Arctic charr *(Salvelinus alpinus)* distribution in seawater cages in relation to environmental conditions

A. Ratsimandresy[1], D. Hamoutene[1], C. Lang[1], C. MacSween[1], K. Marshall[1], S. Kenny[1], B. Kealey[2], and J. Kealey[2]

[1]Science Branch, Newfoundland and Labrador Region
Fisheries and Oceans Canada,
Northwest Atlantic Fisheries Centre,
80 East White Hills Road,
St. John's, NL, Canada A1C 5X1

[2]Nordic Salmon Co. Inc.
PO Box 358,
St. Alban's, NL, Canada A0H 3E0

2017

Canadian Technical Report of Fisheries and Aquatic Sciences 3203

Fisheries and Oceans Canada | Pêches et Océans Canada

Canada

Canadian Technical Report of Fisheries and Aquatic Sciences

Technical reports contain scientific and technical information that contributes to existing knowledge but which is not normally appropriate for primary literature. Technical reports are directed primarily toward a worldwide audience and have an international distribution. No restriction is placed on subject matter and the series reflects the broad interests and policies of Fisheries and Oceans Canada, namely, fisheries and aquatic sciences.

Technical reports may be cited as full publications. The correct citation appears above the abstract of each report. Each report is abstracted in the data base *Aquatic Sciences and Fisheries Abstracts*.

Technical reports are produced regionally but are numbered nationally. Requests for individual reports will be filled by the issuing establishment listed on the front cover and title page.

Numbers 1-456 in this series were issued as Technical Reports of the Fisheries Research Board of Canada. Numbers 457-714 were issued as Department of the Environment, Fisheries and Marine Service, Research and Development Directorate Technical Reports. Numbers 715-924 were issued as Department of Fisheries and Environment, Fisheries and Marine Service Technical Reports. The current series name was changed with report number 925.

Rapport technique canadien des sciences halieutiques et aquatiques

Les rapports techniques contiennent des renseignements scientifiques et techniques qui constituent une contribution aux connaissances actuelles, mais qui ne sont pas normalement appropriés pour la publication dans un journal scientifique. Les rapports techniques sont destinés essentiellement à un public international et ils sont distribués à cet échelon. Il n'y a aucune restriction quant au sujet; de fait, la série reflète la vaste gamme des intérêts et des politiques de Pêches et Océans Canada, c'est-à-dire les sciences halieutiques et aquatiques.

Les rapports techniques peuvent être cités comme des publications à part entière. Le titre exact figure au-dessus du résumé de chaque rapport. Les rapports techniques sont résumés dans la base de données *Résumés des sciences aquatiques et halieutiques.*

Les rapports techniques sont produits à l'échelon régional, mais numérotés à l'échelon national. Les demandes de rapports seront satisfaites par l'établissement auteur dont le nom figure sur la couverture et la page du titre.

Les numéros 1 à 456 de cette série ont été publiés à titre de Rapports techniques de l'Office des recherches sur les pêcheries du Canada. Les numéros 457 à 714 sont parus à titre de Rapports techniques de la Direction générale de la recherche et du développement, Service des pêches et de la mer, ministère de l'Environnement. Les numéros 715 à 924 ont été publiés à titre de Rapports techniques du Service des pêches et de la mer, ministère des Pêches et de l'Environnement. Le nom actuel de la série a été établi lors de la parution du numéro 925.

Canadian Technical Report of Fisheries and Aquatic Sciences 3203

2017

Arctic charr *(Salvelinus alpinus)* distribution in seawater cages in relation to environmental conditions

by

A. Ratsimandresy[1], D. Hamoutene[1], C. Lang[1], C. MacSween[1], K. Marshall[1], S. Kenny[1], B. Kealey[2], and J. Kealey[2]

[1]Science Branch, NL Region
Fisheries and Oceans Canada
PO Box 5667
St. John's, NL, Canada A1C 5X1

[2]Nordic Salmon Co. Inc.
PO Box 358,
St Alban's, NL, Canada A0H 3E0

Cat. No. Fs97-6/3203E-PDF ISBN 978-0-660-07677-5 ISSN 1488-5379

Correct citation for this publication:

Ratsimandresy, A., Hamoutene, D., Lang, C, MacSween, C., Marshall, K., Kenny, S., Kealey, B., and Kealey, J. 2017. Arctic charr (*Salvelinus alpinus*) distribution in seawater cages in relation to environmental conditions. Can. Tech. Rep. Fish. Aquat. Sci. Fs97-6/3203E-PDF: vi + 20 p.

TABLE OF CONTENTS

TABLE OF FIGURES

ABSTRACT

Ratsimandresy, A.W., Hamoutene, D., Lang, C, A.W., MacSween, C., Marshall, K., Kenny, S., Kealey, B., and Kealey, J. 2017. Arctic charr (*Salvelinus alpinus*) distribution in seawater cages in relation to environmental conditions. Can. Tech. Rep. Fish. Aquat. Sci. Fs97-6/3203E-PDF: vi + 20 p.

The aim of this study is to use Arctic charr distribution in two commercial sea cages in relation to spatial and temporal variations in environmental factors to infer preferred environmental conditions of two farmed strains: a Labrador strain (LAB) and a hybrid strain between Tree Rivers and Nauyuk Lake, Nunavut (NU), Canada. Our results show that neither strain exhibits a strong diel rhythm but both display preferences in temperature and salinity. Results suggest a range of preferred temperatures from 12 to 16 °C for the NU strain and 10 to 14 °C for the LAB strain. Salinity preferences found in this study are bimodal for the LAB strain (30% of maximum observed fish densities at 20-31 and 40% at 5-10) but had only one preferred mode for the NU strain (50% at 20-31). Our results suggest a more conservative behaviour of the NU strain when choosing environmental conditions as they appear to show less flexibility in their choice of conditions in comparison to the LAB strain.

RÉSUMÉ

L'objectif de cette étude est d'utiliser la distribution spatiale et temporelle de deux souches d'omble chevalier d'élevage en fonction de facteurs environnementaux dans deux cages marines commerciales pour en conclure les conditions environnementales de prédilection. Les poissons d'élevage viennent d'une souche provenant du Labrador (LAB) et d'une souche hybride provenant de Tree River et de Nauyuk Lake (NU) au Nunavut (Canada). Nos résultats indiquent qu'aucune des deux souches ne présente un comportement diurne, mais que les deux montrent des préférences en matière de température et de salinité. Les poissons NU montrent une préférence en température entre 12 et 16°C et les LAB entre 10 et 14°C. Les préférences en salinité constatées au cours de cette étude sont bimodales pour les LAB (avec 30% des observations de densités maximales de poissons se produisant entre 20 et 31 et 40% entre 5 et 10) et en un seul mode pour les NU (50% des observations des densités maximales de poissons se produisant entre 20 et 31). Nos résultats suggèrent un comportement plus modéré de la part des NU au moment de choisir les conditions environnementales puisqu'elles semblent faire preuve de moins de souplesse dans leur choix de conditions en comparaison avec ceux des LAB.

INTRODUCTION

Arctic charr has been identified as a potential alternative species for sea cage culture in Northern Europe and North America (Jobling et al. 1993; Johnston 2002), including Canada (Delabbio 1995; Le François et al. 2002; Chiasson et al. 2014). With respect to temperature, Arctic charr tolerance ranges from 0 to 24 °C (Lyttikäinen et al. 1997; Thyrel et al. 1999; Johnston 2002) with preferences between 10 and 12 °C (Sæther et al. 2016 and references therein). For salinity, they can tolerate a large range of salinity from freshwater to full-strength seawater (Sæther et al. 2016 and references therein). Most of the Arctic charr being cultured in Canada originate from the Fraser River in Labrador, Nauyuk Lake and the Tree River system in Nunavut (de March and Baker 1990; de March 1991). Initial seawater trials completed in Bay d'Espoir, Newfoundland (Canada) in 2008 showed that two Arctic charr strains (the Nauyuk Lake strain and the Fraser River Labrador strain) survive and can grow in seawater despite Atlantic Canada's harsh winter and Bay d'Espoir's high surface water summer temperatures. A drawback of growing Arctic charr in sea cages is their poor performance during overwintering in seawater, which has been related to seasonal changes in their osmoregulatory capacity (Wandsvik and Jobling 1982b; Finstad et al. 1989; Arnesen et al. 1993). Despite this problem, the production of Arctic charr in marine conditions is thought to have potential (Heasman and Black 1998; Sæther et al. 2013); however, there is little scientific information available to aid the development of marine aquaculture of this species in the Newfoundland region. Differences between strains of Arctic charr have been documented in the literature. In particular, dissimilarities in osmoregulatory capacity (Delabbio et al. 1990; Jørgensen and Arnesen 2002), oxygen consumption (Giles 1991), as well as growth characteristics (de March 1997) influence how different strains perform in seawater.

Bay d'Espoir, the location of the present study, is a fjord estuary of approximately 185 km^2 located on the south coast of Newfoundland, Canada. The fluctuating physical characteristics of the water column (e.g. salinity and temperature) present a physiological challenge to farmed salmonids reared in sea cages and is also an incentive for farmers to undertake considerable planning for farm selection and evaluation of alternative strains/species well suited for these conditions (Sutterlin and Stevens 1992; Pepper et al. 2003). A stratified environment can provide a temperature-salinity gradient wherein the fish can select optimum conditions at smolt entry (Sutterlin and Stevens 1992) by choosing between different chemophysical habitats (Dempson and Kristofferson 1987; Oppedal et al. 2001; Johansson et al. 2006). In this report, we document the vertical distribution within a stratified sea cage environment of Arctic charr from the Labrador strain (LAB) and a hybrid strain between Tree Rivers and Nauyuk Lake, Nunavut (NU), Canada. A similar study was conducted by Sutterlin and Stevens (1992) comparing rainbow trout and Arctic charr (strain was not identified) using implanted acoustic tags. Sutterlin and Stevens (1992) examined temperature preferences using 6 individuals of each species during a five day

period in early summer but did not identify constraints in preference due to interactions between salinity, depth and temperature. In the present study, temporal variation of environmental factors (salinity and temperature) as well as feeding times and diel cycles are analyzed with fish vertical distribution, to identify preferred environmental conditions and cage behaviour patterns of Arctic charr.

MATERIAL AND METHODS

CAGE DESCRIPTION AND ENVIRONMENTAL MONITORING

This study was conducted at one marine aquaculture site located at Jersey Cove, Newfoundland, Canada (47º 51' N, 55º 49' W) (Figure 1) comprised of two Arctic charr cages and a small raft. Both cages had a circumference of 60 m and a depth of 9 m in a location with water depths around 20 m. Both cages were stocked (prior to the initiation of this project) with Arctic charr fingerlings purchased from a charr hatchery (North River Fish Farms, Nova Scotia, Canada). Each cage had one strain of Arctic Charr; cage 1 was stocked with the Labrador strain while cage 2 contained the Nunavut hybrid strain. For the present study, the fish distribution was monitored for a period of 46 days from September 8th to October 23rd, 2010 with 18 days of data not used due to probe malfunction. The LAB cage was stocked with ~14,300 fish (stocking density: 3.6 to 6.7 kg m^{-3}) with an average weight of ~470 g in August growing to ~1,250 g in October. The NU cage was stocked with ~20,600 fish (stocking density: 1.3 to 3.7 kg m^{-3}) with fish of an average weight of ~233 g in August growing to ~467 g in October. Environmental conditions in each cage were monitored using YSI® 6600 V2 Series sondes (YSI Incorporated, Yellow Springs, Ohio, USA) during the summer and fall of 2010 (from August to November). The sondes were deployed at the inside periphery of the two cages at three different depths; shallow (S1); middle (S2); and deep (S3). The collected environmental data included water temperature (°C), salinity (measured using Practical Salinity Scale), pH, chlorophyll (µg L^{-1}), and dissolved oxygen (DO, %). The LAB cage was monitored at depths of (S1) 1.3, (S2) 4.7, and (S3) 6.3 m while the NU cage was monitored at (S1) 1.5, (S2) 4.7, and (S3) 6.3 m depth. Fish were fed two meals per day; between 8:00 and 9:00 am for the morning feed and around 4:00 pm for the afternoon feed though times did vary when environmental conditions limited access to the cage site. Feeding rate during this study ranged from a mean rate of 4.9 kg feed tonne biomass^{-1} day^{-1} for LAB to 8.7 kg feed tonne biomass^{-1} day^{-1} for the NU hybrid strain. The average fish yearly mortality was ~1.4% for the LAB strain and ~0.5% for the NU hybrid strain.

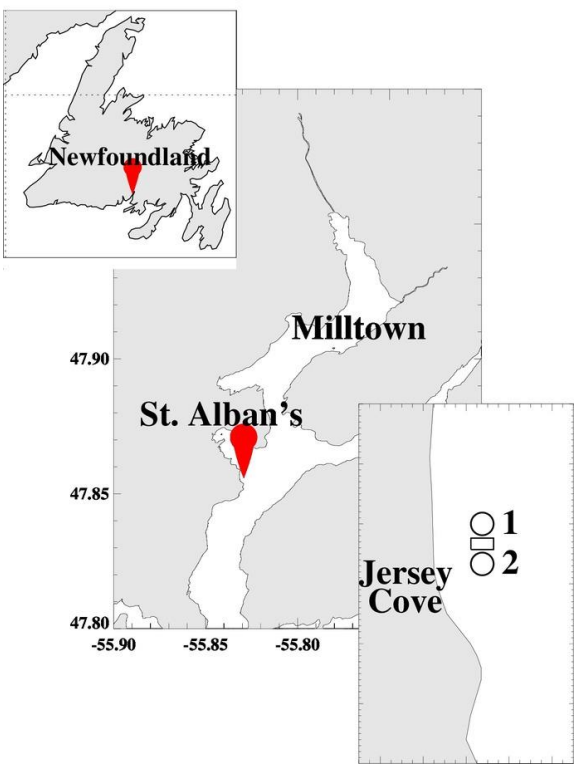

Figure 1: Location of cages at the site in Jersey Cove. Cage 1 with Labrador strain and cage 2 with Nunavut hybrid strain Arctic charr.

HYDROACOUSTIC MONITORING

Hydroacoustic monitoring was used to characterize the temporal variation of the vertical distribution of Arctic charr. Monitoring was conducted simultaneously at both cages during September and October 2010. A Simrad ES-60 echosounder (Simrad AS, Horten, Norway) was deployed with two "38/200 Combi W" transducers (23° conical beam aperture) in a downward-looking configuration operating at an acoustic frequency of 200 kHz. The transducers were located within the cages at a single fixed position between the edge and centre of the cage at a depth of 1.0 m. The cone volume sampled by the echosounder represents 1.1% of the cage volume (Figure 2). Using Echoview software (Myriax Pty Ltd., Hobart, Australia), measurements were converted to volume backscatter units (m^2 m^{-3}) expressed in decibels (dB). Background noise was removed by applying a range-adjusted threshold of -90 dB at 1 m and data outside the depth range of 1.3-11.0 m was removed. The water volume contributing to each original measurement (the propagating ensonified shell) had a thickness of about 0.1 m (comparable to the vertical extent of one fish) and a diameter that increases linearly with depth; reaching a maximum diameter of about 3.6 m at a depth of 10.0 m. This arrangement ensures that the number of fish (swim bladders) in each backscatter measurement is relatively low and facilitates the inference of fish density from the statistical analyses of the measurements. Subsequently, these data were averaged in bins (cells) of 0.1 m

depth by 30 seconds duration in order to generate a more manageable dataset for visualization (echograms) and further processing and analysis.

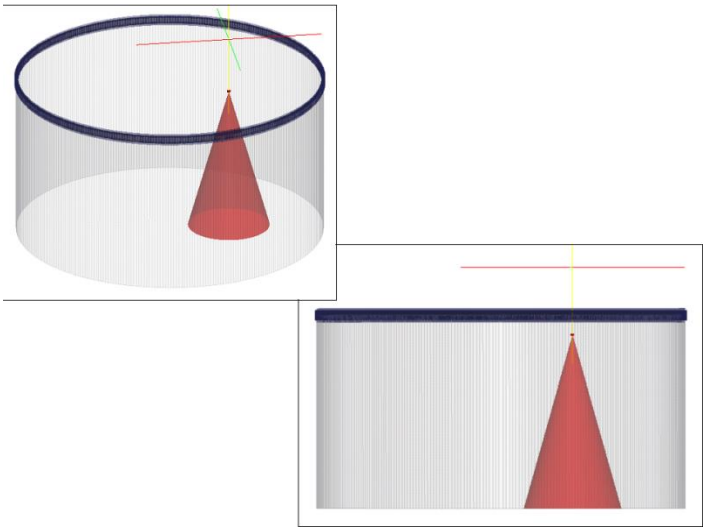

Figure 2: Representation (to scale) of the cone volume sampled by the echosounder as located in the cage. The transducers were located within the cages at a single fixed position between the edge and centre of the cage at a depth of 1.0 m.

STATISTICAL ANALYSES

To describe environmental conditions in the cages, time series of the different parameters were analyzed by using least squares linear regressions and calculating mean average, maximum and minimum values. To better quantify similarities and potential differences between conditions measured in the two cages root mean square differences (RMSD) were calculated (e.g. Wu et al. 2009). RMSD is defined as

$$\text{RMSD} = \sqrt{\frac{\sum_{t=1}^{n}(x_{1,t}-x_{2,t})^2}{n}}$$

where n is the number of records, $x_{1,t}$ is the environmental variables (temperature, salinity, pH, or dissolved oxygen) at the LAB cage, $x_{2,t}$ same but at the NU cage. It represents the sample standard deviation of the differences between two data sets.

Fish distribution in the echosounder cone was calculated by dividing data at single depths with the total biomass of the fish contained in the cone to generate a set of relative densities less influenced by the fact that fish get in and out of the “cone” of measurements. Fish relative density was extracted at each of the depths of sonde deployment and compared with environmental data. Time intervals (every 30 minutes), and dates were matched to generate six data sets (one for every sonde) containing environmental data and fish relative density for

the two cages. Mann-Whitney rank-sum test were performed on the preferred environmental conditions to verify the significance of the differences in preferences between the two strains. It allows to test whether two sample means are equal or not.

Similar to the method of Oppedal et al. 2007, the swimming depth distribution for each cage, recorded every 30 minutes, was also transformed into values that identified the most preferred swimming depths. Wilcoxon rank-sum tests (Hollander and Wolfe 1999) were used to compare the daily time spent at the surface for both strains. This test is suitable to compare two sets of independent data not normally distributed. A least-squares spectral analysis following Lomb-Scargle periodogram method (Lomb 1976; Scargle 1982) and written in Interactive Data Language (IDL, from Exelis Visual Information Solutions, Boulder, Colorado) was applied to the depth of maximum densities to determine the potential periodicity of the data as a result of feeding and/or light. This method estimates the frequency spectrum of the time series using a least squares fit of sinusoid and provides results when the data set is unevenly sampled or presents gaps. Depth and time of maximum densities were matched with corresponding sondes data (when available) to extract the environmental conditions of charr maximum distribution. Frequency distribution of these conditions (measured at the most preferred depths) was generated to infer fish preferred conditions.

RESULTS

DESCRIPTION OF ENVIRONMENTAL CONDITIONS IN CAGES

Figure 3 illustrates the temperature, between September 8th and October 23rd, in the NU and LAB cages at different depths. The temperature time series shows a typical seasonal variability for the region with higher temperatures in summer and decreasing temperatures into the fall. Figure 4 illustrates the salinity at different depths in the two cages and shows lower salinity in shallow waters. However, some mixing can be observed within the cage (e.g. September 22-24th, September 28-30th, and October 3rd). Minimum and maximum temperatures, salinities, DO and pH values (as recorded by the three sondes) during the fish monitoring period are summarized in Table 1. Overall the fish experienced temperatures between 8.7 and 18.3 °C and salinities between 1.6 and 30.5 during the period of monitoring. On the other hand, DO and pH values were quite stable; for DO in particular, values never reached conditions that could be considered as hypoxic for salmon.

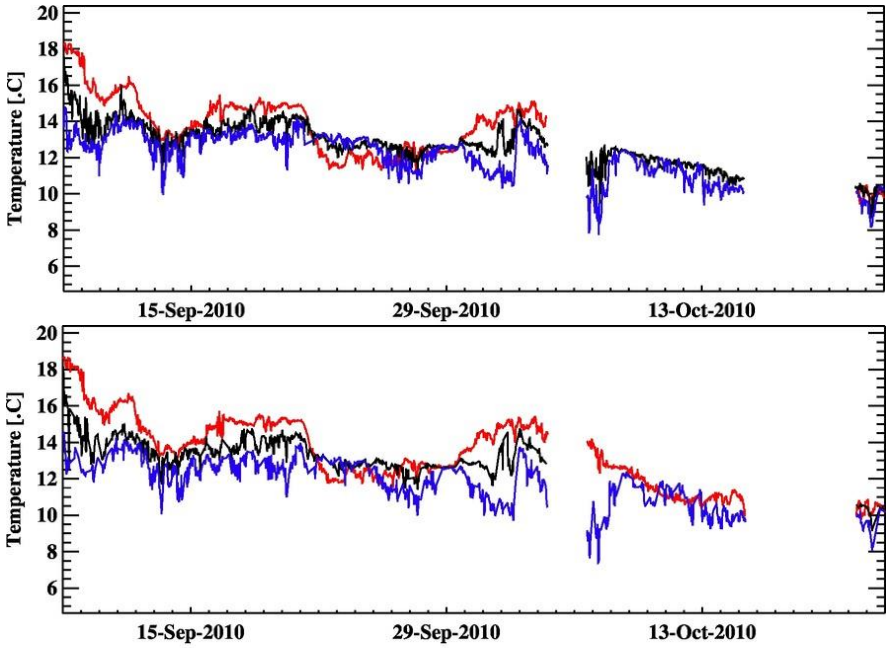

Figure 3: Temperature in the NU (top panel) and LAB (bottom panel) cages measured at different depths by the three sondes. Red line (S1) shallow; black (S2) middle; and blue (S3) deep.

Table 1: Maximum (Max), minimum (Min), and mean values (± standard deviation; SD) of environmental parameters measured by the three sondes (shallow S1, middle S2, deep S3) in the NU cage from September 8th to October 23rd, 2010.

Parameter	S1			S2			S3		
	Min	Max	Mean ± SD	Min	Max	Mean ± SD	Min	Max	Mean ± SD
Temp [°C]	9.4	18.3	13.7 ± 1.7	8.7	17.6	12.8 ± 1.2	7.7	14.8	12.1 ± 1.2
pH	*	*	*	7.4	7.8	7.7 ± 0.1	7.8	8.0	7.9 ± 0.1
DO [%]	88.4	106.6	99.5 ± 3.4	87.0	103.7	93.1 ± 3.1	85.6	99.3	90.9 ± 2.1
Sal	1.6	23.7	10.7 ± 5.2	9.3	30.5	22.7 ± 5.2	13.6	31.0	26.9 ± 3.5

Temp: temperature; DO: dissolved oxygen; Sal: salinity. Sondes S1, S2, and S3 were deployed at 1.3 (0.5 - 1.7 m), 4.7 (4.0 - 5.1 m), and 6.3m (6.0 - 7.5 m) respectively.

* pH probe malfunction

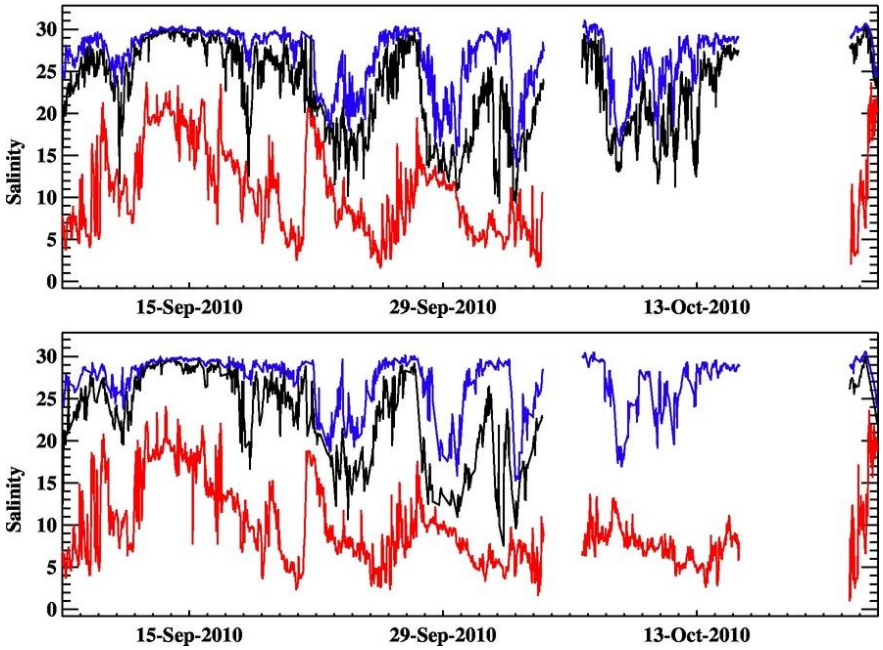

Figure 4: Salinity in the NU (top panel) and LAB (bottom panel) cages measured at different depths by the three sondes. Red line (S1) shallow, black (S2) middle, and blue (S3) deep.

Comparison of the environmental conditions at both cages shows that both strains of Arctic charr experienced similar temperature and salinity conditions with slight differences as reported in Table 2. There is a weaker linear relation in DO values measured in both cages, though differences are quite low (4% change in DO) and do not reflect meaningful differences in environmental conditions between the two cages.

Table 2: Regression coefficients (*b*) from linear regression analyses and root mean square differences (RMSD) between time series (every 30 minutes) recorded at similar depths in both cages (Shallow S1, Middle S2, Deep S3) of the main parameters measured at 3 depths in both cages from September 8th to October 23rd, 2010.

-	S1		S2		S3	
Parameter	***b***	**RMSD**	***b***	**RMSD**	***b***	**RMSD**
Temp [°C]	0.99	0.48	0.97	0.47	0.94	0.52
pH	-	-	0.55	0.20	0.35	0.10
DO [%]	0.53	3.54	0.68	4.98	0.42	3.81
Sal	0.94	2.05	0.97	1.32	0.93	1.11

FISH DISTRIBUTION

Spatial distribution

Despite the fact that the sound beam covers only a portion of the volume of the cage, the position of the echo transducer midway in the cage gives a representative sample as fish in cages often form an annular distribution, with few fish in the middle of the cage (Ferno et al. 1988; Ferno et al. 1995). Analysis of fish movement in the cages for the whole period of measurement shows that the LAB fish occupy the entire cage environment (Figure 5A for a two-day sample in September) while the NU fish remain in their preferred depths between 4 and 10 m (Figure 5B for a similar period as for the other cage). LAB fish also spent more time near the surface. These are also illustrated in Figure 6 where recorded maximum densities every 30 minutes are represented according to time of day and depth. For the NU strain, the proportion of maximum densities observed between 4 to 10 m depth is 85.1% in comparison to 72.7% for the LAB strain. The proportion of maximum densities observed above 4 m depth is 14.4% and 23.3% for NU and LAB strains, respectively.

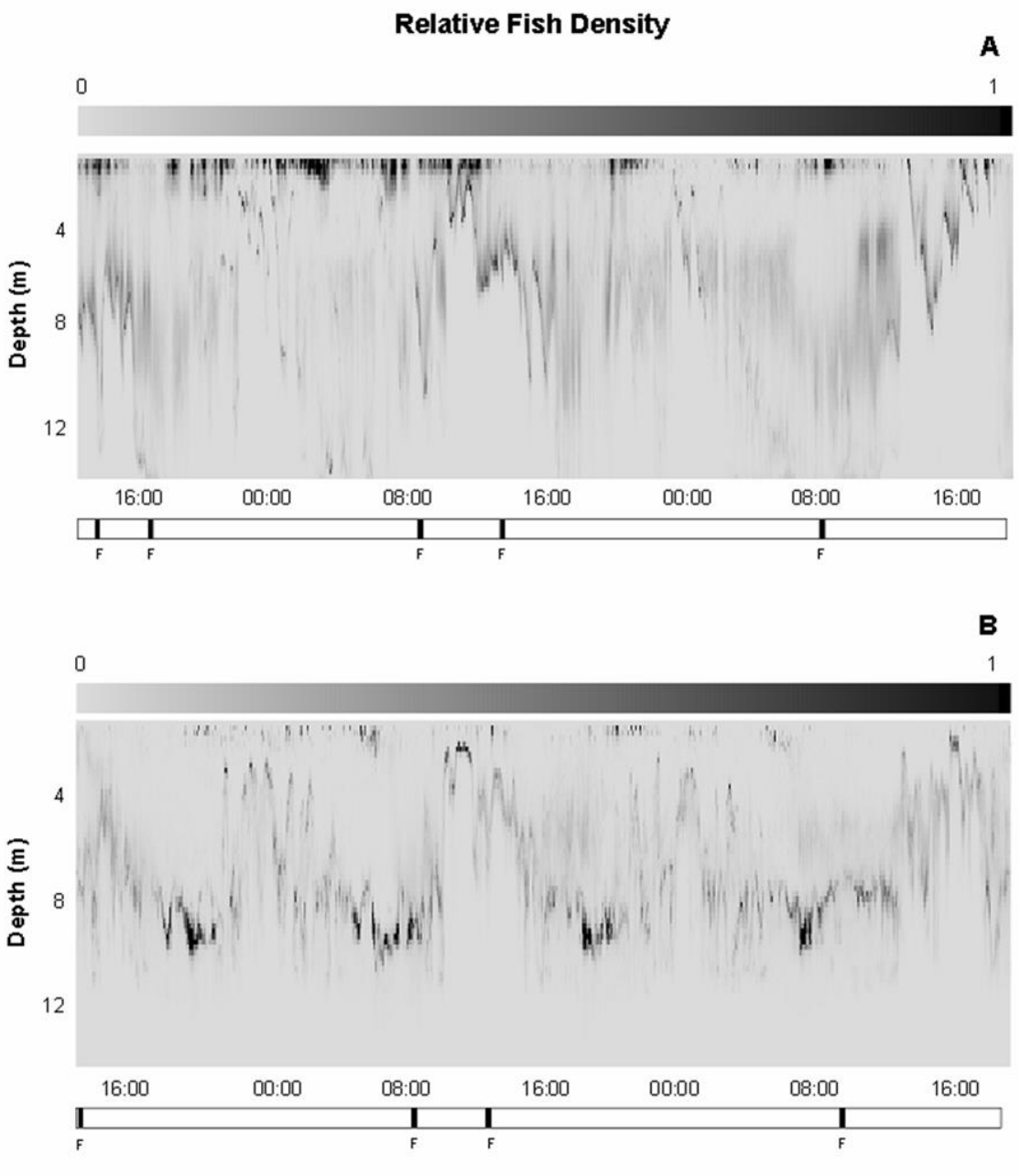

Figure 5: A sample 48 h period (September) of relative fish density of two strains of Arctic char; (A) Labrador, and (B) Nunavut strains. Color bar at the top of each figure represents the relative density with light to dark color corresponding to low relative to high relative density. Horizontal axis is time of the day and black bars with “F” specify feeding times.

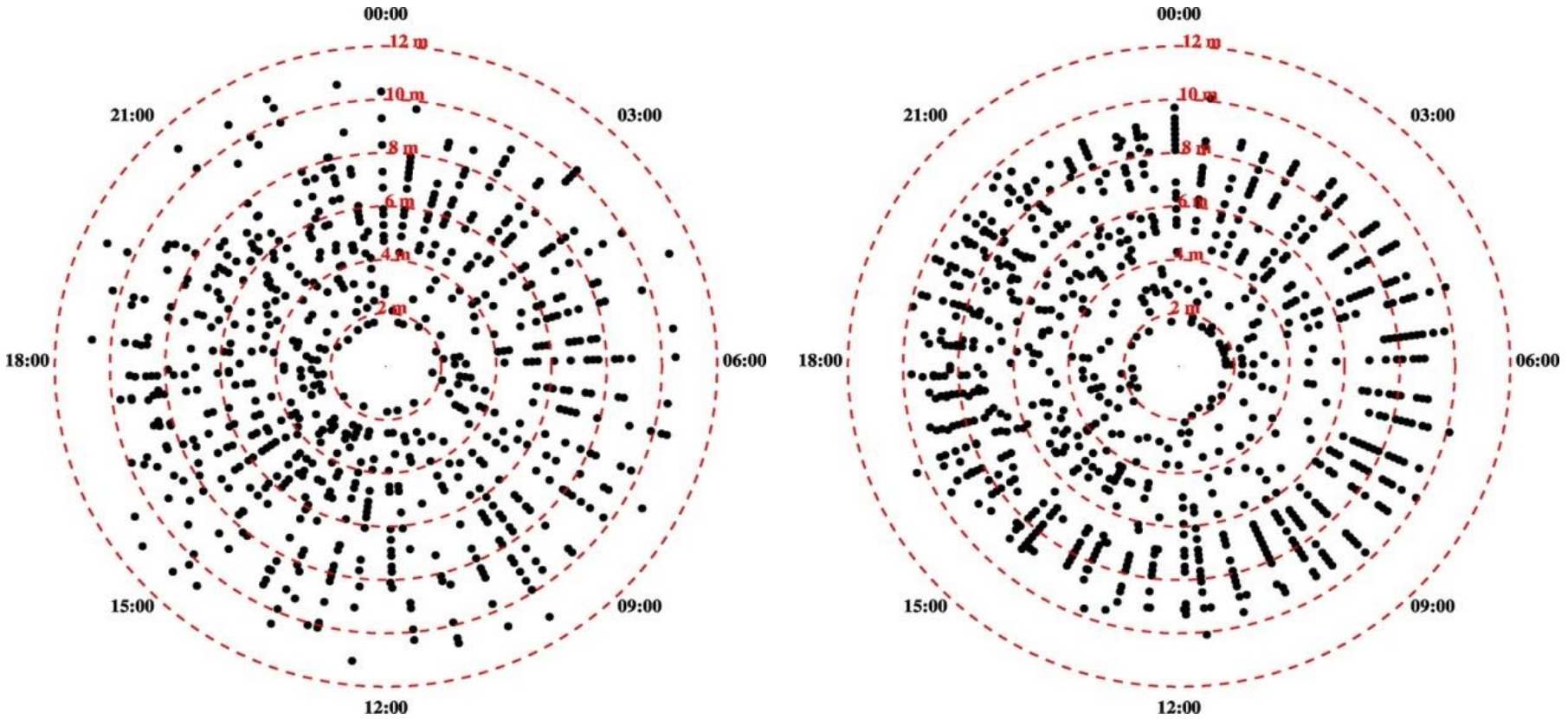

Figure 6: Depths of maximum relative densities according to time of the day in the LAB cage (left panel) and in the NU cage (right panel) for the study period.

The number of instances where most fish went to the surface (whether it was feeding related or not) were counted for both cages. For the observation period of 28 days, the LAB fish were present 85 times at the surface for an average duration of 69.9 ± 83.0 minutes while the NU charr were found 46 times at the surface for a mean duration of 56.8 ± 84.5 minutes. With a median daily time spent at the surface of 126 minutes for the LAB strain and 40 minutes for the NU strain, the rank sum comparison was found significant at 0.05 (P = 0.002).

Diurnal cycles

Using spectral analyses based on Lomb-Scargle method (Lomb 1976; Scargle 1982), periodicity in the depths of maximum density were observed at periods of 15.5 and 27 h for LAB (Figure 7A) and at periods of 12.5 and 26 h for NU (Figure 7B). The strongest oscillatory signals were observed with the NU at a 12.5 h period.

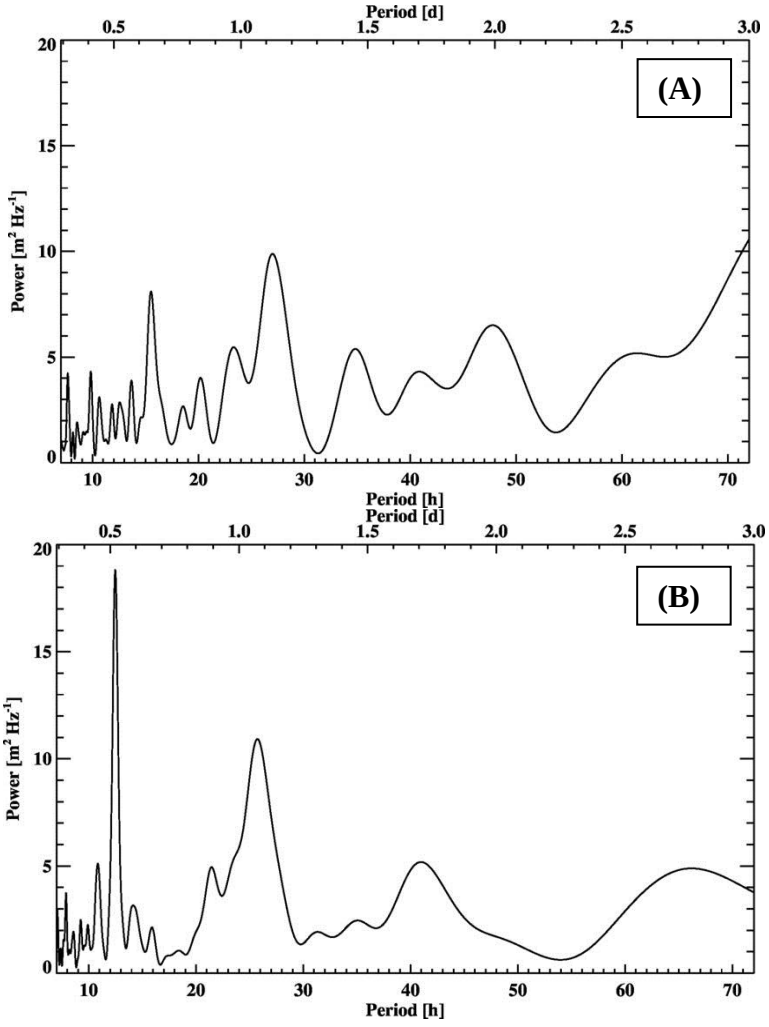

Figure 7: Periodogram showing the dominant periodic signals of depths of maximum density for (A) LAB strain and (B) NU strain.

Preferred environmental conditions

Environmental parameters corresponding to the depth and time of maximum densities were extracted. When the corresponding depth was similar to the sonde depth the matching environmental parameters were extracted and incorporated in the same data set. The resulting data sets produced 443 observations of maximum densities and associated environmental parameters for the LAB cage and 222 observations for the NU cage. Figure 8 (left panels) shows that for the NU strain, 80% of DO values corresponding to maximum fish densities are between 90 and 110% oxygen, ~50% of the temperature measurements range from 12 to 14 ºC and ~30% between 14 to 16 ºC, while ~50% of salinity values are between 20 and 31. For the LAB strain (Figure 8, right panels), frequencies of DO values are equivalent to the results obtained for the NU strain while ~50% of the temperature measurements also range from 12 to 14 ºC but ~30% are within a colder range of temperatures (10 to 12 ºC). Frequencies of salinity values of the LAB strain are bimodal with two higher frequencies representing 30 and 40% of the observations and corresponding to 20-31 and 5-10, respectively.

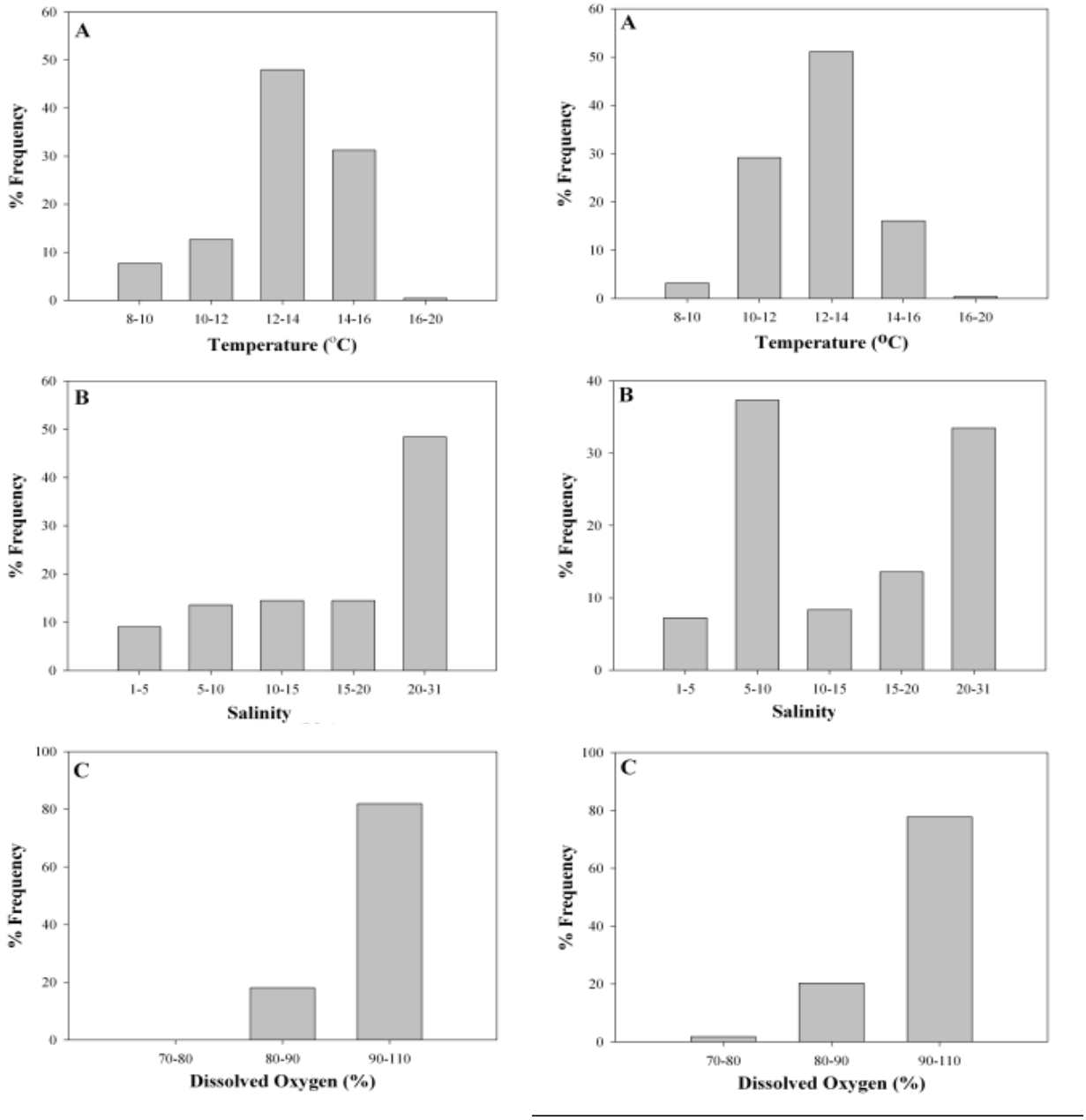

Figure 8: Frequency of main environmental parameters corresponding to the depths of maximum densities for the NU strain (left panels) and LAB strain (right panels). (A) Temperature, (B) Salinity, and (C) DO.

Using the Mann-Whitney rank sum test on the different ranges of preferred temperature (10-12, 12-14, 14-16 ºC) and salinity (5-10, 20-31), we have found that the difference in the median values between the two groups is greater than would be expected by chance, stating that there is a statistically significant difference ($p \leq 0.001$) between the preferred environmental conditions of the two strains.

DISCUSSION

The observation of Arctic charr movement within a cage in a fluctuating and thermally stratified fjord environment can bring useful information on charr's preferred environmental conditions during mariculture. There is a paucity of information on preferred temperatures for adult charr (> 500 mm in length) in sea water, and clearly some studies are required to test if the relationships described in previous studies of Arctic charr in freshwater (e.g. Klemetsen et al. 2003) are generally applicable (Rikardsen et al. 2007). The upper Bay d'Espoir, where this study took place, is influenced by large freshwater runoff from the hydroelectric plant north of St. Alban's. This part of the bay is also, to some degree, subject to semi-diurnal tides, with period of 12.5 h (DFO 2016), which results in variation of the environmental conditions with a 12.5 h oscillation at depth. Stratification in temperature and salinity with surface brackish water extending to 3-4.5 m depth and decreasing away from the plant is found throughout the bay (Sutterlin 1980). Despite the fact that rapidly fluctuating temperatures and salinities have been reported to be stressful to fish (Beveridge 2004), sites with these characteristics allow caged fish to choose between different chemophysical microhabitats (Oppedal et al. 2001; Johansson et al. 2006).

DIFFERENCES BETWEEN STRAINS

In the present study, both strains were subjected to the same environmental conditions (differences between cages in DO values do not represent meaningful variations). However, strains differed in fish size and sexual maturity. Fish size, sex, time of season, local adaptation, acclimation temperature and experimental design can affect preferred (and consequently distribution in the water column) and optimal temperatures for growth of fish (e.g. Hall et al. 1978, Stauffer et al. 1985, Kelsch and Neill 1990; Larsson 2005). A study on the effect of different size distributions in fish (matched versus different sizes) has also showed that feeding rates of a group of charr of different sizes was higher than that of a group of same size fish (Lahti and Lower 2000). No regular weight measurements were completed as part of the present study; nonetheless, the LAB strain displayed a wider range of sizes than the NU strain. Weight measurements made in August on the NU strain (n = 86) showed an average weight of 233.0 ± 41.2 g with a coefficient of variation (CV) of 17.7% while the LAB fish (n = 100) had a mean weight of 467.0 ± 201.4 g with a CV of 43.1%. Moreover, the LAB strain fish showed signs of early maturation and a mortality rate of 1.4% while the NU fish remained immature with a mortality rate of 0.5% throughout the year.

ENVIRONMENTAL PREFERENCES

The thresholds of environmental parameters corresponding to the highest frequencies of maximum fish presence are a good indication of fish preferred conditions. In the present study, both groups of fish had 50% of their maximum densities occurring between 12 and 14 °C. The next large set of data

represented 30% of the observations for both strains but with the temperature occurring at a different range, 14-16 °C for the NU strain and 10-12 °C for the LAB fish. In experimental/tank conditions, Arctic charr between 200 and 530 g preferred temperatures around 11-12 °C (Larsson 2005; Sutterlin and Stevens 1992). Likewise, a tagging study reported by Rikardsen et al. (2007) suggested that juvenile anadromous charr (~400 mm) show temperature preferences in the wild, as fish maintained a narrow range of mean daily temperatures while in the marine environment (10.7 ± 0.66 °C). The temperature preferences described in our study were above 10 °C and in agreement with these previous studies. Our results suggest a wider range of preferred temperatures than what has been described by other authors, 12 to 16°C for the NU strain and slightly colder temperatures (10 to 14 °C) for the LAB charr. Larsson (2005) described a tendency for the larger charr to prefer lower temperatures than the smaller charr. The size differences between the LAB fish (467 g) and the NU charr (233 g) could explain the temperature choices observed in this study. The fact that NU fish remain mainly within a specific range of depth can be attributed to their response to environmental preferences. This response is confirmed by a periodic signal at ~12.5 h for depths of maximum density clearly identifiable for the NU strain. This pattern has the same frequency as the semidiurnal variability of temperature and salinity observed at mid- and bottom depth of the cage and confirms that the NU strain responds to the natural variation of environmental conditions due to tides (DFO 2016).

DO percentages in the cages were between 72.9% (only 0.5% of the observations were lower than 80%) and 108.5% for the LAB strain and 85.6 and 106.6% for the NU strain; overall oxygen levels above 80% saturation are not regarded as either a respiratory stressor or a limiting factor for growth (e.g. Wedemeyer 1997). We can hypothesize that DO might not be a limiting factor nor a strong driver of fish movement in this study.

Salinity preferences found in this study were bimodal for the LAB strain (30% at 20-31 and 40% at 5-10 respectively) but had only one unique preferred range for NU fish (50% at 20-31). In a study of long-term saltwater rearing of Arctic charr, Delabbio et al. (1990) showed that among the Labrador charr (with weight of 291.8 ± 191 g), the development of a bimodal pattern in weight became evident at 130 days in saltwater while no distinctive bimodal distribution was evident for the Nunavut fish (with weight of 276.6 ± 168.7 g). Earlier work by Wandsvik and Jobling (1982a) speculated that the bimodal behaviour is caused by an inability for some fishes to fully adapt to saltwater. Changes in mechanisms for osmoregulation related to increasing fish size allow larger fish to better tolerate osmoregulatory stress than smaller ones (McCormick and Saunders 1987; Klemetsen et al. 2003; Jensen and Rikardsen 2012). The larger size variability of the LAB fish might explain the bimodal preferences with larger fish tolerating a wider range of salinity. This is confirmed by the vertical distribution of the LAB fish that were more evenly distributed in the cage environment than the NU fish. Differences between fish groups can be attributed to dissimilar sizes and/or strain differences.

Periodograms did not identify a strong 24 h signal suggesting that light is not an important driver of Arctic charr distribution in the water column as in the case of Atlantic salmon previously described by other authors (e.g. Ferno et al. 1995). Using a combined PIT-tag system and demand feeders, Eriksson et al. (2010) found that Arctic charr appear to have a plastic behaviour regarding their diel feeding patterns. They can show both a stable diurnal as well as a stable nocturnal activity pattern (Brännäs and Alanärä 1997; Alanärä and Brännäs 1997) and can easily learn when a temporally restricted resource is available and adapt their activity to it (Brännäs et al. 2005). It has also been suggested that Arctic charr may be able to visually locate and capture prey at lower light levels than other salmonids (Dervo et al. 1991). Different feeding times are not a consideration of this study as fish were fed regularly between 8:00 am and 4:00 pm. The absence of a repetitive pattern due to feeding times might also be due to the potential avoidance of high surface temperatures as already highlighted by other authors (Sutterlin and Stevens 1992, Rikardsen et al. 2007).

Overall, our study shows that both the Labrador and the hybrid Nunavut strains of Arctic charr exhibit preferences in temperature and salinity as reflected by their distribution in cages. The NU strain fish appear less “flexible” in their choice of environmental conditions in comparison with the LAB strain, this choice being driven by a careful combination of salinity and temperature thresholds. These preferences could be due to strain differences and/or size disparities (both in terms of averages and CVs) of the two groups of fish requiring further trials with similar size fish to conclude on that matter. Fish from both strains do not exhibit a strong diel rhythm and are less influenced by light changes than Atlantic salmon (e.g. Ferno et al. 1995). The observed lack of strong surface behaviour driven by feeding and the fish preferred depths highlight their temperature thresholds (i.e. avoidance of warm temperatures) and the importance of choosing sites with appropriate environmental conditions for charr culture.

ACKNOWLEDGEMENTS

This study was supported by the Aquaculture Collaborative Research and Development Program (ACRDP). The support and help of aquaculture industry personnel involved is greatly appreciated.

REFERENCES

Alanärä, A. and Brännäs, E. 1997. Diurnal and nocturnal feeding activity in Arctic charr and rainbow trout. Canadian Journal of Fishery and Aquatic Sciences. 54: 2894-2900.

Arnesen, A., Jørgensen, E. and Jobling, M. 1993. Feed intake, growth and osmoregulation in Arctic charr, *Salvelinus alpinus* (L.), transferred from freshwater to saltwater at 8°C during summer and winter. Fish Physiology and Biochemistry. 12: 281-292.

Beveridge, M.C.M. 2004. Cage aquaculture. 3rd Edition. Blackwell Publishing Ltd., Oxford, UK. 376 p.

Brännäs, E. and Alanärä, A. 1997. Is diel dualism in feeding activity influenced by competition between individuals? Canadian Journal of Zoology. 75: 661-669.

Brännäs, E., Berglund, U., and Eriksson, L.O. 2005. Time learning and anticipatory activity in groups of Arctic charr. Ethology. 111: 681-692.

Chiasson, M., Quinton, M., Pelletier, C., Danzmann, R. and Ferguson, M. 2014. Family × Environment interactions in the growth and survival of Arctic charr (*Salvelinus alpinus*) grown in brackish and fresh water. Aquaculture Research.45: 1953–1963..

de March and Baker. 1990. Culture history of the first hatchery generation of Arctic charr (*Salvelinus alpines*) from the Fraser River, Labrador (1980-1987). Canadian Manuscript Report of Fisheries and Aquatic Sciences. 2084. 11 pp.

de March, B.G.E. 1991. Origins of cultivated Arctic charr in Canada. Arctic charr. Culture Bulletin 2: 1-24.

de March, B.G.E. 1997. Social and genetic determinants of size variation in tanks of Nayauk, Norwegian, and hybrid Arctic charr, *Salvelinus alpinus* (L.). Aquaculture Research. 28: 305-315.

Delabbio, J. 1995. Arctic charr culture in Atlantic Canada. *In* Cold-Water Aquaculture in Atlantic Canada. Edited by A.D. Boghen. The Canadian Institute for Research on Regional Development, Université de Moncton, Moncton, New Brunswick, Canada. pp.83–106.

Delabbio, J.L., Glebe, B.D. and Sreedharan, A. 1990. Variation in growth and survival between two anadromous strains of Canadian Arctic charr (*Salvelinus alpinus*) during long-term saltwater rearing. Aquaculture. 85: 259-270.

Dempson, J.B. and Kristofferson, A.H. 1987. Spatial and temporal aspects of the ocean migration of anadromous Arctic char. Am. Fish. Sot. Symp. 1: 340-357.

Dervo, B.K., Hegge, O., Hessen, D.O. and Skurdal, J. 1991. Diel food selection of pelagic Arctic charr, *Salvelinus alpinus* (L.), and brown trout, *Salmo trutta* (L.) in Lake Atnjo, SE Norway. Journal of Fish Biology. 38: 199-209.

DFO. 2016. State of Knowledge of the Oceanography and Water Exchange on the South Coast of Newfoundland to Support the Development of Bay Management Areas for Finfish Aquaculture. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2016/039.

Eriksson, L.O., Alanärä, A., Nilsson, J. and Brännäs, E. 2010. The Arctic charr store: development of subarctic freshwater farming in Sweden. Hydrobiologia. 650: 265-274.

Ferno, A., Furevik, D.M., Huse, I. and Bjordal, A. 1988. A multiple approach to behaviour studies of salmon reared in marine net pens. Council Meeting of the International Council for the Exploration of the Sea, C.M. F. 15.

Ferno, A., Huse, I., Juell, J.E. and Bjordal, A. 1995. Vertical distribution of Atlantic salmon (*Salmo salar* L.) in net pens: trade-off between surface light avoidance and food attraction. Aquaculture 132, 285-296.

Finstad, B., Nilssen, K.J. and Arnesen, A.M. 1989. Seasonal changes in sea-water tolerance of Arctic charr (*Salvelinus alpinus*). Journal of Comparative Physiology B: Biochemical, Systemic, and Environmental Physiology. 159: 371-378.

Giles, M.A. 1991. Strain differences in haemoglobin polymorphism, oxygen consumption, and blood oxygen equilibria in three hatchery broodstocks of Arctic charr, *Salvelinus alpinus*. Fish Physiology and Biochemistry. 9: 291-301.

Hall, L.W. Jr., Hocutt, C.H. and Stauffer, J.R. Jr. 1978. Implication of geographic location on temperature preference of white perch, *Morone americana*. Journal of the Fisheries Research Board of Canada. 32: 1464-1468.

Heasman, M.S. and Black, K.D. 1998. The potential of Arctic charr, *Salvelinus alpinus* (L.) for mariculture. Aquaculture Research. 29: 67-76.

Hollander, M. and Wolfe, D.A., 1999. Nonparametric Statistical Methods, 2nd Edition. Wiley, New York.

Jensen, J.L.A, and Rikardsen, A.H. 2012. Archival tags reveal that Arctic charr *Salvelinus alpinus* and brown trout *Salmo trutta* can use estuarine and marine waters during winter. Journal of Fish Biology. 81: 735–749.

Jobling, M., Jørgensen, E.H., Arnesen, A.M. and Ringo, E. 1993. Feeding, growth and environmental requirements of Arctic charr: a review of aquaculture potential. Aquaculture International. 1: 20-46.

Johansson, D., Ruohonen, K., Kiessling, A., Oppedal, F., Stiansen, J.-E., Kelly, M. and Juell, J.E. 2006. Effect of environmental factors on swimming depth preferences of Atlantic salmon (*Salmo salar* L.) and temporal and spatial variations in oxygen levels in sea-cages at a fjord site. Aquaculture. 254: 594-605.

Johnston G. 2002. Arctic Charr Aquaculture. Fishing News Books, Blackwell Publishing, Oxford, U.K.

Jørgensen, E. and Arnesen, A. 2002. Seasonal changes in osmotic and ionic regulation in Arctic charr, *Salvelinus alpinus*, from a high- and a sub-Arctic anadromous population. Environmental Biology of Fishes. 64: 185-193.

Kelsch, S.W. and Neill, W.H. 1990. Temperature preference versus acclimation in fishes: selection for changing metabolic optima. Transactions of the American Fisheries Society. 119: 601-610.

Klemetsen, A., Amundsen, P.-A., Dempson, J.B. et al. 2003. Atlantic salmon *Salmo salar L*., brown trout *Salmo trutta L*. and Arctic charr *Salvelinus alpinus (*L.): a review of aspects of their life histories. Ecol. Freshwater Fish. 12: 1–59.

Lahti, K. and Lower, N. 2000. Effects of size asymmetry on aggression and food acquisition in Arctic charr. Journal of Fish Biology. 56: 915-922.

Larsson, S. 2005. Thermal preference of Arctic charr, *Salvelinus alpinus*, and brown trout, *Salmo trutta*, implications for their niche segregation. Environmental Biology of Fishes. 73: 89-96.

Le François, N.R., Lemieux, H. and Blier, P.U. 2002. Biological and technical evaluation of the potential of marine and anadromous fish species for cold-water mariculture. Aquaculture Research. 33: 95-108.

Lomb N R 1976. Least-squares frequency analysis of unevenly spaced data. Astrophys. Space Sci. 39: 447-462.

Lyttikäinen, T., Koskela, J. & Rissanen, I. 1997. Thermal resistance and upper lethal temperatures of underyearling Lake Inari Arctic charr. Journal of Fish Biology. 51: 515–525.

McCormick, S.D., and Saunders, R.L. 1987. Preparatory physiological adaptations for marine life of salmonids: osmoregulation, growth, and metabolism. Am. Fish. Soc. Symp. 1: 211-229.

Oppedal F., Juell J.E., Taranger, G.L. and Hansen, T. 2001 Artificial light and season affect vertical distribution and swimming behaviour of post-smolt Atlantic salmon in sea cages. Journal of Fish Biology. 58: 1570-1584.

Oppedal, F., Juell, J.E. and Johansson, D. 2007. Thermo and photoregulatory swimming behaviour of caged Atlantic salmon: Implications for photoperiod management and fish welfare. Aquaculture. 265: 70-81.

Pepper V., Collier, C. and Withler, R. 2003. Newfoundland experience with salmonid broodstock for application to aquaculture industry needs. AAC Special Publication. 6: 27-30.

Rikardsen, A.H., Diserud, O., Elliott, J.M., Dempson, J.B., Sturlaugsson, J. and Jensen, A. 2007. The marine temperature and depth preferences of Arctic charr and sea trout, as recorded by data storage tags. Fisheries Oceanography. 16: 436-447.

Sæther, B.-S., Siikavuopio, S.I. and Jobling, M. 2016. Environmental conditions required for intensive farming of Arctic charr (*Salvelinus alpines* L.). Hydrobiologia. 783: 347-359.

Sæther, B.-S., Siikavuopio, S. I., Thorarensen, H., and Brännäs, E. 2013. Status of Arctic Charr (*Salvelinus alpinus*) Farming in Norway, Sweden and Iceland. Journal of Ichthyology. 53: 833-839

Scargle JD 1982. Studies in astronomical time series analysis. II—Statistical aspects of spectral analysis of unevenly spaced data. Astrophys J. 263: 835–853.

Stauffer, J.R., Hocutt, C.H. and Goodfellow, W.F. 1985. Effects of sex and maturity on preferred temperatures: a proximate factor for increased survival of young *Poecilia latipinna*? Archiv Hydrobiol. 103: 129-132.

Sutterlin, A.M. 1980. Bay d'Espoir aquaculture feasibility study. Marine Science Research Laboratory, Memorial University, St. John's, NL, Vol. 2, Chapter 10. 37pp.

Sutterlin, A.M. and Stevens, E.D. 1992. Thermal behaviour of rainbow trout and Arctic charr in cages moored in stratified water. Aquaculture. 102: 65-75.

Thyrel, M., Berglund, I., Larsson, S. and Näslund, I. 1999. Upper thermal limits for feeding and growth of Arctic charr. Journal of Fish Biology. 55: 199–210.

Wandsvik, A. and Jobling, M. 1982a. Observations on growth rates of Arctic charr, *Salvelinus alpinus* (L.), reared at low temperatures. Journal of Fish Biology. 20: 689-699.

Wandsvik, A. and Jobling, M. 1982b. Observations on mortality of migratory Arctic charr, *Salvelinus alpinus*, (L.) reared in salt water. Journal of Fish Biology. 20: 701-706.

Wedemeyer, G.A. 1997. Effects of rearing conditions on the health and physiological quality of fish in intensive culture. *In* Fish stress and health in aquaculture. Edited by G.K. Iwama, A.D. Pickering, J.P. Sumpter and C.B. Schreck. Society for Experimental Biology, Seminar Series 62. Cambridge University Press, Cambridge, UK. pp. 35-71.

Wu, Y., Senciall, D. and Tang, C. 2009. An evaluation of operational sea-surface temperature analysis using AZMP data over the Eastern Canadian shelves. Atlantic Zone Monitoring Program Bulletin. 8:35-39.