6	5	5	5	5	5	X	2 otoliths broken
FAR22-242	AC	LEY	M	19,00	74	1,079	2			2.0	043	044	045	6/7	6/7	6	6	6	6	6	X	
FAR22-243	AC	LEY	M	14,50	38	1,246	2			2.0	170	171	172	2	2	2	2	-	-	2	X	
FAR22-244	AC	LEY	M	15,10	38	1,104	2			2.0	079	080	081	2	ITR	2	2	3	3		X	
FAR22-246	AC	LEY	M	14,30	28	0,958	X	X	X	X	X	X	X	X	X	X	X	X	X		X	Could not reidentify based on pictures and loose heads in buckets
FAR22-254	AC	LEY	M	14,00	31	1,13	2			2.0	049	050	051	3	3	3	3	-	-	3	X	
FAR22-255	AC	LEY	M	14,10	29	1,035	2			2.0	088	089	179	2	2	2	2	-	-	2	X	
FAR22-256	AC	LEY	M	13,00	23	1,047	2			2.0	146	147	148	4	4	4	4	-	-	4	X	
FAR22-257	AC	LEY	M	16,30	47	1,085	2			2.0	152	153	154	4	4	3	3	3	3	3	X	

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FAR22-260	AC	LEY	M	16,80	57	1,202	2			2.0	037	038	039	ITR	ITR	4	4	4	4	4	X	
FAR22-263	AC	LEY	M	13,30	38	1,615	2			2.0	096	097	098	2	2	2	2	3	3	2	X	
FAR22-264	AC	LEY	M	14,60	33	1,06	2			2.0	103	104	105	3	3	3	3	-	-	3	X	
FAR22-265	AC	LEY	M	15,20	39	1,111	2			2.0	031	032	033	4	4	4	4	-	-	4	X	
FAR22-267	AC	LEY	M	18,20	77	1,277	2			2.0	007	008	009	3	ITR	3	ITR	3	6	3	X	
FAR22-272	AC	LEY	M	16,80	56	1,181	2			2.0	021	022	023	3	3	3	3	-	-	3	X	
FAR22-276	AC	LEY	M	19,00	87	1,268	2			2.0	017	018	019	5	5	5	5	-	-	5	X	
FAR22-280	AC	LEY	M	16,6	51	1,115	2			2.0	100	101	102	5	5	4	4	4	4	4	X	
FAR22-297	AC	LEY	M	16,00	53	1,294	2			2.0	179	180	181	4	4	6	6	6	6	6	X	
FAR22-198	AC	LEY	X	12	17	0,984	X	X	X	X	X	X	X	X	X	X	X	X	X		X	Could not reidentify based on pictures and loose heads in buckets
FAR22-200	AC	LEY	X	10,50	11	0,95	2			2.0	070	071	072	1/2	1/2	1	1	1	1	1	X	
FAR22-282	AC	LEY	X	17,20	57	1,12	2			2.0	106	107	108	2	2	3	3	3	3	3	X	
FAR22-161	BT	LEY	F	21,40	95	0,969	2			2.0	206	207	208	3	3	3	3	3	3	3	X	
FAR22-166	BT	LEY	F	11,60	19	1,217	2			2.0	218	219	220	2	2	2	2	-	-	2	1	
FAR22-175	BT	LEY	F	16,00	38	0,928	2			2.0	228	229	230	3	3	3	4	3	4	3	X	
FAR22-181	BT	LEY	F	17,50	59	1,101	1			2.0	X	232	X	3	X	2	X	2	X	2	X	
FAR22-184	BT	LEY	F	11,50	19	1,249	2			2.0	233	234	235	3	3	3	3	3	3	3	X	
FAR22-210	BT	LEY	F	25,60	174	1,037	2			2.0	242	243	244	ITR	ITR	6	6	6	6	6	X	2nd otolith broken
FAR22-231	BT	LEY	F	17,00	50	1,018	2			2.0	272	273	274	5	6	6	6	6	6	6	X	
FAR22-240	BT	LEY	F	15,90	42	1,045	2			2.0	284	285	286	5	5	5	5	6	6	5	X	
FAR22-241	BT	LEY	F	40,00	656	1,025	2			1.6	287	288	289	ITR	11	12	12	12	12	12	X	Huge otoliths
FAR22-153	BT	LEY	M	19,50	86	1,16	2			2.0	203	204	205	ITR	4	4	4	-	-	4	3	
FAR22-162	BT	LEY	M	13,20	26	1,13	2			2.0	209	210	211	4	4	5	5	5	5	5	1	
FAR22-164	BT	LEY	M	18,60	66	1,026	2			2.0	212	213	214	5	4	4	4	4	6	4	3	
FAR22-165	BT	LEY	M	40,40	34	0,052	2			2.0	215	216	217	4	4	4	4	-	-	4	2	
FAR22-167	BT	LEY	M	12,50	23	1,178	1			2.0	X	221	X	X	3	X	3	X	-	3	X	Otolith broken
FAR22-169	BT	LEY	M	20,50	90	1,045	2			2.0	222	223	224	4	4	4	4	-	-	4	X	2nd otolith damaged
FAR22-173	BT	LEY	M	13,00	24	1,092	2			2.0	225	226	227	2	2	2	2	3	3	2	1	
FAR22-180	BT	LEY	M	11,10	15	1,097	1			2.0	X	231	X	2	X	2	X	2	X	2	X	
FAR22-194	BT	LEY	M	18,00	71	1,217	2			2.0	236	237	238	5	5	5	5	-	-	5	X	
FAR22-202	BT	LEY	M	24,00	159	1,15	2			2.0	239	240	241	6	6	6	6	7	7	6	X	
FAR22-215	BT	LEY	M	25,50	189	1,14	2			2.0	245	246	247	ITR	5/6	6	6	6	6	6	5	
FAR22-216	BT	LEY	M	18,30	63	1,028	2			2.0	248	249	250	4	4	5	5	5	5	5	X	
FAR22-222	BT	LEY	M	18,50	67	1,058	2			2.0	251	252	253	7	5	7	5	7	ITR	7	4	
FAR22-223	BT	LEY	M	17,00	55	1,119	2			2.0	254	255	256	6	6	6	6	5	6	6	4	
FAR22-224	BT	LEY	M	22,00	124	1,165	2			2.0	257	258	259	5	5	6	6	6	6	6	X	
FAR22-225	BT	LEY	M	17,00	58	1,181	2			2.0	260	261	262	4	4	4	4	4	4	4	X	
FAR22-226	BT	LEY	M	24,50	171	1,163	2			1.6	263	264	265	8	8	9	9	9	9	9	X	Very large otoliths
FAR22-227	BT	LEY	M	24,50	163	1,108	2			2.0	266	267	268	8	ITR	7	7	7	7	7	X	2nd otolith is dirty/yellow
FAR22-228	BT	LEY	M	18,60	65	1,01	2			2.0	269	270	271	5	5	6	6	5	5	5	X	
FAR22-233	BT	LEY	M	19,00	67	0,977	2			2.0	275	276	277	4	4	4	4	4	6	4	3	

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FAR22-237	BT	LEY	M	13,20	24	1,043	2			2.0	278	279	280	4	ITR	4	ITR	5	ITR		2	
FAR22-238	BT	LEY	M	20,30	94	1,124	2			2.0	281	282	283	7	6	6	6	7	6	6	4	
FAR22-270	BT	LEY	M	16,70	45	0,966	2			2.0	200	201	202	4	3	4	4	4	4	4	1	
FAR22-290	BT	LEY	M	23,00	145	1,192	2			2.0	290	291	292	8	7	7	7	8	7	7	X	
FAR22-292	BT	LEY	M	23,50	139	1,071	2			2.0	293	294	295	7	ITR	8	7	8	8		X	
FAR22-294	BT	LEY	M	22,00	114	1,071	2			2.0	296	297	298	6	6	8	8	8	8	8	X	
FAR22-296	BT	LEY	M	21,30	107	1,107	2			2.0	299	300	301	6	7	7	7	6	7	7	X	
FAR22-300	BT	LEY	X	18,00	52	0,892	2			2.0	305	306	307	5	5	6	6	5	5	5	X	

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Page - Description	Comlumn	Meaning	Color code - why?	Color categories
Data **Page used for the otolith ageing process** Empty cells in this color are like X, but empty in order to use the data to make graphs	fish number	FishFAR number	YES For the ageing through randomisation	Aged successfully with the 2 first ageings:> not included in the randomisation process Aged successfully with the 2 first ageings -> still included in the randomisation process Not aged successfully with the 2 first ageings -> included in the randomisation process Fish not found in buckets
	species	Fish species	YES To visual identify BT/AC	BT: Brown trout AC: Arctic charr
	Sex	Fish sex	YES To visually identify males/females/unknown	M: Males F: Females X: Unknown
	Fork length	Fish fork length (in cm), extracted from the page "FishFAR"	YES To visually identify missing data	X: Missing data
	Weight	Fish weight (in g), extracted from the page "FishFAR"	YES To visually identify missing data	X: Missing data
	Condition factor	Fish condition factor, calculated as follow: (100*LENGTH)/(WEIGHT^3)	YES To visually identify missing data	X: Missing data:> also means either length or weight is missing
	Number of otoliths found	Number of otoliths found in the fish head	YES To visually identify missing data	X: No otolith found -> means the head was missing (fish decapitated or not found)
	Otolith length	Otolith length 1: From rostrum to opposite edge, through the middle 2: From rostrum to middle	YES To visually identify missing data	X: No data -> either no otolith found or otolith broken
	Magnification	Magnification used to take otolith picture with the microscope	YES To visually identify missing data	X: Missing data no picture because no otolith
	Picture number of otoliths	Picture number of otoliths Begins with "FISHFAR-" + number All: Number of the picture with the two otoliths 1: Number of the picture with the left otolith 2: Number of the picture with the right otolith	YES To visually identify missing data	X: No picture taken -> only 1 otolith found means only 1 picture was taken instead of 3
	Age of the fish (microscope)	Age of the fish assessed visually using the microscope at the time as when otolith pictures were taken	YES To visually identify missing data	X: No age -> no picture ITR: The otolith was "Impossible To Read"
	Age of the fish (pictures) 1ST READING	Age of the fish assessed by counting the annuli on the treated otolith pictures	YES To visually identify missing data	X: No age -> no picture ITR: The otolith was "Impossible To Read"
	Age of the fish (pictures) RANDOMISED	Age of the fish assessed by counting the annuli on the treated otolith pictures during the randomisation process	YES To visually identify missing data	X: No age -> no picture ITR: The otolith was "Impossible To Read" - : No age -> didn't go through the randomisation process (not needed)
	Final age of the fish	Final age of the fish, assessed as follow: - If 2 otoliths were found, at least 4 out of the 6 ageings had to produce the same result to assume the final age of the fish. - If only 1 otolith was found, at least 2 out of the 3 ageings had to produce the same result to assume the final age of the	YES To visually identify missing data	X: No age -> no otolith found
	Age obtained with scales	Age of the fish assessed by using the fish scales (done by Krista) Extracted from the page "Scale ageing"	YES To visually identify missing data	X: No age -> Could not assess the fish age using the scales
	Comments	Comments	NO	

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Variation in age to length relationship in Arctic charr (Salvelinus alpinus) from Lake Leynavatn, Faroe Islands

Simon DEHOVE
2022-2023

Abstract:

The Arctic charr (*Salvelinus alpinus*) is a salmonid species found in the most northerly ecosystems: lakes, rivers and sometimes even the sea. As a result of global warming, Arctic char populations are threatened by a number of factors, including rising water temperatures and the colonisation of their habitat by competing species such as brown trout (*Salmo trutta*). The Faroe Islands contain a few untouched areas where Brown trout have been introduced into Arctic charr habitat, providing an invaluable opportunity to study how the two species cohabit and interact. In order to determine whether this allopatric relationship is beneficial or not, lakes in the Faroe Islands were sampled and the fish were aged in order to study the relationship between age and length, a key factor in assessing the sustainability of Arctic char populations in the Faroe Islands.

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