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[Article]

Influence of Photoperiod and Feed Delivery on Growth and Survival of First-Feeding Arctic Char

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Abstract.—First-feeding Arctic char *Salvelinus alpinus* were subjected to two different photoperiods (light conditions at latitude 43°28′N [normal] and 24 h of continuous light) and two different feeding schedules (fed only during the natural photoperiod [normal] and 24-h continuous feeding) for 12 weeks. Arctic char subjected to 24 h of continuous light and continuous feed availability had a significantly lower cumulative mortality ($P < 0.05$) and higher mean final weights ($P < 0.05$) without an accompanying increase in within-treatment variability compared with fish raised in either ambient photoperiods or under restricted feeding regimens. These results indicate potential commercial benefits associated with extended photoperiod and feeding regimens for the culture of juvenile Arctic char.

The purpose of this study was to assess the effects of two photoperiods and two feeding regimens on the survival and growth of first-feeding Arctic char *Salvelinus alpinus*. Our objective was to test the hypothesis that extended feeding and photoperiod regimens would result in a more successful transition from endogenous yolk reserves to exogenous commercial starter feeds, leading to improved survival and better growth of Arctic char fry. Such a result could be beneficial to the industry through the development of new strategies for the early rearing of Arctic char.

The Arctic char is the northernmost-living freshwater fish and has a circumpolar distribution (Finstad et al. 1989). This distribution exposes Arctic char to large changes in photoperiod not experienced (to the same degree) by other salmonids (Johnson 1980). Feeding and growth of Arctic char in the wild are seasonally variable (Johnston 2002). For example, immature anadromous Arctic char from a northern Norwegian population grew much less during winter (Jørgensen et al. 1997). In addition, landlocked wild populations in Lake Muzelle in the French Alps were found to feed most vigorously and grow fastest during a 5-week period from late June until the end of July (Cavalli and Chappaz 1996).

It is often assumed that such seasonal trends are related to water temperature without careful consideration of the possible effects of natural dramatic changes in photoperiod upon feeding behavior. However, there are data that suggest factors other than temperature affect seasonal variations in feeding. Higgins and Talbot (1985) reported that some seasonal differences in feeding were recorded even when fish were held at constant temperature, suggesting that factors other than temperature are involved in this seasonality. A full understanding of the effects of photoperiod and feeding cycles is important to aquaculture. Johnston (2002) previously described the effect of photoperiod light–dark cycles as being one of the most exciting areas of experimentation in Arctic char culture techniques.

Methods

Experimental animals.—A 12-week experiment was conducted at the Alma Aquaculture Research Station (AARS) at the University of Guelph in Ontario, Canada, from March to May 2000. Fish were from a Labrador strain of Arctic char that had been held at the AARS since 1989. Eggs were fertilized in November 1999 on two dates that were 7 d apart and then incubated in a vertical tray incubator (Flex-a-lite Consolidated, Inc., Milton, Washington). Seven days posthatch, 24,500 fry (determined by volumetric weight measurements) were removed from the incubator and placed into two flow-through fiberglass fry troughs held at ambient groundwater temperatures of 8.5°C. At that time, fry with obvious skeletal deformities and yolk sac abnormalities were culled. Five days before the first feeding, fry from both tanks were pooled together and then randomly distributed into

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TABLE 1.—Environmental parameters measured immediately before (influent water quality) or during (light intensity) photoperiod experimentation at the University of Guelph, Ontario, Canada, to assess the effects of two photoperiods and two feeding regimens on survival and growth of first-feeding Arctic char, March–May 2000.

Environmental variable	Measured value(s)
Temperature[a]	8.5 ± 0.1°C
Oxygen concentration[a]	10.6 ± 0.2 mg/L
pH	7.8
Alkalinity	230 mg $CaCO_3$/L
Hardness	261 mg $CaCO_3$/L
Total suspended solids	1.2 mg/L
Nitrate nitrogen	0.54 mg/L
Nitrite nitrogen	<0.1 mg/L
Ammonia nitrogen	0.06 mg/L
Light intensity[a]	47.36 ± 5.38 lx
Photoperiod	24 h or ''natural''

[a] Mean ± SD.

experimental units in lots of 100 fry until each unit held 2,000 fry.

Experimental rearing units.—Experimental units consisted of 12 fiberglass fry troughs (2.20 m long × 0.40 m wide × 0.25 m high). Water depth was initially 6 cm and a screen was positioned in the middle of the tank to restrict the rearing volume to 0.024 m^3 (1.00 m long × 0.40 m wide × 0.06 m deep). Initial flow rates were 10.5 ± 0.5 L/min that resulted in a current that forced fry to hold station and allowed the tank to remain relatively clean. At week 10, water depth and flows were increased to 9 cm and 15.5 ± 0.5 L/min, respectively, to reduce fry densities while maintaining the original current speed.

Influent groundwater quality was constant throughout the course of the trial at a temperature of 8.5 ± 0.1°C, a dissolved oxygen concentration of 10.6 ± 0.2 mg/L, and a total gas saturation of 100.4%. All other water quality parameters were within acceptable limits (Stickney and Kohler 1990) for salmonid culture (Table 1).

Experimental design and procedures.—To investigate the effect of photoperiod regimen and time of food delivery on the growth and mortality of first-feeding Arctic char, a 2 × 2 factorial experiment (two photoperiods [natural and 24-h continuous light] × two feeding regimens [normal and 24-h continuous feeding]) that utilized three replicates per treatment was employed. Six fry troughs were located in each of two lightproof rooms. Each room was illuminated with four 150-W incandescent lightbulbs that produced approximately 47.36 ± 5.38 lx (at full intensity). One experimental room was supplied with continuous 24-h light (24-h photoperiod treatment). The second experimental room had a photoperiod set to simulate the ambient light at the AARS (43°28′N, 80°31′W; Greenwich time less 5.0 h; natural photoperiod treatment). Lights were controlled by a self-written computerized software program that simulated dusk and dawn and allowed the lights to be turned on or off incrementally over 45 min. The duration of the natural photoperiod was adjusted weekly according to sunrise–sunset tables provided by the Herzberg Institute of Astrophysics (National Research Council of Canada, no date).

One group of three randomly selected tanks in each experimental room was fed at 90-min intervals the entire 24 h of each day (24-h feeding treatment) so that feed was offered regardless of absence or presence of light. The second group of three tanks in each experimental room was fed every 90 min during the identified local natural photoperiod (normal feeding treatment) so that feed was only introduced during periods of light. Feed was dispensed with vibrating feeders (Sweeney Enterprises, Inc., Boerne, Texas; Model SF6) and programmable automatic controllers (Sweeney Enterprises; Model AFT1-QA) so that each tank was equipped with a single feeder. One controller operated the feeders in both rooms that were designated ''24-h feeding,'' while a second controller operated feeders in both rooms that were designated ''normal feeding.'' The duration of feeding events and feeders were adjusted on a weekly basis so that the daily ration of feed was evenly dispensed.

Feeding.—Fry were fed Nutra Starter mash (Moore-Clark Company, Inc., Vancouver, British Columbia, Canada) at 10 g/tank from first feeding until the fry averaged 0.15 g. At mean sizes of 0.15 g to 0.8 g, the fry were fed Nutra Starter #0 at a ration of 4.25% body weight/d. From an average initial size of 0.8 g through the end of the trial, fry were fed Nutra Starter #1 at a ration of 4.25% body weight/d. Feed rations for each tank were adjusted weekly based on either the actual tank biomass or on an estimation of the biomass with the use of growth predictions determined with thermal-unit growth coefficients (Cho 1992).

Every morning the tanks were cleaned of any uneaten feed and fish waste by briefly removing the standpipe at the end of the tank and gently brushing the floor of the tank with a test-tube brush. Mortalities were removed from the tank and the number and condition of mortalities were recorded. Feeders were then replenished with the appropriate ration for the tank biomass.

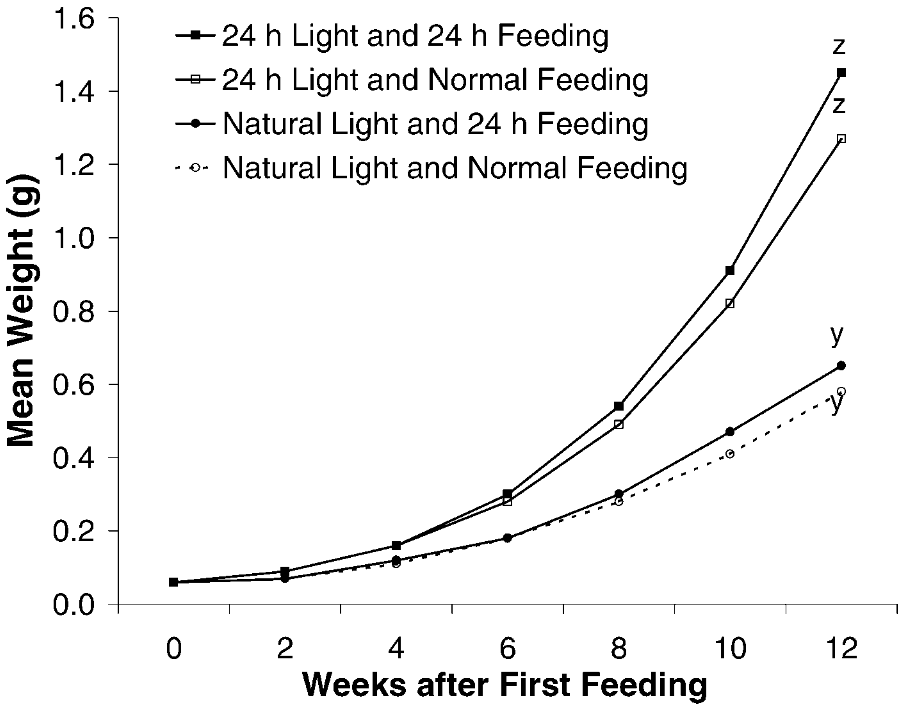

FIGURE 1.—Growth of first-feeding Arctic char held under 24-h continuous light or natural-photoperiod light conditions and fed continuously over 24 h or only during those hours associated with the daylight portion of the natural photoperiod. Lines with the same letter are not significantly different from one another. Plotted symbols represent means (N = 3).

Measurements and analysis.—At the start of the trial (T_0) and at 2-week intervals through the end of the trial at week 12 (T_2, T_4,. . . , T_{12}), fry from each tank were mass weighed to determine total tank biomass. Using the initial count of fry and mortality records, the average weight of fry within a tank was determined. At T_{12}, 20 fry from each tank were individually weighed. Flows were measured and adjusted at the time of each sampling. Dissolved oxygen concentrations were measured with a Handy Beta (OxyGuard International A/S, Birkerød, Denmark) at T_0, T_4, T_8, and T_{12} immediately before sampling.

Statistical analysis.—All data were subjected to analysis of variance (ANOVA) with the Statistical Analysis Software general linear model procedure (SAS Institute 2001). Significance was assessed at a level of $\alpha = 0.05$.

Results

Continuous photoperiod (24 h versus natural) was a more important factor than feeding period (24 h versus normal) in increasing both growth and survival of first-feeding and early-rearing Arctic char.

Growth

At the end of the 12-week experiment, Arctic char reared under a 24-h photoperiod had a significantly higher mean weight than Arctic char reared under a natural photoperiod ($P < 0.001$; Figure 1). Under both lighting regimens, the presentation of food over the 24-h period versus normal feeding resulted in a higher, though not statistically different ($P = 0.0572$), final mean weight. Fish also had greater final mean weights without a commercially significant increase in variance between individuals when reared under a continuous lighting regimen (Table 2).

Mortality

Fish under a 24-h photoperiod had significantly lower cumulative mortalities than fish reared under the natural photoperiod after the 12-week experiment ($P = 0.0016$; Figure 2). Under the 24-h photoperiod, the presentation of food continuously over the 24-h period versus normal feeding resulted in a lower cumulative mortality level. The opposite was observed under the natural photoperiod; the 24-h presentation of food was associated with an increase in cumulative mortality.

TABLE 2.—Individual weights (g) of Arctic char under experimental rearing treatments for 12 weeks at the University of Guelph, Ontario, Canada, to assess the effects of two photoperiods and two feeding regimens on survival and growth of first-feeding Arctic char, March–May 2000. Data with the same letter indicate that no significant differences exist. see text for treatment descriptions.

Statistic	Natural light and normal feeding (N = 20)	Natural light and continuous feeding (N = 20)	Continuous light and normal feeding (N = 20)	Continuous light and continuous feeding (N = 20)
Mean (g)	0.526 y	0.650 y	1.279 z	1.420 z
Variance (g)	0.077	0.142	0.132	0.121

Discussion

Growth

Arctic char fed continuously (24 h) with a 24-h photoperiod grew faster than in all other treatments. Furthermore, within the 24-h-photoperiod group, there was no significant increase in observed size variation between fish in the same group, possibly indicating that fish had equal access to feed and grew at similar rates. Variation in individual growth has been a problem in the commercial culture of Arctic char, causing lower overall production and higher production costs; in fact, variation in growth has been listed as one of the major problems with current culture practices (Jobling et al. 1998). A decrease in within-class variability by maximizing feeding success for all young fish would result in increased feed efficiencies and reduced handling of fish and lead to improved commercial production at the fry stage.

There have been previous studies of salmonid photoperiod manipulation effects upon growth rates. The results in this study differ from Skilbrel

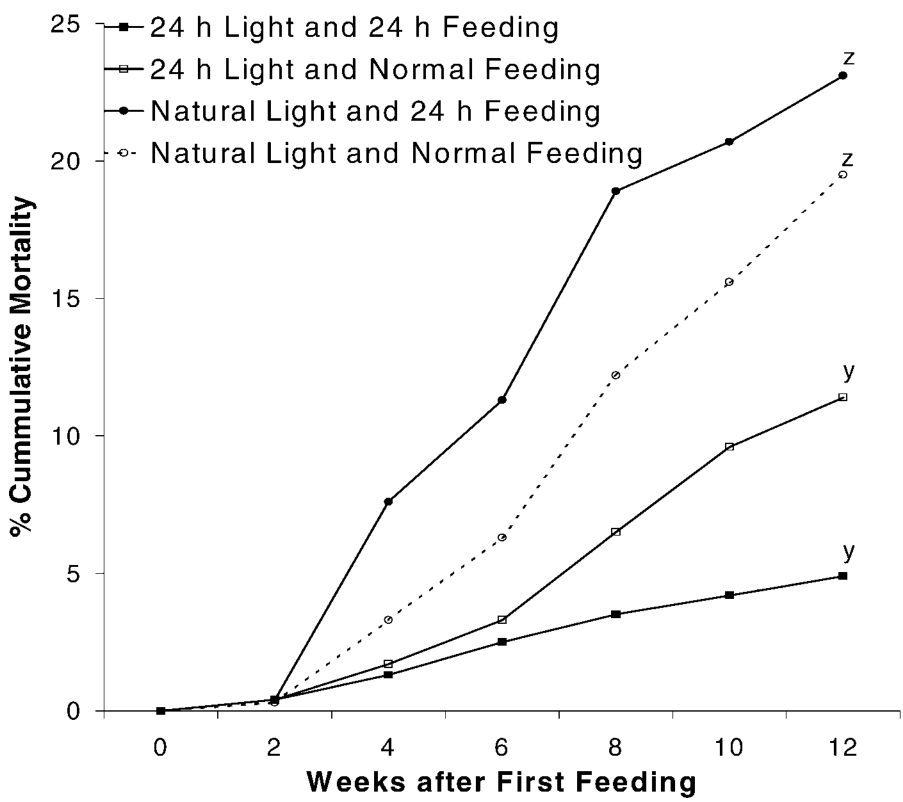

FIGURE 2.—Cumulative mortality expressed as a percentage of the total tank population of first-feeding Arctic char held under 24-h continuous light or natural-photoperiod light conditions and fed continuously over 24 h or only during those hours associated with the daylight portion of the natural photoperiod. Lines with the same letter are not significantly different from one another. Plotted symbols represent means (N = 3).

et al. (1997), who found no significant change in growth rates of Atlantic salmon *Salmo salar* with an increase in day length. However, Stefansson et al. (1990) reported that Atlantic salmon growth rate and survival during the first 3 weeks was higher under constant light compared with a simulated natural photoperiod.

Longer photoperiods have been associated with increased growth in fishes of various ages. Giri et al. (2002) observed a lower growth rate with a shortened photoperiod in larval giant catfish *Wallago attu* (a freshwater catfish commonly fished in rivers of the Indian subcontinents) with a 0-h lighting regimen (total darkness) that resulted in the lowest mean final weight. It is generally accepted in such cases that darkness reduces growth by inhibiting food intake, the method by which a 24-h photoperiod in this study is suggested to have increased growth. Johnston et al. (2003), investigating continuous light treatment in sea-caged Atlantic salmon, reported a 30% mean biomass increase relative to ambient photoperiod in under 10 months along with a significant relative increase in body mass observed after 126 d. The authors showed that muscle fiber recruitment was increased by a continuous light treatment. Moreover, there was a shift in relative ratio of the type of muscle fiber in the continuous light treatment (a 28.5% increase in fast muscle fibers). This work suggested that photoperiod increases might also contribute to changes in fish muscle content or type. Leiner and MacKenzie (2001) reported an increase in muscle mass with increasing photoperiod and suggested that photoperiod-induced changes were mediated through a growth-related endocrine pathway. Appreciable changes in the body composition of a farmed fish can require subsequent changes in the diet for optimal growth and can have positive or negative effects upon consumer preference of the final product.

Mortality or Survival

This study shows that a 24-h photoperiod with increased food presentation decreased cumulative mortality in Arctic char fry. There are similar reports of larval survival being enhanced in other fish through elongation of the photoperiod. For example, with giant catfish it was demonstrated that culture of larvae under a 24-h lighting system maximized survival (Giri et al. 2002). Such changes in mortality rates could be directly related to changes in larval feeding success. Low survival (seen in previous experimental treatments with a shorter-than-natural photoperiod) may be a result of impaired feeding during darkness caused by reduced feed contrast. Giri et al. (2002) reported a similar result by demonstrating higher survival with longer photoperiods while showing the lowest survival in a 24-h-dark lighting regimen, presumably a result of reduced feed contrast for the larvae. In addition, Hinshaw (1985) reported that feed contrast at feeding onset was an important factor for yellow perch *Perca flavescens* survival and growth. Other reports of food contrast being important for first feeding have been made in young Dover sole *Microstomus pacificus* (Dendrinos et al. 1984; Howell 1997). These results are consistent with the findings of this study, as a 24-h photoperiod would enable more young Arctic char an opportunity to access feed that is more readily distinguishable by improved contrast. Therefore, an increase in feeding success could result in the observed reduction in mortalities caused by undernourishment.

Implications

Although studies of Arctic char indicate that feeding patterns might be complex and not evenly distributed over a 24-h cycle nor simply classifiable as being either ''daytime or nighttime'' (Jørgensen and Jobling 1989), there is often a peak in feeding behavior at either dusk or dawn. It should be noted that virtually all of these studies involve juvenile or adult fish and the behavioral response of first-feeding fry to photoperiod could be both different and less flexible. It has been suggested that Arctic char may be able to visually locate and capture prey at lower light levels than other salmonids (Dervo et al. 1991). Arctic char, like other salmonids, are known to prefer lower basic working light levels in the range of 50–100 lx (Johnston 2002). Reliance on visual cues for feeding is common in most teleosts (Miner and Stein 1993; Hart et al. 1996), and although salmonids are generally considered to be visual feeders (feeding constantly during daylight), nighttime feeding and feeding in complete darkness has been observed in some species (Hoar 1942; Landless 1976; Higgins and Talbot 1985; Jørgensen and Jobling 1989; Dervo et al. 1991). Giri et al. (2002) reported highest survival with a 24-h photoperiod and a red light source for giant catfish. The authors concluded that the use of a red light might have improved feed intake by the larvae and resulted in a higher survival rate. A potential consideration for future studies is the effect of light intensity and wavelength on Arctic char growth and survival.

An important consideration for optimizing fish culture is recognizing that feeding behavior in fish is often cyclic and light dependent. Bolliet et al. (2001) reported that groups of rainbow trout *Oncorhynchus mykiss* displayed a very consistent diurnal feeding behavior. They reported that in a 12 h light: 12 h dark photoperiod study with demand feeding, groups of rainbow trout fed 80–100% during the light phase demonstrated a diurnal feeding preference, while groups of Wels catfish *Silurus glanis* fed 60–90% during the dark phase showed a nocturnal feeding preference. These feeding cycles are synchronized (at least partially) by differences in photoperiod associated with seasonal daylight changes (Boeuf and Le Bail 1999). Hansen et al. (1992) stated that photoperiod is probably the most important cue to adjust seasonal timing in salmonids and is also important in synchronizing salmonid feeding rhythms. When subjected to restricted feed cycles and photoperiod cycles to synchronize demand-feeding behavior, rainbow trout feeding rhythm was preferentially synchronized to the light–dark photoperiod manipulation (Bolliet et al. 2001). Results in this study demonstrate that first-feeding Arctic char feeding behavior may also be synchronized to photoperiod and, thus, photoperiod should be an important consideration in their culture.

Although further study is required to adequately investigate what the results of this study suggest, the response of Arctic char fry to various photoperiod regimens is not as flexible as that of older fish. In northern Labrador, the fry commence first feeding at a time when illumination exceeds 19 h/d. It seems likely that fry have adapted to long periods of daylight by seeking food visually and that the absence of light might impair foraging ability to the point where some fry are unsuccessful in the transition from yolk reserves to exogenous foods. Ali et al. (1984) concluded in their study on the retinal structure of the Arctic char that, while the retina had no special features that would limit the Arctic char to a particular photoperiod environment, there was an innate flexibility in its circadian system of photoreceptors. This flexibility ensures that the Arctic char is adaptable to continuous light or continuous darkness as well as the alternating light–dark cycle in the spring and fall. It is possible that the initial retinal structure of newly hatched Arctic char fry is in a light-adapted condition, enabling the fry to forage under the well-illuminated conditions it initially encounters in the wild. Conversely, such a retinal adaptation would decrease the fry's ability to capture food under conditions of low illumination or absence of light.

Conclusion

The results from this study validate anecdotal reports in the industry that an increased photoperiod (i.e., 24 h of light) with an increased availability of food results in faster growth, reduced size variation, and higher survival in first-feeding and early-rearing Arctic char. Commercial farmers could use these methods to improve growth and survival of Arctic char fry.

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