Growth, condition and energy stores of Arctic grayling fry inhabiting natural and artificial constructed Arctic tundra streams

Kimberlea L.F. Driedger a, Lynn P. Weber a, Ian K. Birtwell b, David M. Janz a, * 

a Department of Veterinary Biomedical Sciences, University of Saskatchewan, 52 Campus Drive, Saskatoon, SK, Canada S7N 5B4  
b Fisheries and Oceans Canada, West Vancouver Laboratory, 4160 Marine Drive, West Vancouver, BC, Canada V7V 1N6

ABSTRACT

Juvenile north-temperate and Arctic fishes are faced with trade-offs between energy allocation to growth and energy storage (primarily lipids) prior to over-wintering. We determined classical morphometric (fork length, body weight and condition factor) and biochemical (whole body triglycerides, muscle RNA/DNA ratio, muscle proteins) measures of growth and condition in individual young-of-the-year (YOY) Arctic grayling (Thymallus arcticus). Grayling were collected just prior to over-wintering in late August (approximately 50 days after swim-up) from two natural streams and five locations within a 3.4 km long artificial stream constructed as a fish habitat compensation project and diversion channel for the diamond mining industry in Northwest Territories, Canada (64°45′N). Fork lengths, body weights and whole body triglyceride levels in grayling collected from all sites along the artificial stream were significantly lower than fish collected from one of the natural streams. Condition factor (weight-at-length) was not different among grayling collected from natural and artificial streams. Muscle proteins were lower in grayling collected from four sites along the artificial stream compared to the natural streams. In contrast, muscle RNA/DNA ratios were greater in grayling collected from two sites in the artificial stream compared to natural streams. There were no consistent differences in any variable among grayling collected at the five artificial stream sites or among grayling collected from the two natural streams. The higher RNA/DNA ratios and lower fork lengths, whole body triglycerides and muscle proteins in grayling inhabiting the artificial stream are consistent with energy still being primarily allocated to growth in these fish at this late stage of summer. Individuals that are both larger and possess greater energy storage in the form of triglycerides are more likely to survive the long over-wintering period at this latitude. Our results suggest that YOY grayling using the artificial stream as nursery habitat will likely face increased over-winter mortality, thus raising concerns over the use of fish presence, spawning and rearing as criteria for the initial success of artificial streams as habitat compensation measures in Arctic tundra regions. Further research is needed to determine the potential consequences of reduced size and energy storage in juvenile fishes in order to assess the viability of stream fish habitat compensation and restoration projects associated with industrial development in Arctic tundra regions.

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Introduction

At higher latitudes, fish are subject to seasonally short periods of growth potential followed by a long over-wintering period with greatly limited availability of food resources. This seasonal environment puts constraints on the ability of fish, particularly juveniles, to acquire sufficient growth and energy reserves to survive winter (Cunjak, 1988; Miller et al., 1988; Post and Parkinson, 2001). Among underyearlings, smaller fish tend to be more susceptible to over-winter mortality due to relatively higher basal metabolism and subsequent exhaustion of energy reserves (Shuter and Post, 1990; Post and Parkinson, 2001). A major source of winter mortality in underyearling fish is depletion of lipid reserves (Pratt and Fox, 2002; Biro et al., 2004). Triglycerides (triacylglycerols), the major energy storage form in fish, have important ecological and physiological relevance as indicators of growth potential and survival (Cunjak, 1988; Adams, 1999; Post and Parkinson, 2001). Although traditional morphometric indices of fish growth and condition such as body length, body weight and condition factor (weight-at-length) are easy to measure and provide useful information, determination of biological macromolecules such as triglycerides may provide more sensitive and relevant measures of condition (Adams, 1999; Weber et al., 2003). Other biochemical indices of growth, particularly RNA/DNA ratio,
have also been used to assess nutritional status and growth rates of juvenile fish (Buckley, 1984; McNamara et al., 1999). Tissue protein content is also an important biochemical index of growth and condition since it reflects longer term growth and is a measure of energy storage (McLaughlin et al., 1995). We have established techniques to determine triglycerides, RNA/DNA ratio and proteins in individual juvenile fish (Weber et al., 2003) and are currently evaluating these biochemical indices of condition in field and laboratory experiments.

Native fishes inhabiting Arctic aquatic ecosystems are faced with an extremely short growing season (approximately 3 months) and long over-winter period (approximately 8–10 months of ice cover), thus making juveniles particularly susceptible to over-winter mortality if sufficient growth and energy storage is not acquired prior to this period. There is currently much research interest in Canada’s Arctic ecosystems in light of expanding industrial activities such as extraction of minerals, oil and gas. With respect to the management of habitat for fisheries resources, activities that negatively impact upon habitat are required to be compensated for to ensure “no net loss of productive capacity of fish habitats” (Minns, 1997). In 1998, a 3.4 km long artificial stream was constructed that diverted water around two lakes that were eliminated for open-pit diamond mining in the Northwest Territories, Canada. The artificial stream was created with the goals of diverting water from the mine site and maintaining connectivity within the watershed for fish migration, and to provide spawning and rearing habitat for local fish species, particularly Arctic grayling (Thymallus arcticus). The artificial stream permitted fish migration and provided spawning and nursery habitat for grayling. However, studies conducted from 1998 to 2001 reported that growth and density of young-of-the-year (Y0Y) grayling at the end of summer were lower in the artificial stream compared to grayling collected from nearby natural streams (Jones et al., 2003a; Jones and Tonn, 2004). The reduced growth of grayling in the artificial stream was attributed primarily to relatively low quantities of autochthonous and allochthonous organic matter and poor physical habitat that limited the productivity of invertebrate prey for grayling (Jones et al., 2003a). Further research is needed to evaluate the viability of stream fish habitat compensation in Arctic tundra regions, and thereby guide future decisions regarding compensation and restoration activities.

The current study was initiated to investigate potential physiological and biochemical mechanisms underlying the reported differences in growth of Y0Y grayling between artificial and natural streams. Our objective was to determine biochemical measures of fish growth and condition (whole body triglycerides, muscle RNA/DNA ratio and muscle proteins) in Y0Y grayling collected near the end of the growing season, just prior to outmigration from streams to surrounding lakes for over-wintering. Classical morphometric measures of fish growth and condition (fork length, body weight and condition factor) were also determined and compared to the biochemical indices in the same fish. Based on previous research conducted in these artificial and natural streams (Jones et al., 2003a; Jones and Tonn, 2004), we hypothesized that the reduced morphometric growth (fork length and body weight) of Y0Y grayling collected from the artificial stream would be related to concomitant changes in the biochemical indices of growth and condition. Specifically, we predicted that (1) grayling collected from natural streams near the end of the growing season would exhibit greater energy stores (triglycerides) and muscle proteins compared to grayling collected from the artificial stream and (2) grayling collected from the artificial stream would exhibit greater muscle RNA/DNA ratios as an index of short-term growth rate. These predictions were based on existing knowledge of energy allocation strategies in young fish inhabiting northern aquatic ecosystems (Buckley, 1984; Cunjak, 1988; McLaughlin et al., 1995; Adams, 1999; McNamara et al., 1999; Post and Parkinson, 2001).

Materials and methods

Study sites and fish collections

The study sites were located in an area known as the Barrenlands region within the southern Arctic ecozone, approximately 300 km northeast of Yellowknife, NWT, Canada. Grayling fry were collected in late August, just prior to outmigration of fry from streams to surrounding lakes for over-wintering. Fry were collected on August 23–24, 2003, from five sites located along the Panda Diversion Channel (PDC; artificial stream), using the following sampling methods. Fry were collected using fyke nets employed at the lower (outflow) end of the PDC (n=15) and the upper (inflow) end of the PDC (n=6), and by electrofishing at three intermediate locations along the PDC (PDC site 6, n=12; PDC site 7, n=12; PDC site 10, n=15). Fyke nets and electrofishing were also used to collect grayling fry on August 24–25, 2003, from Polar-Vulture stream (n=15) and Pigeon stream (n=15), two nearby streams that are representative of natural streams in this region (Jones et al., 2003b). Detailed maps of the fish collection sites have been published previously (Jones et al., 2003b; Jones and Tonn, 2004). After fish were euthanized, lengths and weights were recorded and then fish were placed in plastic storage bags and immediately frozen on dry ice for shipment by air to the University of Saskatchewan, Saskatoon, SK, Canada. Once received at the university, fish were stored at −90 °C until determinations of muscle RNA/DNA ratio, muscle proteins and whole body triglycerides.

Muscle RNA/DNA ratio and protein concentration

All chemicals and reagents were obtained from Sigma-Aldrich (Oakville, ON, Canada) unless specified otherwise. A 5–10 mg portion of caudal muscle was removed from each fish with a scalpel and used for RNA/DNA and protein determinations. Muscle samples were homogenized in TE buffer (10 mM Tris, 1 mM EDTA, pH 8.0). A modification of the method described by Clemmesen (1988) was used to determine muscle RNA/DNA ratio as described previously (Weber et al., 2003). Calf thymus DNA and calf liver RNA were used as standards. Muscle proteins were measured using a modification of the Lowry et al. (1951) protein assay method (BioRad DC protein assay, Hercules, CA, USA). An aliquot of the initial muscle sample homogenate prepared for RNA/DNA determination was used to determine protein using bovine serum albumin as standard.

Whole body triglycerides

The graying carcasses (minus 5–10 mg of tail muscle) were used to determine whole body triglycerides as described previously (Weber et al., 2003). Thawed fish were finely minced with scissors and homogenized in 2x volume deionized and distilled water for 3 × 10 s with a Tissue Tearer (BioSpec, Bartlesville, OK, USA). Whole body triglyceride concentrations were determined using a method developed for serum triglycerides (McGowan et al., 1983) and modified for use in fish (Weber et al., 2003) using glycerol as a standard. Glycerol in the sample arising from acyl glyc erides (mono-, di- and triglycerides) was then calculated and expressed as µmol triolein/g fish (Weber et al., 2003). On a day, a set of 18 samples (10 natural stream and
8 artificial stream) were lost during preparation, resulting in a reduced sample size for whole body triglyceride determinations compared to the other endpoints in the current study.

**Statistical analyses**

Bartlett’s test and the Kolmogorov–Smirnov test were used to examine data for homogeneity of variance and normality, respectively. Body weight and whole body triglyceride data displayed heterogeneity of variance and were log-transformed prior to using parametric statistics. Comparisons of fork length, body weight, muscle RNA/DNA ratio, muscle protein concentration and whole body triglyceride concentration in grayling among sampling sites (5 artificial [PDC] stream sites and 2 natural stream sites) were conducted using one-way analysis of variance (ANOVA) followed by the Bonferroni multiple comparisons test if appropriate. Potential differences among study sites for grayling condition factor were conducted by comparing body weight with body length as covariate in one-way analysis of covariance (ANCOVA). To examine relationships between morphometric and biochemical measures of growth and condition, Pearson correlations were performed between these parameters using all collected fish. Based on the variance observed in data collected for fork length, body weight, whole body triglycerides, muscle RNA/DNA ratio and muscle protein, statistical power analyses were performed *a posteriori* using software obtained from Lenth (2009). Statistical significance was set at 0.05. Data are presented as mean ± standard error of the mean (SEM).

**Results**

Grayling collected from all five sites along the artificial stream (PDC) had significantly lower fork lengths compared to grayling collected from Pigeon stream (P < 0.001 for lower PDC, PDC site 6 and PDC site 7; P < 0.01 for upper PDC and PDC site 10; Fig. 1). Grayling collected from lower PDC, PDC site 6 and PDC site 7 had significantly lower fork length compared to grayling collected from Polar-Vulture stream (P < 0.001; Fig. 1). Mean fork lengths ranged from 50.6 to 55.8 mm in fish collected from the five artificial stream sites (overall mean 52.5 mm) and 60.8–63.9 mm in the two natural streams (overall mean 62.3 mm). There were no significant differences in fork lengths among grayling collected from the two natural streams or among grayling collected from the five artificial stream sites (Fig. 1). Similarly, body weight was significantly lower in grayling collected from all artificial stream sites compared to Pigeon stream (P < 0.001 for all sites), and in grayling collected from lower PDC (P < 0.001), PDC site 6 (P < 0.01) and PDC site 7 (P < 0.001) compared to Polar-Vulture stream (Fig. 2). Mean body weight ranged 1.05–1.54 g in fish collected from the artificial stream (overall mean 1.21 g) and 1.99–2.45 g in fish collected from the natural streams (overall mean 2.22 g; Fig. 2). When comparing condition factor (body weight as a function of length as covariate) of grayling, there was no significant difference among all collection sites in the artificial and natural streams (P = 0.086; data not shown).

Whole body triglycerides were significantly lower in grayling collected from all five sites along the artificial stream compared to fish collected from Polar-Vulture stream (P < 0.001 for PDC sites 6,
7 and 10; P < 0.01 for lower PDC and upper PDC; Fig. 3). In contrast, there were no significant differences in whole body triglycerides among grayling collected from Pigeon stream and the five PDC sites (Fig. 3). Mean whole body triglycerides ranged 0.30–0.37 \( \mu \text{mol/g} \) in fish collected from the artificial stream (overall mean 0.33 \( \mu \text{mol/g} \)) and 0.52–0.67 \( \mu \text{mol/g} \) in fish collected from the natural streams (overall mean 0.60 \( \mu \text{mol/g} \); Fig. 3). There were no significant differences in whole body triglycerides among grayling collected from the two natural streams or among grayling collected from the five artificial stream sites (Fig. 3).

Muscle RNA/DNA ratio was significantly greater in grayling collected from PDC sites 6 and 7 compared to grayling collected from Pigeon stream (\( P < 0.05 \) and \( P < 0.001 \), respectively; Fig. 4). Muscle RNA/DNA ratio was also significantly greater in grayling collected from Pigeon stream compared to grayling collected from Pigeon stream (\( P < 0.01 \); Fig. 4). Mean RNA/DNA ratios ranged 3.73–5.00 in fish collected from the artificial stream (overall mean 4.20) and 3.24–3.76 in fish collected from the natural streams (overall mean 3.50; Fig. 4). There was no significant difference in muscle RNA/DNA ratio among grayling collected from the two natural streams. Among grayling collected from the five sites in the artificial stream, the only significant difference in RNA/DNA ratio was between fish collected from PDC site 7 and the lower PDC site (\( P < 0.01 \); Fig. 4).

In comparison to grayling collected from Polar-Vulture stream, muscle proteins were significantly decreased in grayling collected from PDC site 10 compared to Pigeon stream (\( P < 0.01 \); Fig. 5). Mean muscle protein levels ranged 13.7–15.4 \( \mu \text{g/mg tissue} \) in fish collected from the artificial stream (overall mean 14.5 \( \mu \text{g/mg tissue} \)) and 18.7–19.6 \( \mu \text{g/mg tissue} \) in fish collected from the natural streams (overall mean 19.2 \( \mu \text{g/mg tissue} \); Fig. 5). There were no significant differences in muscle protein levels among grayling collected from the two natural streams or among grayling collected from the five artificial stream sites (Fig. 5).

Correlational analyses were performed comparing morphometric and biochemical measures among all fish collected from natural and artificial streams. Significant direct (positive) correlations were observed between morphometric measures in grayling (fork length and body weight) and whole body triglycerides (\( r = 0.53, P < 0.001 \) and \( r = 0.56, P < 0.001 \), respectively; data not shown). Similarly, significant direct correlations were observed between fork length/body weight and muscle protein concentration (\( r = 0.48, P < 0.001 \) and \( r = 0.50, P < 0.001 \), respectively; data not shown). There was a trend for an inverse (negative) correlation between fork length/body weight and muscle RNA/DNA ratio, but these correlations were not statistically significant (\( r = -0.19, P = 0.068 \) and \( r = -0.19, P = 0.067 \), respectively; data not shown).

**Discussion**

Previous work in these same study sites reported that the age of YOY grayling collected just prior to outmigration from streams to lakes in late August was approximately 50 days after swim-up.
over-wintering period (Jones et al., 2003a). Similar to previous
thus represents a large percentage of first year growth prior to the
mass and length of grayling at this time
fish.

Multiple comparison test. Data are means ± standard errors of the mean of 6–15
fish.

(Jones et al., 2003a,b). The mass and length of grayling at this time
thus represents a large percentage of first year growth prior to the
over-wintering period (Jones et al., 2003a). Similar to previous
years (Jones et al., 2003a), grayling fry collected in late August
from the artificial stream in the current study were smaller in size
(fork length and body weight) compared to grayling collected
from nearby natural streams. Comparing all grayling collected
from artificial (n = 60) and natural (n = 30) streams, there was an
overall 16% decrease in fork length and 61% decrease in body
weight in fish from the artificial stream. However the classical
measure of fish condition, mass-at-length, was not different
among study sites. Thus, growth allometry of grayling was similar
among study sites but the growth rate of YOY grayling in the
artificial stream was slower than in natural streams. Bioenergetic
analysis in a previous study reported this difference in body
length between the artificial and natural streams to be primarily
due to decreased productivity of invertebrate prey in the artificial
stream compared to fish collected from natural streams. The natural streams used as reference sites in the current
study were chosen as representative tundra streams based on a
comprehensive study of 20 tundra streams within a 40 km radius
of the artificial stream (Jones et al., 2003b). The lack of differences in
morphometric and biochemical indices of growth and condi-
tion among grayling collected from the two natural streams

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Fig. 5. Muscle protein concentrations of YOY Arctic grayling collected from two
natural streams (Polar-Vulture and Pigeon) and five sites within an artificial
stream (lower PDC, PDC 6, PDC 7, PDC 10 and upper PDC). Bars with different
letters indicate significant differences between artificial stream sites and natural
streams as detected using one-way analysis of variance followed by Bonferroni’s
multiple comparison test. Data are means ± standard errors of the mean of 6–15
fish.

The higher muscle RNA/DNA ratios in grayling collected from
certain sites along the artificial stream are consistent with these
fish allocating a greater proportion of energy to growth at the
time of sampling compared to fish collected from natural streams.
Comparing all fish collected from artificial and natural streams,
there was an overall 20% increase in muscle RNA/DNA ratio in
grayling inhabiting the artificial stream. Although there was a
trend for negative correlations between RNA/DNA ratio and both
fork length and body weight among all grayling, these relation-
ships were not statistically significant. The RNA/DNA ratio has
been proposed as a sensitive measure of short-term (days to
weeks) growth rate in juvenile fish. Use of the RNA/DNA ratio is
based on the premise that although DNA per cell remains
relatively constant, the quantity of RNA is directly proportional
to the amount of protein synthesis, and thus reflects recent
growth and nutritional condition (Buckley, 1984; McNamara
et al., 1999). The RNA/DNA ratios ranging from 3 to 5 in the
current study indicate that all YOY grayling were allocating
significant energy to growth at the time of collection (McNamara
et al., 1999; Weber et al., 2003). However, the large variability in
RNA/DNA ratios among fish and the lack of a significant
correlation between classical morphometric measures of growth
and muscle RNA/DNA ratio suggests that it may not be a reliable
measure of short-term growth rate in grayling at this life stage.
Indeed, previous studies have reported that RNA/DNA ratio is
most relevant as a measure of growth rate in very young (larval)
fish, where the majority of RNA synthesis is devoted to growth
processes (Buckley, 1984; McNamara et al., 1999).

In addition to reduced growth of YOY grayling inhabiting the
artificial stream, whole body triglyceride levels were consistently
lower in grayling collected from the artificial stream compared to
grayling collected from the natural streams. Combining all fish
analyzed from artificial and natural streams, whole body
triglycerides in fry collected from the artificial stream (n = 52)
were 44% lower than triglyceride levels determined in fry
collected from the natural streams (n = 20), and there were
significant positive relationships between morphometric growth
measures (fork length and body weight) and triglycerides. These
findings may be of considerable biological significance. Given the
importance of acquiring sufficient energy stores in the form of
triglycerides to the over-winter survival of underyearling fish
(Adams, 1999; Post and Parkinson, 2001; Biro et al., 2004),
grayling fry using the artificial stream as nursery habitat may
experience higher over-winter mortality compared to natural
tundra streams in this region. In addition, the reduced length of
YOY grayling collected from the artificial stream also increases
the chance of over-winter mortality due to relatively higher meta-
bolic rate, and thus energy utilization, of smaller fish (Post
and Parkinson, 2001). With only a few weeks remaining until ice-on
in lakes of this region, it is unlikely that YOY grayling that were
reared in the artificial stream would compensate for the lag in
growth and triglyceride storage prior to the over-wintering
period. Further research is needed to accurately assess the
over-winter survival of YOY grayling in these aquatic systems.

Similar to whole body triglycerides, muscle protein levels were
consistently lower in YOY grayling collected from the artificial
stream compared to grayling collected from the natural streams.
Combining all fish from artificial or natural streams, muscle
proteins in fry collected from the artificial stream (n = 60) were
24% lower than protein levels determined in fry collected from the
natural streams (n = 30), and there were significant positive
relationships between morphometric growth measures (fork
length and body weight) and muscle proteins. Muscle protein
content provides a measure of longer term growth than RNA/DNA
ratio (weeks to months) and is also a measure of energy storage
since proteins can be utilized as an energy source, particularly
under conditions of severe energy depletion or physiological
stress (McLaughlin et al., 1995). The muscle protein levels in the
current study provide further indication that grayling using the
artificial stream as nursery habitat exhibited impaired growth and
condition compared to grayling fry inhabiting natural streams.

The natural streams used as reference sites in the current
study were chosen as representative tundra streams based on a
comprehensive study of 20 tundra streams within a 40 km radius
of the artificial stream (Jones et al., 2003b). The lack of differences in
morphometric and biochemical indices of growth and condi-
tion among grayling collected from the two natural streams
further supports the suitability of the two natural streams as reference sites in the current study. Among grayling collected from the five sites located along the entire 3.4 km long artificial stream, there were no differences in fork length, whole body triglycerides or muscle proteins. The RNA/DNA ratio of grayling collected from the artificial stream was only different between two sites out of ten possible comparisons (PDC 7 and lower PDC). Thus, the current study suggests that growth and condition of grayling was distinctly different between the artificial and natural streams. However, further research is needed investigating the integrated nature of morphometric and biochemical measures of growth and condition during early life stages of northern fish species in order to understand how allocation of energy between growth and storage are regulated prior to the over-winter period.

A major finding of the current study was the magnitude of difference in whole body triglycerides between grayling collected from the natural and artificial streams in comparison to the other morphometric and biochemical variables measured. Among the classical morphometric variables, fork length was 16% lower overall in grayling collected from the artificial stream, while mass-at-length was not different among grayling collected from artificial and natural streams. In contrast, whole body triglycerides were 44% lower overall in grayling collected from the artificial stream compared to natural streams. In addition to the ecological and physiological importance of triglycerides in juvenile fish survival (Adams, 1999), our results suggest that triglyceride levels may also provide a sensitive biochemical measure of growth potential and condition. Our previous laboratory work reported whole body triglycerides to decrease more rapidly and to a greater extent than other morphometric and biochemical growth and condition indices, including RNA/DNA ratio (Weber et al., 2003). Muscle protein levels also appeared to be a sensitive measure of growth and condition in the current study since the overall muscle protein values in grayling collected from the artificial stream were 24% lower than proteins in grayling collected from the natural streams. Further field studies are needed to continue the field validation of these biochemical measures of condition, and to link changes in biochemical indices to ultimate factors such as over-winter survival and predation rate.

In the current study, relatively low sample sizes of grayling collected from each site (n = 6–15) might have limited the ability to statistically detect actual differences in growth and condition measures among sites. Statistical power (1 − β) is a particularly important consideration for studies investigating potential impacts of human activities such as the suitability of artificial streams in Arctic regions, since Type II errors (accepting the null hypothesis of “no effect” when it should be rejected) can influence management decisions and regulations regarding the suitability of such streams for the sustainability of native fish populations. Although power of 0.8 is traditionally considered adequate, it has recently been argued that in environmental monitoring studies equal probabilities of Type I and Type II errors (i.e., α = β) be implemented (Munkittrick et al., 2009). The variances observed for fork length, body weight, whole body triglycerides, muscle RNA/DNA ratio and muscle protein in the current study were thus used a posteriori to determine the power associated with comparisons between natural and artificial streams. Effect sizes (detectable contrasts) were based on overall mean differences in each parameter between natural and artificial streams in the current study, while retaining the n = 7 treatment levels (sites). Using this approach, comparisons of fork length and body weight between natural and artificial streams resulted in power of 0.99 and 0.98, respectively. In contrast to these morphometric measures, power was lower for the biochemical measures of growth and condition. For whole body triglycerides, overall power was 0.67, although this was influenced by the high variation in fish collected from one of the artificial stream sites (PDC 7). Excluding this site, power ranged from 0.88 to 0.99 for triglyceride comparisons among natural and artificial stream sites, suggesting adequate power for most comparisons. Statistical power associated with the overall comparison of RNA/DNA ratio between natural and artificial streams was very low (0.14), indicating that much greater sample sizes are required to reliably detect differences. Indeed, only one specific site comparison (Pigeon stream vs. PDC 7) exhibited significantly different RNA/DNA ratios in the current study. The power associated with comparisons in muscle protein concentrations was acceptable (0.81). Overall, the power analyses suggest that greater sample sizes are recommended to reliably detect differences among sites in the biochemical measures of growth and condition in grayling. To our knowledge, this is the first published evaluation of statistical power associated with these biochemical measures in native fishes.

Based on the results of the current study and past work conducted on the same sites (Jones et al., 2003a; Jones and Tonn, 2004), YOY Arctic grayling using the artificial stream as nursery habitat prior to over-wintering may be at a disadvantage with respect to their potential to survive beyond the first year and be recruited into local grayling populations. The results provide strong inferences that, at least over the short-term, artificial streams in this region may not contribute viable underyearling individuals to populations of Arctic grayling. The results also emphasize the importance of evaluating the success of fish habitat compensation projects by using integrated biological, biochemical, behavioural and physiological metrics at the appropriate life cycle stage. Fish presence is but a coarse indicator of ecosystem health and if populations of fish are deemed to be the important determinant and integrative measure of successful habitat compensation measures, it is essential that events that detract from the recruitment of individuals to the population are identified and understood. The viability of stream fish habitat compensation and restoration projects in Arctic tundra regions may not be realized for many years if nutrients, and hence food resources for higher trophic levels, remain impoverished. Further assessment of grayling reproduction and rearing in this artificial stream over the longer term may be useful; however, given the slow rates of ecological succession in streams at this latitude the required time frame for resolution may be impractical. However, short-term research on the survival of these fish over winter is feasible and thus it would be possible to determine a criterion of success for habitat compensation measures through the production of individuals with the vitality to enable recruitment to populations of the species.

Acknowledgements

This research was funded by BHP Billiton Diamonds Inc. We thank ResCan Environmental Services Ltd. for collection of Arctic grayling fry used in this study.

References
