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SHORT COMMUNICATION

RATE OF BIOTIC COLONIZATION FOLLOWING FLOW RESTORATION BELOW A DIVERSION DAM IN THE BRIDGE RIVER, BRITISH COLUMBIA

A. SCOTT DECKER,[a] MICHAEL J. BRADFORD[b]* and PAUL S. HIGGINS[c]

[a] *1034 Fraser Street, Kamloops, BC V2C 3H7, Canada*
[b] *Fisheries and Oceans Canada and Cooperative Resource Management Institute, School of Resource and Environmental Management, Simon Fraser University, Burnaby, BC V5A 1S6, Canada*
[c] *BC Hydro, 6911 Southpoint Drive, Burnaby, BC V3N 4X8, Canada*

ABSTRACT

In August 2000, a continuous flow release was initiated below a diversion dam in the Bridge River, British Columbia, to rewater 4 km of stream bed that had been without flow for 37 years. Within a month after the start of flows, periphyton and invertebrate populations were present in the previously dry reach. Juvenile salmonids were common downstream of the rewetted reach, but only a few moved upstream to the new habitats after flow restoration. However, adult salmon quickly colonized the rewetted area and spawned 1–8 months after the onset of flow. Age-0 salmonid abundance was high 1 year later and appeared to be largely due to successful spawning in the new reach rather than the upstream migration of juveniles. We conclude that the full colonization of the new reach will take more than a year as a consequence of the migratory patterns of the salmonids species in the river, and that monitoring programs for habitat restoration should be cognizant of the lags in the response of target populations because of their life histories. Copyright © 2008 John Wiley & Sons, Ltd.

KEY WORDS: stream restoration; colonization; salmonids; instream flow; Bridge River

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INTRODUCTION

Although stream restoration is widely practiced in North America as a means to improve the diversity and productivity of aquatic communities, the absence of carefully designed monitoring studies hinders the evaluation of these activities and the advancement of the science and practice of stream rehabilitation (Moerke *et al*., 2004).

One aspect of the assessment of newly created or restored habitats which has not often been documented is the rate at which these habitats become colonized and productive. Most colonization studies have focused on the response of streams to disturbances, such as floods or anthropogenic factors, such as chemical spills (reviewed by Detenbeck *et al*., 1992). Monitoring recovery rates could lead to insights into the colonization of novel or altered habitats by aquatic species (Malmqvist *et al*., 1991; Moerke *et al*., 2004). In addition, an understanding of how quickly the new habitat reaches a steady state is important for the design of monitoring or adaptive management studies because if there are long lags, additional years of monitoring may be required to evaluate the benefits of restoration (Bradford *et al*., 2005).

The augmentation or normalization of streamflows in stream reaches whose discharge regimes have been altered by dams is commonly used to restore aquatic ecosystems. In some cases, little or no water is released from these facilities, resulting in highly altered or degraded stream habitats until tributary inflows restore more natural flow regimes downstream (Harris *et al*., 1991). Increasing the base flow, reducing unnatural flow variation and providing a seasonal hydrograph are all thought to be needed to improve instream and riparian conditions (Stanford *et al*.,

*Correspondence to: Michael J. Bradford, School of Resource and Environmental Management, Simon Fraser University, Burnaby, BC V5A 1S6, Canada. E-mail: mbradfor@sfu.ca

1996). However, as is the case with other stream restoration methods, there are few documented case studies of flow augmentation, and the results of those have been mixed (e.g. Harris *et al*., 1991; Scruton *et al*., 1998).

Here, we document the initial colonization of a rewatered stream channel after the institution of a naturalized flow regime downstream from a diversion dam in the Bridge River, British Columbia. With the exception of infrequent forced spill events (Higgins and Bradford, 1996) no water has been released below the diversion dam since it was built. The purpose of our study was to describe the process of colonization, and identify the temporal scale for any lags that might occur between the time of water release and the onset of fish production. We hypothesized that biotic colonization would occur in a step-wise manner, beginning with the establishment of suitable physical conditions, the development of periphyton and invertebrate populations and finally the colonization of the reach with fishes.

METHODS

The Bridge River is a tributary of the Fraser River (confluence: 50°45′N, 121°56′W) located on the east side of the Coast Mountains of British Columbia. The Bridge River is impounded 43 km upstream of its confluence by the Terzaghi Dam, which was completed in 1963. Prior to dam construction, the Bridge River had a mean annual discharge of 100 $m^3 s^{-1}$ with maximum streamflows exceeding 900 $m^3 s^{-1}$ (PS Higgins, unpublished data). With the exception of 11 forced spills lasting 1–13 weeks each, between 1963 and 2000 all inflows above the dam were diverted to the adjacent Seton Lake (see Higgins and Bradford, 1996 for more detail and a map). This interbasin water diversion resulted in the complete dewatering of a 4 km long section of the river immediately downstream of the dam, although there were two large pools caused by depressions in the relic streambed that were supplied by groundwater and leakage from the dam. Although not sampled, these pools were likely a source of periphyton and invertebrates for the colonization of the restored reach. About 4 km below the dam groundwater and small tributaries provide a continuous flow cumulating in a mean annual discharge of approximately 0.7 $m^3 s^{-1}$, 15 km from the dam. The stream channel is confined by steep mountain slopes and has a moderately high (1–3%) gradient in both the dry and wetted sections. Substrate composition is predominantly large boulders (>25 cm diameter) and cobble (13–25 cm diameter). Fifteen kilometres downstream from the dam, the unregulated Yalakom River joins the Bridge River and supplies, on average, an additional 4.3 $m^3 s^{-1}$ (monthly mean minimum 0.92 $m^3 s^{-1}$, maximum 20.8 $m^3 s^{-1}$; Water Survey of Canada gauge 08ME025, 1983–2005) to the remaining 28 km long section extending to the confluence with the Fraser River.

The fish community of the Bridge River is largely juvenile salmonids that are progeny of adults that spawn below the dam. Both andromous (steelhead trout) and non-migratory resident (rainbow trout) forms of *Oncorhynchus mykiss* are found, and are the most abundance salmonid. Coho (*O. kisutch*) and chinook salmon (*O. tshawytscha*) are also common. Juvenile densities >1 fish m^{-2} have been observed about 10 km downstream from the dam (Bradford and Higgins, 2001), indicating the river was quite productive prior to the flow release. Bull trout (*Salvelinus* spp.) and mountain whitefish (*Prosopium williamsoni*) are also present in the Bridge River, but are most common in downstream reaches.

A water release program was initiated in 2000 to restore flow to the dewatered stream channel immediately below the dam. The flow release is part of an adaptive management experiment to explore the relationship between flow and salmon productivity (Failing *et al*., 2004). Continuous flows were made possible through the installation of a water release valve in an existing outlet at the bottom of the dam. The valve was tested and sediments that had accumulated in the intake structure were flushed during a 2-h flow release in April 2000. The continuous flow release (4 $m^3 s^{-1}$) was initiated at 1100 h on 1 August 2000. This flow was part of a semi-naturalized flow regime that ranged from 2 $m^3 s^{-1}$ during the winter months and peaked at 5 $m^3 s^{-1}$ during summer.

Because the dry riverbed was shaped by the pre-regulation flows, and further modified by forced spills (Higgins and Bradford, 1996) and placer mining, the first 2.2 km of the channel downstream from the dam was regraded prior to the release to be more appropriate for the magnitude of the flows to be released from the dam. A pool-riffle structure with some small side channels was constructed. Boulders and woody debris were added for habitat complexity and gravel was placed in riffle areas resulting in the construction of 1600 m^2 of new spawning habitat for salmonids.

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MONITORING PROGRAM

The establishment of biota in the rewetted reach was evaluated by monitoring periphyton, invertebrate drift and salmonid abundance. We defined two study reaches. The first 4 km below the dam that lacked continuous flow is referred to as the rewetted reach, and was distinguished from the area further downstream that experienced continuous flow from groundwater and small tributary inputs. Sampling was conducted at four main sites; three were located in the rewetted 1.3, 2.8 and 3.5 km from the dam, and a fourth was in the continuously flowing reach 4.3 km from the dam.

Periphyton colonization was assessed by estimating the accrual of periphyton on artificial substrates following the method of Perrin *et al*. (1987). Three styrofoam sheets weighted with concrete blocks were placed at depths of approximately 30 cm in the stream at the four main sampling sites. We also obtained data from an additional site in the continuous flow reach 6.7 km from the dam. Sampling was conducted at approximately weekly intervals by punching three replicate 5 cm diameter disks from each sheet. The density of chlorophyll *a* ($\mu g\,cm^{-2}$) on each styrofoam core was measured using acetone extraction and spectrophotogammetry (Strickland and Parsons, 1972). The first series was started immediately after the start of the flow and continued for 4 weeks; the second was started on 28 August and was terminated in early November 2000.

We sampled invertebrate drift at the four study sites using Mundie (1964) samplers equipped with 250 μm mesh nets. The site in the continuous flow reach was sampled on 28 July 2000, just prior to the flow reintroduction, and all sites were sampled 8, 31, 65 and 103 days after the initiation of the flow. On each sampling occasion, four samplers were operated continuously for 24 h in duration. The volume of water sampled was calculated from the cross sectional area of the sampler, and the mean water velocity at the opening was measured at the start and end of the sampling period. Samples were preserved in 3% formalin and subsequently identified to family, and counted. Following sorting and counting the samples were dried at 50°C for 24 h, and total weight for each sample was measured using an electronic balance accurate to 0.0001 g.

The periphyton and drift data were analysed with a mixed-model ANOVA, with sites treated as a random effects nested within reach (rewetted, or continuously flowing) using the SAS procedure MIXED. Data were log-transformed to stabilize variances.

The colonization of the newly rewetted reach by salmonids was assessed by underwater surveys conducted at the three sites in the rewetted reach 8, 31, 65, 103 and 403 days following the reintroduction of streamflow. The site in the continuous flow reach was sampled on these days and was also sampled on 28 July 2000, just prior to the flow reintroduction. In order to sample the range of habitat conditions in the Bridge River, our sites were 100 m long, composed of 60–70% riffle and 30–40% run/pool habitat.

Counts of salmonids at each site were made by two divers and were conducted at night because juvenile salmonids are often concealed in the substrate during the day (Bradford and Higgins, 2001). The divers entered each site at its downstream end and systematically moved upstream, each covering half the width of the channel. Surveys were begun about 0.5 h following civil twilight and completed within 4 h. Each diver used a handheld light that cast a diffuse beam to minimize the disturbance of fish. Underwater visibility was 4–5 m during the surveys. Divers visually estimated the fork length of each fish to the nearest 5 mm using ruled scales drawn on the cover of their notebooks. The divers were typically able to hold the notebooks within 30 cm of a fish to estimate its length without disturbing it.

The salmonid data were organized as steelhead or rainbow trout (*O. mykiss*) fry (age-0, <100 mm FL) and parr (age-1 and age-2, 100–220 mm FL), adult rainbow trout (age-3 to age-6, >220 mm FL), and juvenile (predominately age-0) coho and chinook salmon. For each survey and fish type, we used a *t*-test to evaluate differences in mean length between fish observed in the continuous compared to the rewetted reach.

Estimates of the abundance of spawning salmon using the rewetted reach were conducted by Fisheries and Oceans Canada stock assessment personnel. Coho and chinook salmon spawner abundances were based on area-under-the-curve and expanded peak count methodology, respectively (Cousens *et al*., 1982). Escapement estimates were not available for steelhead or rainbow trout, but an informal survey of steelhead trout was conducted during the first spawning period following the flow reintroduction (spring 2001, A. Caverly, Ministry of Water Land and Air Protection, Kamloops Region, personal communication). No estimates of resident rainbow trout spawners were available.

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RESULTS

When the continuous flow was first initiated from the dam it took approximately 8 h for the leading edge of the water to travel the 4 km to connect to the continuously flowing reach. Water temperatures ranged from 12 to 14°C on the first day. As the water moved downstream turbidity initially increased as accumulated fine material in the channel was picked up by the current, but turbidity levels fell to less than 10 NTU after 2–3 h.

The accrual of periphyton on styrofoam plates was delayed 1 week in the newly wetted reach compared to the continuously flowing reach for the first sampling series (Figure 1, upper panel). Chlorophyll *a* levels were lower in samples from the rewetted reach throughout August (ANOVA, $F_{1,3} = 18$, $p = 0.025$). Accrual was also significantly lower in the rewetted reach in the September–November 2000, series (Figure 1, lower panel; $F_{1,3} = 28$, $p = 0.014$). For both series the time × reach interactions were significant ($p < 0.001$), because of the slower rate of accrual at sites in the rewetted reach in the first few weeks of each series.

Invertebrate drift density (#/m^3) was low at all sites 1 week after the start of the flow release compared to densities in the continuously flowing reach before the release (Figure 2). Zooplankton was the dominant taxa in samples collected during the first week after the release. One month later chironomids became abundant at all sites in the rewetted reach; other stream taxa were not common. In November ephemoptera were the most common of the benthic taxa at all sites except the one closest to the dam (Figure 2). For all sampling periods zooplankton were most abundant at the upstream sites. There was significant heterogeneity in both invertebrate total abundance and dry weight among dates (abundance: $F_{3,48} = 28$, $p < 0.0001$, weight: $F_{3,48} = 6.5$, $p < 0.001$); reach × date interactions were also significant (abundance: $F_{3,48} = 11$, $p < 0.001$, weight: $F_{3,48} = 3.3$, $p = 0.03$). There was no overall difference between abundance or weight of drift organisms between the rewetted and continuously flowing reach (abundance: $F_{1,2} = 0.23$, $p = 0.68$, weight: $F_{1,2} = 6.5$, $p = 0.48$).

Few juvenile salmonids were observed in the rewetted reach in the first 3 months after the flow reintroduction (Figure 3). Some trout parr were recorded at the two downstream sites 7 days after the flow reintroduction, and after

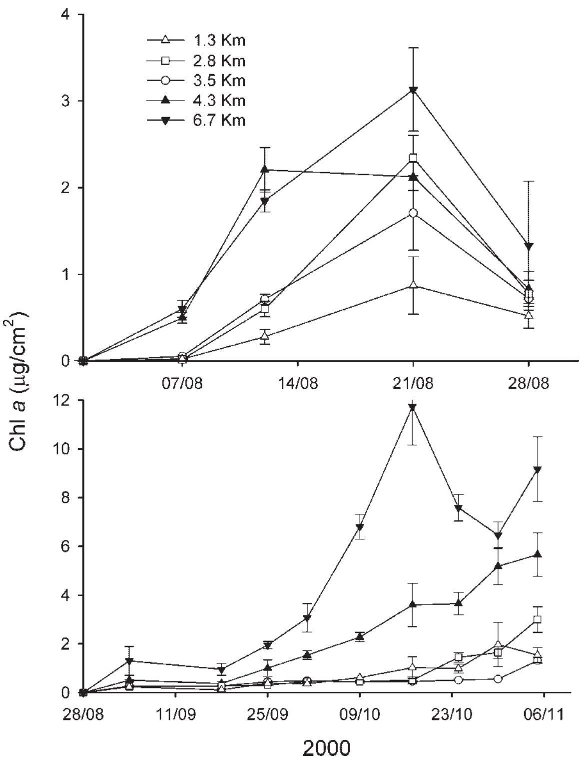

Figure 1. Mean chlorophyll *a* densities (±SE, $N = 9$) measured on styrofoam substrates in placed in the Bridge River immediately after the flow release and sampled for 4 weeks (upper panel) and placed in the river in late August and sampled for 8 weeks (lower panel). Sites are indicated by the distance downstream from the dam. Solid symbols are sites in the continuously flowing reach. Note the difference in scale between the panels

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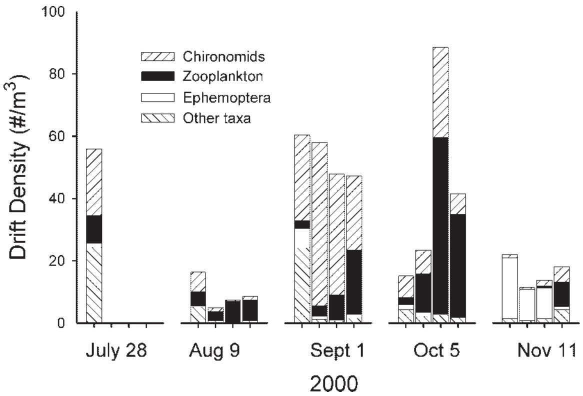

Figure 2. Density of drifting invertebrates by major taxonomic groups (mean of 4 concurrent 24-h samples) in the Bridge River. For each sampling date the histogram bars are ordered from downstream to upstream locations, located 4.3, 3.5, 2.8 and 1.3 km downstream of the dam. The first sampling date occurred prior to the flow release and data were only collected in the continuously flowing reach (4.3 km)

31 days at the uppermost site. A few coho and chinook juveniles were observed at the lowermost rewetted site as early as 7 days after the flow reintroduction, but none were observed at sites further upstream, even after 3 months (Figure 3). No adult trout and only a few trout fry were observed in the rewetted reach.

By September 2001, 1 year after the flow release, the abundance of age-0 trout and juvenile coho and chinook salmon was as high or higher at the three rewetted reach sites than at the site in the continuously flowing reach. Trout parr were found at all rewetted sites, but only at low densities. Older resident trout, which were completely absent in 2000 were present at all rewetted sites, although at very low densities compared to the continuously wetted site. There were no consistent differences in the estimated mean size of fish observed in the rewetted reach compared to those in the continuously flowing section; only 1 of 12 comparisons was significant at $p < 0.05$.

Adult chinook salmon were observed throughout the rewetted reach within a few days of the flow reintroduction, and chinook and coho were observed spawning in the rewetted reach during fall of 2000. Estimates of the abundance of spawning chinook salmon in the rewetted reach were 769 and 198 for 2000 and 2001, and 276 and 634 coho salmon were estimated to have spawned in the same years. Adult steelhead trout were observed spawning in the rewetted reach during spring 2001 (A. Caverly, Ministry of Water Land and Air Protection, Kamloops Region, personal communication), but their abundance was not estimated.

DISCUSSION

The principle result from this study was that although the rewetted reach had become suitable for juvenile salmonids within a few months after the start of the flow release, juvenile salmonids and adult rainbow trout did not immediately move upstream in large numbers into the new habitats. Instead, colonization appears to be primarily the result of upstream migrations by anadromous spawners, and successful reproduction in the new reach. The absence of upstream movements by juvenile fish or resident adult rainbow trout means that the new habitat did not reach its full potential to produce salmonids during the first year after the start of the flow release.

Physical conditions in the restored reach were suitable for colonization by biota shortly after the onset of flows. The suspension of sediments into the water column is always a concern when streamflows are initiated through new habitats or those that were previously lentic (Thompson *et al*., 2005). In our case, the source of such sediments were from the reworking of part of the stream channel, and material that has accumulated by wind and erosion since the last spill from the dam, in August 1997. We did find a short-lived pulse of suspended sediment in the rewetted reach, but it had largely dissipated by the time flows reached the continuous flowing reach.

Within a month after flow restoration algal and invertebrate populations were established in the rewetted reach. The source for these colonizations may have been the reservoir, standing water contained in depressions in the relic stream channel, flows from very small ephemeral streams and in the case of invertebrates, migrations by winged

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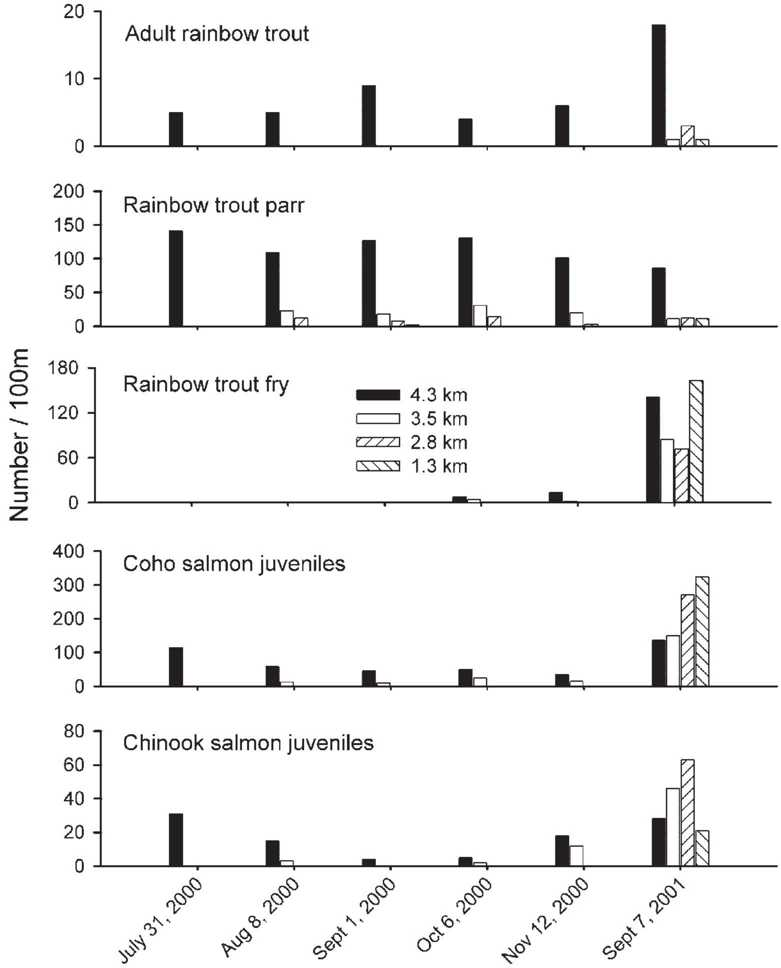

Figure 3. The sum of observations of salmonids made by two divers at the four study sites, standardized by the length of the survey reach. The sites are indicated by their distance downstream from the dam. The site at 4.3 km (solid bars) is located in the continuously flowing reach. Trout fry and parr groups include offspring of both resident and anadromous (steelhead) spawners

adults. Periphyton accrual was lower in the rewetted reach compared to sites downstream, which may have been due to the effects of the dam in limiting recruitment of algae from upstream sources. The initial colonization of invertebrates was dominated by short-lived dipterans and mayflies, as has been found in other early successional studies (Mackay, 1992). Zooplankters from the reservoir were common at the upstream sites and may also be a potentially important food source for fish rearing in the rewetted reach. Further changes in the invertebrate drift are likely as it will take a year or more for allocthonous and detrital materials to accumulate, and for longer-lived and less mobile taxa (e.g. shredders and predators) to colonize (Mackay, 1992). Densities of drifting organisms after the first month were similar to those observed in other salmonid-producing streams (e.g. Koetsier *et al*., 1996) indicating there was likely sufficient food resources to support fish.

The absence of a significant upstream movement of juvenile salmonids or adult trout into vacant, but otherwise suitable, habitats is consistent with other observational and experimental studies that indicate once individuals have established home ranges and feeding areas, many are unlikely to move significant distances (Armstrong *et al*., 1994, 1997). Armstrong *et al*. (1994) suggest that according to optimal foraging theory animals should sample alternative habitats, and move to ones in which may be more profitable. Gowan and Fausch (2002) note that optimal habitats will change with flows, and fish may sample the availability of suitable habitats after a change in flow, at least locally. However, Armstrong *et al*. (1994) found that juvenile Atlantic salmon were reluctant to move to habitats

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experimentally depleted of conspecifics during the summer months; they did find that the habitat became colonized by juvenile salmon the following year as a result of normal seasonal migrations of juveniles among habitats. In the case of the Bridge River, the lack of any natural upstream migrations of juvenile salmonids or adult trout in the summer or fall months apparently prevented the immediate colonization of the rewetted reach. The dependence of colonization rate on the seasonality of migrations relative to the timing of the disturbance has been noted for other species (Detenbeck *et al*., 1992).

In contrast, a significant upstream migration of juvenile salmonids into the upper reach of the Bridge River was observed in August 1992, when a forced spill from the dam resulted in flows that peaked at 62 $m^3 s^{-1}$ (Higgins and Bradford, 1996). A number of these fish became stranded in the channel below the dam after the flows receded and were eventually salvaged and returned downstream. The upstream movement observed in 1992 may have been stimulated by the much higher flows that likely disrupted feeding and rearing territories in the continuously wetted reach (Cowx and Gould, 1985). Although increase in flow in August 2000 may have caused fish to move to different foraging sites within in the continuously flowing reach, the increase was apparently insufficient to cause fish to abandon the reach altogether and move upstream, as was observed in 1992.

The rewetted channel was immediately colonized by adult salmon, and was used by steelhead trout spawners that returned to the Bridge River the following spring. Adult migration as a means of colonization for salmonids is consistent with other accounts of adults readily making use of new habitats created by natural (Milner and Bailey, 1991) or artificial (Bryant *et al*., 1999) means. The large numbers of age-0 fish and the continued near-absence of older fish in the rewetted reach in September 2001 are evidence that reproduction rather than upstream migration was the main mode of colonization. This result implies that it will take 2–3 years for all age classes of trout to be abundant in the restored reach.

In summary, we found that releasing water into a previously dry reach of the Bridge River resulted in the rapid colonization of the river channel with periphyton and invertebrates. Although the channel was likely suitable for juvenile fishes within a few weeks after the flow release, the life history and seasonal migration behaviours of the salmonids did not result in a rapid colonization by juveniles. The way the new reach becomes colonized will affect the utility of the salmonid monitoring data, as habitats will not be fully utilized until enough cohorts have spawned in the restored area to fully seed it with all age classes in the population. Managers may need to delay the initiation of the fish component of a monitoring program for 1 or more years to allow the newly created habitats to reach their full potential.

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