

Enhancing Productive Capacity in the Canadian Arctic: Assessing the Effectiveness of Instream Habitat Structures in Habitat Compensation

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Abstract.—We examined the effectiveness of physical habitat structures (ramps, V-weirs, vanes, and groins) at increasing the productive capacity of a newly created 3.4-km artificial stream in the Barrenlands region of the Northwest Territories, Canada. We quantified changes in fish density and growth in the immediate area of each structure and for the artificial stream as a whole using before–after–control–impact approaches. Emphasis was on young-of-the-year (hereafter, age-0) Arctic grayling *Thymallus arcticus*, the dominant fish in the artificial and nearby natural streams. Structures attracted significantly higher densities of fish than did nearby reference sections, yet the age-0 Arctic grayling at the structures did not experience any density-dependent reduction in growth, suggesting that structures provided energetically favorable microhabitats. Relative to reference streams and prestructure conditions, however, the addition of these physical structures did not increase the density, biomass, or growth rates of age-0 Arctic grayling in the artificial stream as a whole. At that scale, weather conditions and a lake outlet effect strongly affected the production of Arctic grayling. We suggest that stream-scale benefits of structures may not be fully realized until more allochthonous and autochthonous organic matter is available to the benthic fauna and fish.

Traditional approaches to stream restoration focus on small-scale physical prescriptions, including the addition of instream structures, to enhance habitat quality and quantity. Such actions are often relatively short-lived, but can nevertheless be beneficial while natural, habitat-forming processes rebuild fish habitat (Roni et al. 2002). Habitat structures are typically designed to enhance fish production by providing a suitable combination of physical conditions. Successful habitat structures likely provide three important features associated with trade-offs between foraging and predation risk: (1) velocity refuge, (2) visual isolation, and (3) overhead cover (Fausch 1993). Frequently, habitat enhancement structures are designed for a particular life history stage that appears to be limited (e.g., spawning or juvenile habitat). Less frequent are instream structures that focus on nonfish components, such as the production of invertebrates for fish consumption. Regardless of the objective, scientific evaluations of restoration efforts are needed to provide a basis for learning from our collective experiences (Bradshaw 1996; Minns et al. 1996).

The focus on instream habitat structures is based on the notion that the supply of suitable habitat ultimately limits fish populations (Minns 1997). However, relationships between physical characteristics of streams, habitat productivity, and fish production are often poorly understood. This limited understanding between habitat and fish production is particularly true in the Arctic. Unlike temperate regions (see White 1996), few attempts at stream restoration or enhancement have been made in northern areas. However, the need for proven techniques and a better understanding of high latitude stream ecology has never been more pressing. In the last 50 years, arctic regions have experienced a steady expansion in both the development of their natural resources and in environmental impacts (Schindler 2001). Increasing pressures, however, have not been matched by increases in research directed toward mitigating ecosystem impacts.

In the present study, we examined the effectiveness of four types of habitat structures (ramps, V-weirs, vanes, and groins) at increasing the productive capacity for Arctic grayling *Thymallus arcticus* and other fish in a 3.4-km artificial stream created on the Canadian tundra as part of a regulatory program to compensate for fish habitat lost in development (DFO 1986). To date, there have been few serious attempts to restore or enhance fish habitat specifically for Arctic grayling (Stirling 1979;

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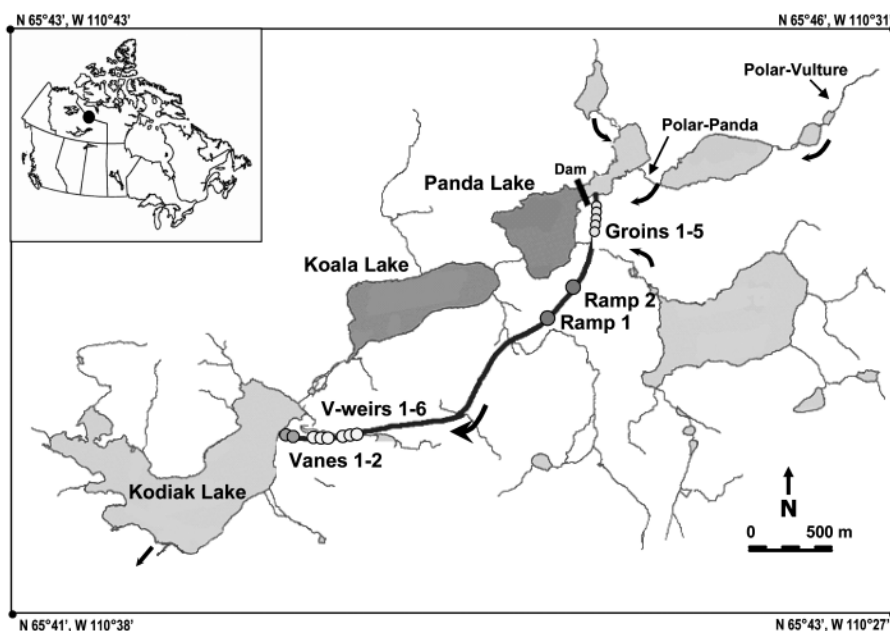


FIGURE 1.—Map showing the location of the artificial stream in relation to lakes in the watershed. Koala Lake and the dark portion of Panda Lake were drained and developed as open-pit mines. Water flow is indicated by the arrows. The locations of fish habitat structures are indicated along the artificial stream.

Hunter and Fernet 1990), especially in high latitude streams (Armstrong 1986; Northcote 1995). Because the “as built” artificial stream largely lacked the typical habitat features produced by natural stream processes, the addition of physical habitat provided an excellent opportunity to examine the contributions that instream structures can make to stream productive capacity. Employing a modified before–after–control–impact (BACI) design (Stewart-Oaten et al. 1986), we quantified changes in fish density, biomass, and growth of fish at two spatial scales in both the immediate area of the structures and for the artificial stream as a whole.

Methods

Study area.—Our study centered on a site at 64°45'N, 110°30'W, which is in an area of the Northwest Territories of Canada known as the Barrenlands. This semiarid region (200–300 mm annual precipitation, 50% of which falls as snow) occurs within the Southern Arctic Ecozone (Environment Canada 2004). In 1991, diamonds were discovered in this remote region. In preparation for mineral extraction at the first of several mines scheduled for development, two lakes and their tributary streams (set within a larger chain of lakes) were drained. A habitat compensation agreement with the Canadian Department of Fish-

eries and Oceans required the mine to construct an artificial stream to restore watershed connectivity for fish migration and to provide spawning and nursery habitats to offset losses in stream habitat. Since 1997, water has been diverted around Panda and Koala lakes, now open-pit mines, through the artificial stream (Figure 1). Starting at the end of the artificial stream's first full year in operation (1998), habitat structures were added to enhance fish production. Structures were built with a particular focus on Arctic grayling as they dominate fish communities in the Barrenlands (Jones et al. 2003a).

Despite its 3.4-km length, the artificial stream originally had a limited number of habitat types. The artificial stream is often constrained by steep (10–90°) and high (2–10 m) banks, with a single channel throughout its entire length. Naturally occurring wetlands and boulder gardens are absent, while riffles and pools are few; about half the artificial stream length consisted of featureless sandy flats. Fine sediments (silt, clay, and sand) comprise 44% of the substrate, versus only 14% in natural streams in the region (Jones et al. 2003b). Rock lines a largely unvegetated riparian zone, whereas natural streams have riparian zones dominated by dwarf birch *Betula glandulosa*, willow *Salix* spp., and sedge *Carex* spp. Aquatic vegetation common

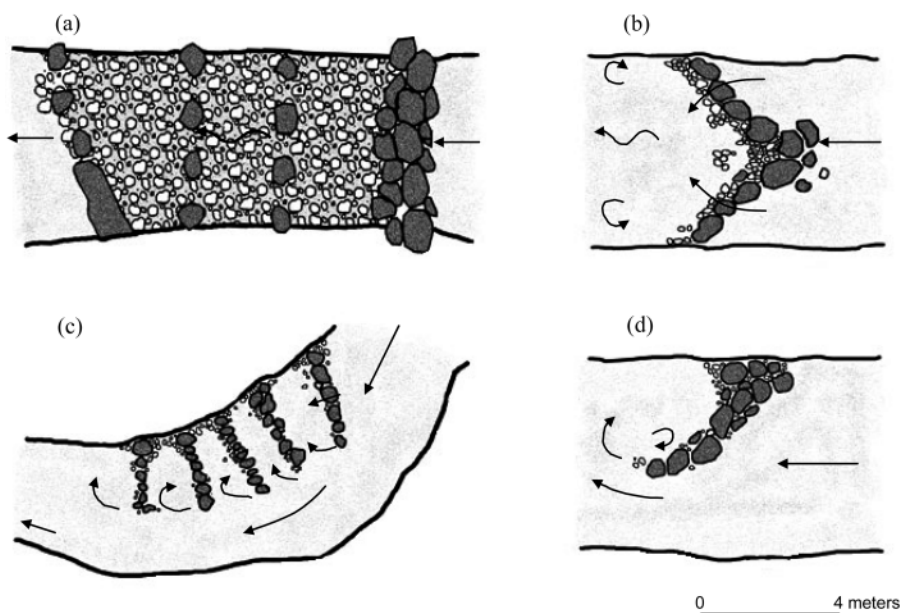


FIGURE 2.—Planar views of each structure constructed in the artificial stream: (a) ramp, (b) V-weir, (c) vanes, and (d) groin. Arrows indicate the general direction of water movement.

in natural streams (e.g., bur reed *Sparganium hyperboreum* and mare's-tail *Hippuris vulgaris*) is also very rare in the artificial stream (Jones et al. 2003b).

Habitat structures.—Because of safe-access constraints to much of the central portion of the artificial stream, added habitat structures were concentrated in the upstream and downstream reaches. In the upper 1 km, five groins and two ramps were added, while six V-weirs and two vanes were added to the downstream end of the artificial stream (Figure 1). Each structure (see Figure 2) was built with aggregate removed from eskers in the region. Because large woody debris is not naturally found in tundra regions, no wood was used in structure construction. Descriptions of each structure type, the type(s) of habitat it provides, the function of those habitats with respect to the needs of adult and age-0 Arctic grayling, and the general influence of each structure on water velocities and depths are summarized in Table 1.

Study design.—Our assessment of structure effectiveness included examinations at two spatial scales: in the immediate area of each structure (mesohabitat) and for the artificial stream as a whole (macrohabitat). For structure-scale assessments, we quantified the effects of structures on Arctic grayling density, biomass, and growth rate using adjacent unmodified sections of artificial stream as

references (as defined by Chapman 1999). At the scale of the whole stream, the first summer (1998) represented the “before” or premanipulation period and the following three summers (1999–2001) postmanipulation. Three nearby natural streams—Polar-Vulture (PV; Figure 1), Polar-Panda (PP; Figure 1), and Pigeon (PG)—were used as references during all or part of the study period.

Structure-scale assessment.—In streams of the study area, larval Arctic grayling can first be observed swimming freely at the beginning of July, with yolk sacs still visible. Subsequently, all fish out-migrate to overwinter in nearby lakes, with the majority of age-0 Arctic grayling leaving by late August. We estimated total fish density (fish/m³) and biomass (g/m³) using the three-pass removal method (Zippin 1958) twice at each structure, on 20 July and 20 August 2000, to incorporate changes in habitat use with increasing age-0 Arctic grayling size. During electrofishing, block nets (5-mm mesh) were used to prevent immigration and emigration, and care was taken during net placement not to displace fish. Reference sections were located upstream and (or) downstream (~10 m) of sections with structures; some references were shared among several structures that were in close proximity. There were at least three reference sections for each structure type studied. In August 2000, the five groin structures were electrofished

TABLE 1.—Description of each structure type in an artificial stream, habitat structure, function of each structure with respect to habitat needs of adult and age-0 Arctic grayling, and general influence on water velocities and depths (Wesche 1985; Lowe 1989; Rosgen 1996).

Structure	Description	Habitat structure	Function	Hydraulic effect
Ramp	Inclined plane sloping downstream	Riffle	Spawning	Structure forces water to be shallow and fast
V-weir	Large boulders forming an upstream-pointing chevron	Pool and run	Nursery habitat and velocity refugia for migrating adults	Water flow is directed to the center of the artificial stream; depth created by scouring and turbulence created by weir boulders provide cover
Vane	A series of five parallel, fingerlike projections perpendicular to shore consisting of large boulders	Riffle and shallow backwater	Nursery habitat and velocity refugia for migrating adults	Deflects the thalweg to opposite side of stream; provides contrasting local water velocities; promotes point-bar formation via erosion of the opposite shore and deposition on the proximate shore
Groin	Single fingerlike projection composed of large boulders angled $\sim 45^\circ$ downstream	Pool, run, and shallow backwater	Nursery and possibly spawning areas may be located off the tips of the structures	Deflects the thalweg to opposite side of the stream; increases local water velocities and scour potential

as a unit because fish densities at individual sites appeared too low for proper estimation. Captured fish were identified, enumerated, weighed (± 0.01 g), measured (fork length ± 1 mm), and released. Section volume (i.e., mean depth from 5 to 10 transects perpendicular to flow multiplied by mean width and section length) was determined for each section shortly after being fished. Computations for population estimates were made separately for Arctic grayling, slimy sculpin *Cottus cognatus*, and burbot *Lota lota* using the program CAPTURE (version 1; White et al. 1982). For each species in each section, we estimated total fish biomass by multiplying the mean individual mass for a species by the number of fish estimated for that section of stream. Upwards of 90% of the estimated numbers of fish were typically captured in each fished section of stream. For each structure type, we used *t*-tests with Bonferroni adjustments to determine if mean fish densities and biomass differed between manipulated and control sections.

We used mass and length data from the previously described sampling at structures and reference sections of stream to determine whether structures affected the growth of age-0 Arctic grayling. This comparison was conducted only for the 20 July sample date (3 weeks after swim-up) because Arctic grayling movements become too extensive later in the summer, which prevented an accurate assessment of the effects of the structures. For each structure type, we used *t*-tests with Bonferroni adjustments to determine if the mean mass

of age-0 Arctic grayling differed between treatment and reference sections of the streams. As above, there were three reference sections for each structure type.

Stream-scale assessments.—Between 1998 and 2001, we conducted analogous assessments of fish density and biomass, and of age-0 Arctic grayling growth, at the whole-stream scale. Both spatial (artificial stream versus natural streams) and temporal (before versus after structure addition) comparisons were used in the assessments.

We estimated total fish density (fish/m³) and biomass (g/m³) in the artificial stream and nearby Polar-Vulture stream in late July 1998–2000 using previously described methods. In the artificial stream, 14 sample sections of stream, 60–100 m in length and typically incorporating several habitat structures, were electrofished per year. In the shorter, 700-m-long Polar-Vulture, 10 sample sections of stream, 30–75 m in length, were electrofished per year. In both streams, roughly half of the sections represented fast-flowing habitat and half were slow habitats. Roughly the same sections were sampled in each year. Upwards of 75% of the estimated numbers of fish were typically captured in each fished section.

The specific growth rate (SGR) of age-0 Arctic grayling was estimated for the artificial stream and Polar-Vulture, Pigeon, and Polar-Panda streams by the equation

$$\text{SGR} = \frac{\log_e M_2 - \log_e M_1}{t_2 - t_1} \times 100, \quad (8)$$

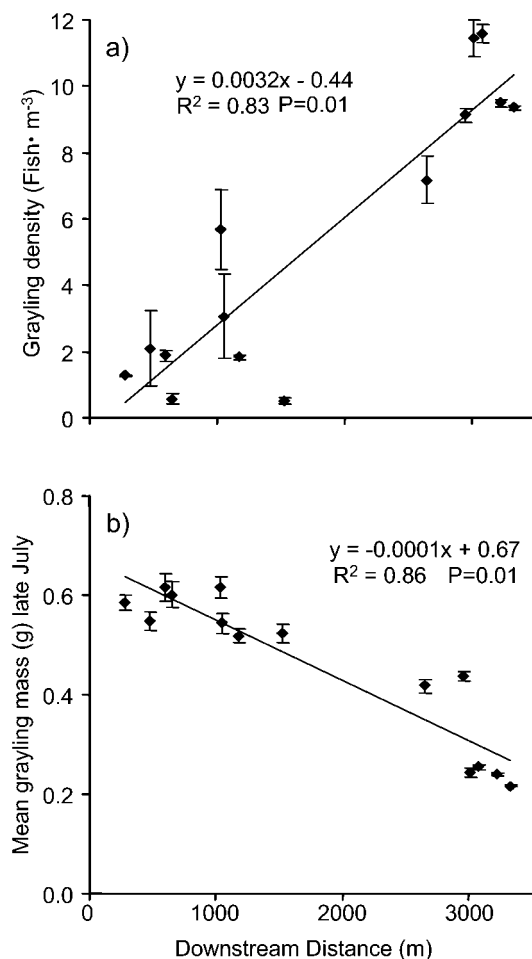


FIGURE 3.—Mean \pm SE (a) density and (b) mass of young-of-the-year Arctic grayling from reference sections of the artificial stream in late July 2000 in relation to downstream distance from the lake outlet. A 900-m stretch of the artificial stream, approximately midway between the source and mouth, is inaccessible to sampling.

where M_1 and M_2 are the mean mass of Arctic grayling shortly after swim-up (approximately 14 mm total length) in early July and shortly before out-migration in late August, respectively, and t_1 and t_2 are the days of the year for those two samplings.

For all statistical testing we used the Kolmogorov–Smirnov test to examine data for normality and Levene’s median test for homogeneity of variances. Where needed, we log-transformed data. For all statistical tests we used 0.05 as a critical level of significance following Bonferroni adjustment when required to reduce experimentwise error rate.

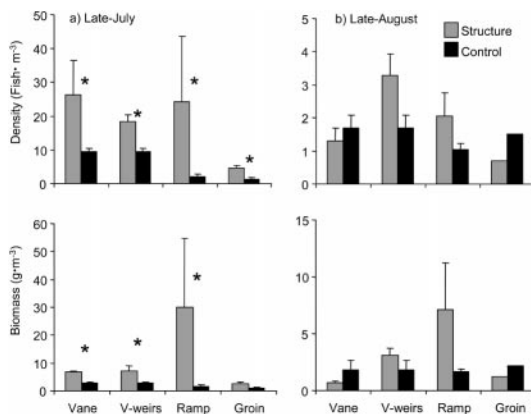


FIGURE 4.—Mean \pm SE density and biomass of fish at each structure and associated reference sections of stream in (a) late July and (b) late August 2000. Asterisks indicate significant differences (t -test with Bonferroni adjustment, $P < 0.05$).

Results

Upwards of 80% and 52% of fish in the artificial stream were age-0 Arctic grayling in July and August, respectively; the remainder consisted of slimy sculpin and burbot. Compositions in the reference streams were similar (Jones et al. 2003b). The highest Arctic grayling densities occurred in the last 700 m of the artificial stream, where the majority of Arctic grayling spawning took place. (Figure 3a). In contrast, there was a strong negative relationship between the size of age-0 Arctic grayling and their location downstream in the artificial stream (i.e., fish closer to the upstream lake outlet were larger; Figure 3b).

Structure-Scale Assessment

Habitat structures maintained their form during the study, even after an estimated 100-year flood in the spring of 1999. This large flood was the first to scour substrata sufficiently to redistribute sediment throughout the artificial stream and among the structures.

Fish density in late July was higher at all structure types than at reference sites (Figure 4a). With the exception of groins, fish biomass was also higher at all structures. Despite higher densities and total fish biomass at structures, the growth of age-0 Arctic grayling at the structures was generally comparable to the growth in reference sections by late July (Figure 5). By late August, however, densities and biomasses were reduced at both reference and structure sites (Figure 4b).

During our sampling, it became clear that ramp

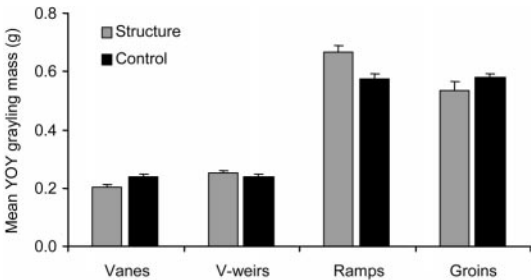


FIGURE 5.—Mean \pm SE mass of young-of-the-year Arctic grayling at each structure and associated control sections of stream in late July 2000. Average sample size is 147 fish per section of stream.

1 presented an exceptional situation. Fish densities at ramp 1 were particularly high in July despite its upstream location: almost twofold higher than at other habitat structures, and almost fourfold higher than at many reference sections of stream. Although densities and biomasses of fish had returned to reference levels by late August at the other structures, both remained elevated at ramp 1 relative to reference sites (density: 43.8 ± 4.8 individuals/ m^3 at ramp 1 versus 2.8 ± 2.2 individuals/ m^3 at references; biomass: 54.6 ± 5.7 g/ m^3 at ramp 1 versus 2.2 ± 1.1 g/ m^3 at references). Yet despite the dramatically higher densities at ramp 1, age-0 Arctic grayling at that structure were almost 20% larger in late July than fish at the nearby reference sites (0.67 ± 0.01 g versus 0.54 ± 0.02 g, respectively).

Stream-Scale Assessment

Spawning stock size in the artificial stream, as determined by a manually operated fish fence, increased consistently over time (1998: 103 adults; 1999: 185 adults; 2000: 411 adults, with a 1:1 sex ratio). In contrast, climatic conditions were most favorable in 1998, least in 1999, and intermediate in 2000 and 2001 (Table 2). Overall, fish densities differed among years and between streams (Figure 6a). Densities decreased slightly in both systems

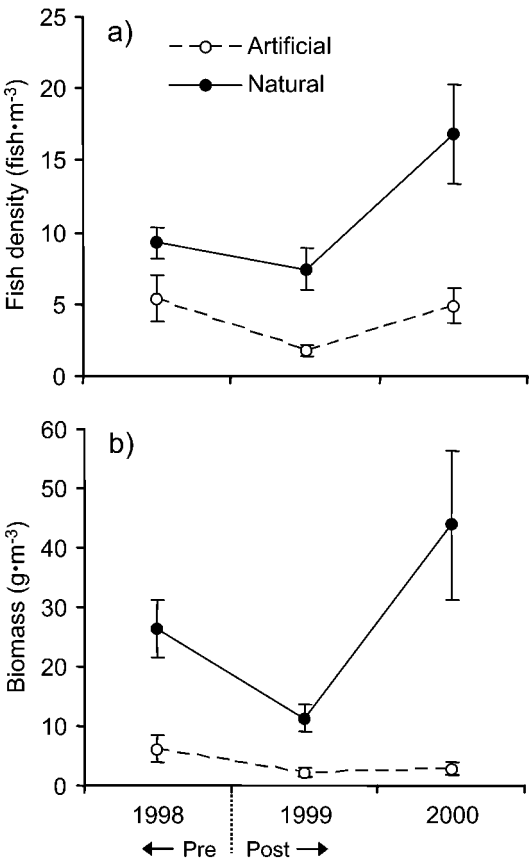


FIGURE 6.—Mean \pm SE (a) density and (b) biomass of fish in the artificial stream and the natural Polar-Vulture stream in late July 1998 (pretreatment period) and late July 1999 and 2000 (posttreatment period).

between 1998 and 1999 before increasing more substantially in 2000. Polar-Vulture typically supported higher fish densities than the artificial stream, and proportional differences between the two streams generally increased over time.

Fish biomass was also affected by year and stream (Figure 6b). Biomass was lower overall in 1999 than in 1998 or 2000, and was consistently

TABLE 2.—Annual variation in weather and discharge during June–August 1998–2001 and accumulated degree-days from spawning to 23 August in relation to mean young-of-the-year mass from the artificial stream and Polar-Vulture stream (see Jones et al. 2003b).

Variable	1998	1999	2000	2001
Accumulated rainfall (mm)	88	180	118	134
Mean discharge (m^3/s)	0.03	0.14	0.13	0.16
Degree-days ($^{\circ}\text{C}$) from spawning to 23 August	1,137	882	1,029	934
Mean mass (g) on 23 August	3.80	1.78	2.55	1.78
Polar-Vulture stream				
Artificial stream	1.60	0.99	1.11	1.01

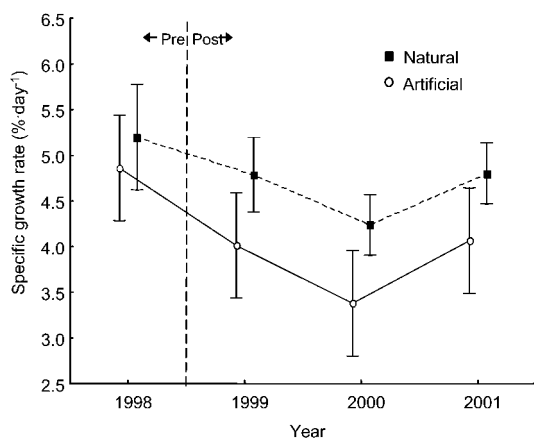


FIGURE 7.—Growth rates \pm SE of young-of-the-year Arctic grayling from swim-up to late August for the artificial stream and three natural streams during 1998 (before habitat structures were added to the artificial stream) and 1999–2001 (after structures were installed).

higher in Polar-Vulture than in the artificial stream. Overall, the relative difference between the artificial stream and Polar-Vulture increased from 1998 to 2000 (i.e., posttreatment). Density and biomass were typically higher in fast-flowing versus slow sections in both streams.

For the 1998–2001 study period, SGR differed among years. Growth was highest in all streams in 1998 and lowest in 2000 (Figure 7). Still, the relative difference in growth between the artificial stream and Polar-Vulture was larger after structures were constructed (Figure 7). The SGRs of Arctic grayling from natural Barrenland streams were consistently greater than rates for fish from the artificial stream.

Discussion

Structure-Scale Assessment

All structures were effective at attracting fish, as evidenced by their higher densities (numerical and biomass) in late July relative to neighboring reference sites. This suggests that structures provided some appealing characteristics (e.g., velocity refuge, visual isolation, and/or overhead cover, all important components of habitat for stream fishes; Fausch 1993).

Young-of-the-year Arctic grayling experienced an ontogenetic shift in habitat use between the July and August samplings, reducing their concentration in the vicinity of the structures. Overall, fish density and biomass decreased 10-fold and four-fold, respectively, during this period, but decreases were relatively greater at vanes and groins. Indeed,

densities at these two structure types fell slightly below levels at the reference sites in August. Observations from streambanks indicated that the two structures provided quiet, shallow backwaters habitat for age-0 Arctic grayling shortly after swim-up (early July), but as they grew, young of the year moved to deeper, midchannel habitats. In European grayling *Thymallus thymallus*, this ontogenetic shift occurs when fish exceed approximately 30 mm (Sempereski and Gaudin 1995). Results from our study are generally consistent; Arctic grayling were $31 \text{ mm} \pm 4.5 \text{ SD}$ and $46 \text{ mm} \pm 8.3 \text{ SD}$ during our July and August samplings, respectively. Despite the fact that higher densities of fish were attracted to structures (at least through July), the growth of age-0 Arctic grayling did not experience any density-dependent reduction (Keeley 2001), further suggesting that structures provided energetically favorable microhabitats for the smaller young of the year.

Another pattern revealed by the structure-scale assessment was the longitudinal gradients in density and growth of age-0 Arctic grayling. Higher densities of young of the year were observed at the downstream end of the artificial stream, whereas greater growth was achieved at the upstream end. These patterns were likely due, in part, to the behavior of spawning adults who concentrated their activities within the downstream reaches, and to the density-dependent growth of young of the year that resulted from this. We suggest, however, that the pattern was also the result of the ecology of lake outlet streams (see Haraldstad et al. 1987; Richardson and Mackay 1991). A steady supply of lake-derived energy (fine particulate and dissolved organic matter) and stable flows and temperatures often support higher densities and biomass of filter-feeding benthic invertebrates within the first 100–400 m in such streams (Carlsson et al. 1977). These filter feeders, in turn, serve as prey for small fish, facilitating their growth (Gibson 2002).

This lake outlet gradient, rather than any inherent superiority of the upstream structures, probably contributed to the higher growth rates at groins and ramps relative to growth at the vanes and V-weirs, which were located at the downstream end of the stream. In turn, the much-reduced food availability likely contributed to the smaller Arctic grayling at the downstream end of the artificial stream.

Ramp 1 was particularly effective at increasing both the density of fish and the growth of age-0 Arctic grayling, achieving levels of the latter that

rivalled the growth in natural streams (Jones et al. 2003b). Although its performance was not replicated, this structure's success appeared to result from the large number of black fly *Simulium* larvae that this ramp attracted (N. E. Jones, unpublished data). Unlike other structures (including ramp 2), ramp 1 decreased channel depth and forced the water to move swiftly over its incline, creating flow conditions that were favorable for black fly larvae attachment and their capture of particulate organic matter (Hershey et al. 1995; Ciborowski et al. 1997). Although ramp 1 is 1 km downstream from the lake (beyond the typical lake outlet effect), it is the first location where critical flow velocities and suitable benthic habitat are provided, and it is likely the first location where large amounts organic matter are taken out of the water column by filter feeders. This, in turn, supported high densities of fast-growing young of the year.

Stream-Scale Assessment

The density and biomass of age-0 Arctic grayling in the artificial stream varied considerably during the study years. The same qualitative trends were also noted in Polar-Vulture, suggesting that climatic conditions contributed to this year-to-year variation. However, the differences in density and biomass of fish between Polar-Vulture and the artificial stream actually increased, at least proportionately, after habitat structures were installed in the latter (1999–2000). At the outset of this and other research on the artificial stream (see Jones et al. 2003b) we did consider that the artificial stream may be building towards an equilibrium. However, given that the rate of recovery from disturbance in the Arctic is very slow, an equilibrium will likely not be reached for hundreds or thousands of years. As a result, it is unlikely that we would see major changes within our 4 years of study. In fact, we have reason to believe that the artificial stream has been heading in the “wrong” direction, as illustrated by the increased difference between it and the natural streams over time. Initial construction exposed areas of permafrost tundra, which then melted and eroded, carrying organic matter into the stream. Much of this erosion has now stabilized and the small amounts of organics initially added have been processed and/or washed out during spring freshets. We think this might explain the unexpected increase in the difference in growth rates between the artificial and natural stream (Figure 7).

The SGR of age-0 Arctic grayling also varied considerably among years. During their first sum-

mer, the growth of Arctic grayling is strongly affected by climate-related variables, including precipitation, discharge, and growing degree-days (Table 2; Jones et al. 2003b). Specific growth rate in the artificial stream was highest in the year prior to structure construction (1998), but this was also true for the reference stream (Polar-Vulture) and likely reflected the favorable weather and weather-related conditions of that year. As with density and biomass, stream scale differences in growth between the artificial and reference streams increased following the addition of the structures. Thus, there was no evidence to indicate that the addition of the instream structures increased the productive capacity (*sensu* DFO 1986) of the artificial stream in the first 2 years following their installation.

Assessing Structure Effectiveness: Scale of Measurement and the Role of Energy

Our BACI-style examination of the effectiveness of habitat structures at enhancing productivity for fish, especially age-0 Arctic grayling, gave contrasting results at the two spatial scales examined. When comparing densities, biomass, and growth of fish at the instream structures relative to nearby reference sections, it was clear that the structures increased local densities, especially early in the season, without a corresponding density-dependent cost in growth. Observations of Arctic grayling suggested that once habitat structures were built, many age-0 Arctic grayling opted for a “stayer” over a “mover” foraging strategy (Grant and Noakes 1987). Apparently, at least some structures provided one or a combination of the following: velocity refuge, visual isolation, and overhead cover; this resulted in reduced energetic costs associated with foraging, maintaining position, predator vigilance, or territoriality (Fausch 1993). In contrast, we saw no evidence of a stream scale enhancement of Arctic grayling in the artificial stream, either in an absolute sense or relative to the performance of reference streams. This suggests Arctic grayling were simply drawn from the nearly featureless reference sections to structurally enhanced sections. As noted elsewhere, habitat enhancement can lead to a simple redistribution of animals without actually increasing total numbers, growth, or survival (Van Horne 1983; Reeves et al. 1991; Gowan and Fausch 1996), although that is not likely the ultimate goal of most enhancement projects.

Although habitat structures probably provided favorable habitat for fish in the artificial stream, we suggest that a fundamental paucity of allo-

chthonous and autochthonous organic matter was equally or more limiting than structural deficiencies to the production of age-0 Arctic grayling (and their invertebrate prey) at the whole-stream scale. Jones et al. (2003b) concluded that while the current paucity of autochthonous and riparian-based organic matter in the artificial stream is ultimately limiting the growth and production of age-0 Arctic grayling, physical habitat also appeared to play a role worthy of further investigation. The exceptional success of ramp 1 appears to have resulted from its facilitating the capture of allochthonous organic matter by filter feeders. Ramp 1, although an unreplicated phenomenon, might thus suggest how an increased availability of organic energy can increase the productive capacity of the system.

Typically, the success of stream habitat modification or compensation projects is determined by increasing the net productive capacity of a stream reach rather than at an individual site because a local increase can be achieved simply at the expense of the production of fish at other sites. As observed elsewhere, instream habitat structures do not often address the fundamental problems within a catchment (e.g., lack of riparian vegetation) and, consequently, are often unsuccessful in the long run (Beechie and Bolton 1999). We suggest that a stream scale benefit of structures in this artificial stream, and likely other habitat modification projects in the Arctic and other oligotrophic systems, may not be fully realized until more allochthonous and autochthonous organic matter is available to the benthic fauna and the fish. This suggestion emphasizes the importance of riparian vegetation and other functional biotic components of stream ecosystems to our restoration efforts (Sweeney 1992; Harrison and Harris 2002), and echoes the argument of Sedell and Beschta (1991) to “bring back the bio in bioengineering.”

Acknowledgments

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