Earth Surface Processes and Landforms
Earth Surf. Process. Landforms **31**, 526–530 (2006)
Published online in Wiley InterScience (www.interscience.wiley.com) **DOI:** 10.1002/esp.1344

Letter to ESEX

A field method for the concurrent measurement of fine sediment content and embryo survival in artificial salmonid redds

Mylène Levasseur, Francis Bérubé and Normand E. Bergeron*
INRS- Eau, Terre et Environnement, 490, rue de la Couronne, Québec, G1K 9A9, Canada

Correspondence to: N. E. Bergeron, INRS-Eau, Terre et Environnement, 490 rue de la Couronne, Québec, G1K 9A9 Canada. E-mail: nbergeron@ete.inrs.ca

Received 20 October 2005;
Revised 23 December 2005;
Accepted 23 January 2006

Abstract

The infiltration cube method presented in this paper allows concurrent field measurement of fine sediment content and embryo survival in an incubating environment reproducing, as closely as possible, the morphology and grain size composition of a natural salmonid redd. An infiltration cube is made up of a rectangular (30 cm square and 20 cm high) steel frame with no walls, which has a folded plastic bag attached to its base. Each infiltration cube is buried in the substrate using a procedure aimed at reproducing, as closely as possible, the construction and morpho-sedimentological structure of a natural salmonid redd. Using a tripod installed on the river bed or at the surface of the ice, the infiltration cube method provides a quick, easy and robust way to pull relatively large samples (approximately 65 kg) out of underwater substrate even during tough winter field conditions. The absence of walls on the cube also precludes bias in infiltration rates by both allowing lateral sediment transport within substrate and preventing loss of fine particles during retrieval from underwater. Copyright © 2006 John Wiley & Sons, Ltd.

Keywords: field method; spawning gravel; fine sediment; embryo; incubation; salmonid.

Introduction

It is widely acknowledged that excessive amount of fine sediment within salmonid spawning gravel is detrimental to the survival of embryos through a decrease of the intragravel flow necessary for the oxygenation of the embryos and/or a reduction of the emergence success of fry due to entombment (see Chapman (1988), Reiser (1998) and Armstrong *et al*. (2003) for review). However, it has also been noted that almost regardless of the original fine sediment content of the spawning gravel, the digging and egg-burying process performed by the spawning female causes the removal of a significant amount of fines (Lisle and Lewis, 1992; Reiser and White, 1988), thereby ensuring an appropriate inflow of oxygenated water to the embryos at the beginning of the incubation (Everest *et al*., 1987; Kondolf *et al*., 1993). Thus, the negative effect of fine sediment on embryo survival is more dependent on the amount of fines infiltrating the redds during the period between spawning and fry emergence than on the fine sediment content of the spawning gravel before or immediately after reproduction (Lisle, 1989; Lisle and Lewis, 1992; Acornley and Sear, 1999). For this reason, assessment of gravel suitability for spawning should not be based on samples of undisturbed potential spawning gravels but on measurements of fine sediment content and associated embryo survival obtained within redds during the incubation period.

Although several methods have been used to monitor embryo survival (Harris, 1973; Gustafson-Marjanen and Moring, 1984; Lacroix, 1985; Mackenzie and Moring, 1988; Scrivener, 1988; Rubin, 1995; Donaghy and Verspoor, 1997) or fine sediment infiltration (Lisle, 1989; Wesche *et al*., 1989; Lisle and Eads, 1991; Lisle and Lewis, 1992; Fletcher *et al*., 1995; Clarke and Scruton, 1997, Acornley and Sear, 1999; Soulsby *et al*., 2001; Bond, 2002), none of them allows concurrent field measurements of embryo survival and fine sediment content in an environment reproducing a natural salmonid redd. A natural redd has a surface morphology and grain size composition which is distinct from the adjacent undisturbed gravel (Kondolf *et al*., 1993). Morphologically, it is characterized by an upstream pit and a downstream tailspill inducing a characteristic flow pattern within the redd (Cooper, 1965). In terms of grain size, it is composed of coarser lag gravels with larger pore sizes than outside the redd (Lisle and Eads, 1991; Kondolf *et al*., 1993). Based on these differences, the flow and fine sediment infiltration processes occurring inside and outside the redd area should not be similar, demonstrating the need to develop a method capable of measuring fine sediment content and embryo survival inside the morpho-sedimentological unit of the redd. Moreover, since the amount and timing of fine sediment infiltration within the redds depend on the characteristics of the flow and sediment transport events occurring during the incubation period, this method should allow measurements to be made in the time period between redd construction and emergence of fry (Lisle and Eads, 1991). The method should not utilize containers with vertical walls, whether solid or porous, since they interfere with the intragravel flow of water and infiltration of fines within the redd, as well as modifying the scour and fill processes, which may change redd gravel composition and induce embryo mortality by scouring the eggs (Lisle and Eads, 1991). Finally, the method should preclude any sampling bias due to a loss of fine particles during retrieval of the substrate samples from the channel bed.

In this paper, we present a new field method which allows concurrent measurement of fine sediment content and embryo survival in an incubating environment reproducing, as closely as possible, the morphology and grain size composition of a natural salmonid redd, as well as the flow and sediment transport conditions experienced by the embryos of natural redds during the incubation period.

Description of the method

The general principle of the method is to bury an infiltration cube containing a known amount of fertilized eggs within a morpho-sedimentological unit resembling a salmonid redd. The cube is installed in the spawning gravel during or immediately after the reproduction period of the studied salmonid species, it can then be pulled out of the substrate at any time during the incubation period in order to determine survival up to that moment and to assess the fine sediment content of the redd. However, the cube should be retrieved no later than approximately one week prior to the expected emergence of fry in order to avoid escapement of fry.

The infiltration cube ensues from a modification of the infiltration bag sampling method developed by George Sterling in 1980, but described in detail for the first time by Lisle and Eads (1991). An infiltration cube is made up of a rectangular (30 cm square and 20 cm high) steel frame with no walls, which has a folded plastic bag attached to its base (Figure 1). In our method each infiltration cube is buried in the substrate using a procedure aimed at reproducing, as closely as possible, the construction and morpho-sedimentological structure of a natural salmonid redd. First, a depression about 30 cm deep and 75 cm wide is dug in the substrate by manually excavating the particles underwater

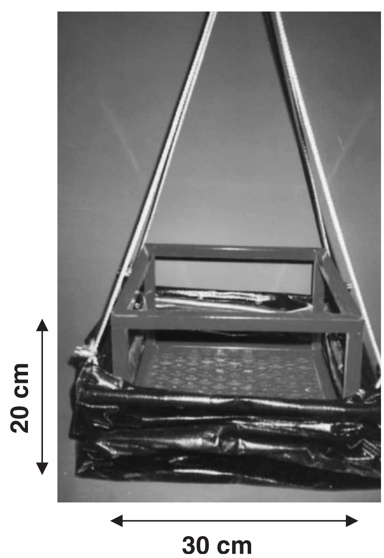

Figure 1. An infiltration cube with the folded bag attached to its base.

and pushing them into the downstream current. The infiltration cube and folded bag are then installed in the depression and covered with a layer of gravel, 5–10 cm deep, by mobilizing particles from the bed just upstream in a manner similar to a spawning female salmon. This enables a portion of fine sediment to be swept downstream by the flow, thereby constructing a redd composed of coarser lag gravels with fewer fines and larger pore sizes than outside the redd. A few large rocks are then positioned at the centre of the cube in order to create large interstices where a known number of fertilized salmonid eggs are carefully placed with a pipette to avoid losing or injuring them. The construction of the redd is then completed by covering the infiltration cube and eggs with upstream gravel in a manner that aims to reproduce the winnowing action of the spawning female. Upon completion of the artificial redd, the infiltration cube is therefore embedded in a morpho-sedimentological unit that has the typical grain size and form characteristics of a natural salmonid redd with an upstream pit and a downstream tailspill (Figure 2).

Four wires are affixed to the corners of the bag and project above the bed surface after installation for later removal. These wires are used to raise the sides of the watertight bag and winch it up along with the substrate contained by the cube using a tripod installed on the river bed (Figure 3a), on a floating platform, or on the surface of the ice (Figure 3b). When pulling the bag upward, the rectangular metal frame leads the opening of the bag in the upright direction, thereby ensuring the proper collection of the unbounded rectangular volume of substrate lying immediately above the bag. Indeed, preliminary trials of the method did not include the metal frame, and we noticed that during extraction, larger bed particles often caused the opening of the bag to deviate from the upright direction, thereby sampling diagonally the substrate towards the surface. Because we needed to ensure that all incubating embryos

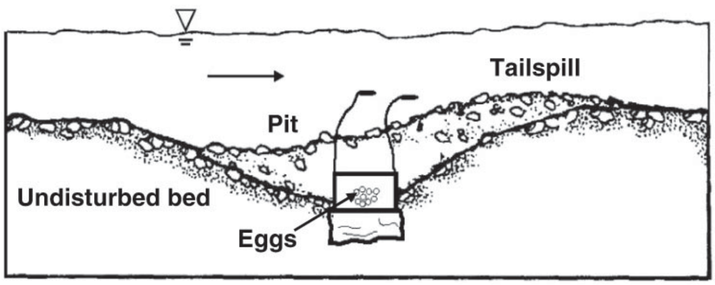

Figure 2. Infiltration cube with eggs embedded in a morpho-sedimentological unit similar to a natural salmonid redd.

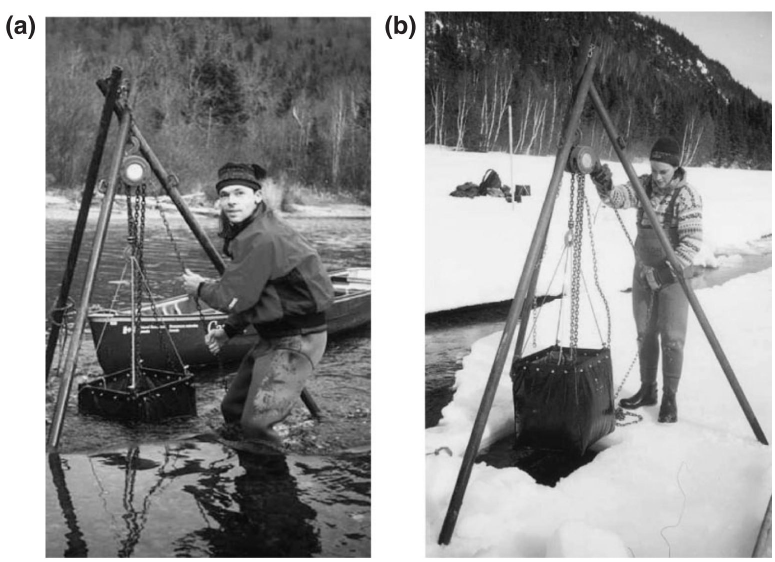

Figure 3. Extraction of an infiltration cube using a tripod installed (a) on the river bed, and (b) on the surface of the ice.

would be enclosed in the sampled volume of substrate, the concept of the rectangular metal frame with no walls was conceived and added to our methodology to solve this problem. Once retrieved from the substrate, the bag containing the substrate sample, embryos and metal cube is put in a larger container and the gravel is carefully inspected in order to count all embryos present, determine whether they are dead or alive, and identify their stage of development. The coarser part of the sample recovered from the infiltration cube (particle sizes >16 mm) is then wet-sieved and weighed in the field, and a well mixed sub-sample of the <16 mm fraction is taken to the laboratory for a standard dry-sieve analysis at 1 phi intervals.

The infiltration cube provides a quick, easy and robust method to pull relatively large samples (approximately 65 kg), yielding more precise grain size statistics, out of underwater substrate even during tough winter field conditions. The cube design also precludes bias in infiltration rates by both allowing lateral sediment transport within substrate (absence of walls on the cube) and preventing loss of fine particles during retrieval from underwater.

Comparison between artificial and natural salmonid redds

Morphologically, the artificial redds obtained by the method outlined above are characterized by an upstream pit and a downstream tailspill very similar to natural salmonid redds. In terms of grain size, we tested the ability of our redd construction method to reproduce the winnowing effect of a salmonid female constructing its redd, by measuring the fine sediment content of substrate samples taken inside and outside artificial redds immediately after construction. Nine paired substrate samples were collected, using the freeze–core technique (Walkotten, 1976; Lisle and Eads, 1991; Petts *et al*., 1989), inside and outside artificial redds constructed on an Atlantic salmon (*Salmo salar*) spawning site of the Sainte-Marguerite River (Saguenay, Québec). The results indicate that the artificial redd construction procedure had the general effect of reducing the percentage of sediment <1 mm of the artificial redds by an average of 2·3 per cent compared to the surrounding gravel. This value is comparable to the 1·1 to 5·1 per cent range of reduction values reported by Kondolf *et al*. (1993) in nine of the 13 studies of changes in fine sediment content due to spawning salmonids he analysed. This result suggests that the artifical redd construction procedure we use is adequate to replicate a natural salmonid redd.

Potential applications

As decribed above, the infiltration cube method is ideally suited for the evaluation of the quality of salmonid spawning gravel and for field studies of the effect of fine sediment on embryo survival. Levasseur *et al*. (2006) used this method at two spawning sites of the Sainte-Marguerite River, Québec, Canada, to conduct a field experiment examining the survival to hatching of Atlantic salmon (*Salmo salar*) embryos in relation to the seasonal and spatial variations of silt and very fine sand (SVFS) content within the redds. The method prevented the loss of SVFS particles during retrieval of the substrate sample from underwater, which allowed the detection of small variations of this fine fraction. Although the proportion of SVFS rarely exceeded 1 per cent of the redd, it was shown to vary seasonally and spatially and to play an important role in embryo survival to hatching, explaining more than 85 per cent of its variation.

Besides its ecological applications, the infiltration cube method could also be used to study only the dynamics of fine sediment content in river gravel by installing the cube in the substrate without reproducing the morphology and grain size composition of a redd. A precise evaluation of the total amount of fine sedimentation during the experiment would then require filling the cube with gravel having a known composition and porosity, since these characteristics are known to greatly affect the fine sediment infiltration process (Lisle and Eads, 1991). This could be accomplished either by taking an initial sample of the *in situ* bed material used to fill the cube, or by preparing an experimental gravel having a known size distribution.

Acknowledgements

We would like to thank our partners, Fonds des Priorités Gouvernementales en Science et en Technologie (FPGST-E), Centre Interuniversitaire de Recherche sur le Saumon Atlantique (CIRSA), Association rivière Ste-Marguerite, Faune et Parcs Québec (FAPAQ) and Pisciculture de Tadoussac. Special thanks to André Boivin, Marc-André Pouliot, Josélito Savard and Véronique Thériault for their assistance in the field. We acknowledge the comments of an anonymous reviewer. The research was partially funded by a discovery grant from the Natural Sciences and Engineering Research Council of Canada to Normand Bergeron. A postgraduate scholarship was provided to Mylène Levasseur by the Natural Sciences and Engineering Research Council of Canada (NSERC). This paper is a contribution to the scientific programme of the Centre Interuniversitaire de Recherche sur le Saumon Atlantique (CIRSA).

References

Acornley RM, Sear DA. 1999. Sediment transport and siltation of brown trout (*Salmo trutta L.*) spawning gravels in chalk streams. *Hydrological Processes* **13**: 447–458.

Armstrong JD, Kemp PS, Kennedy ML, Milner NJ. 2003. Habitat requirements of Atlantic salmon and brown trout in rivers and streams. *Fisheries Research* **62**: 143–170.

Bond NR. 2002. A simple device for estimating rates of fine sediment transport along the bed of shallow streams. *Hydrobiologia* **468**: 155–161.

Chapman DW. 1988. Critical review of variables used to define effects of fines in redds of large salmonids. *Transactions of the American Fisheries Society* **117**: 1–21.

Clarke KD, Scruton DA. 1997. Use of the Wesche method to evaluate fine-sediment dynamics in small boreal forest headwater streams. *North American Journal of Fisheries Management* **17**: 188–193.

Cooper AC. 1965. *The effect of transported stream sediments on the survival of sockeye and pink salmon eggs and alevins*. International Pacific Salmon Commission Bulletin 18.

Donaghy MJ, Verspoor E. 1997. Egg survival and timing of hatch in two Scottish Atlantic salmon stocks. *Journal of Fish Biology* **51**: 211–214.

Everest FL, Beschta RL, Scrivener JC, Koski KV, Sedell JR, Cederholm CJ. 1987. Fine sediment and salmonid production: a paradox. In *Streamside Management: Forestry and Fishery Interactions*, Salo EO, Cundy TW (eds). Contribution No. 57. College of Forest Resources, University of Washington: Seattle; 98–142.

Fletcher WK, McLean WE, Sweeten T. 1995. An instrument to monitor infiltration of fine sediment into stable gravel stream beds. *Aquacultural Engineering* **14**: 289–296.

Gustafson-Marjanen KI, Moring JR. 1984. Construction of artificial redds for evaluating survival of Atlantic salmon eggs and alevins. *North American Journal of Fisheries Management* **4**: 455–461.

Harris GS. 1973. A simple egg box planting technique for estimating the survival of eggs deposited in stream gravel. *Journal of Fish Biology* **5**: 85–88.

Kondolf GM, Sale MJ, Wolman MG. 1993. Modification of fluvial gravel size by spawning salmonids. *Water Resources Research* **29**: 2265–2274.

Lacroix GL. 1985. Survival of eggs and alevins of Atlantic salmon (*Salmo salar*) in relation to the chemistry of interstitial water in redds in some acidic streams of Atlantic Canada. *Canadian Journal of Fisheries and Aquatic Sciences* **42**: 292–299.

Levasseur M, Bergeron NE, Lapointe MF, Bérubé F. 2006. Effects of silt and very fine sand dynamics in Atlantic salmon (*Salmo salar*) redds on embryo hatching success. *Canadian Journal of Fisheries and Aquatic Sciences* (in press).

Lisle TE. 1989. Sediment transport and resulting deposition in spawning gravels, north coastal California. *Water Resources Research* **25**: 1303–1319.

Lisle TE, Eads RE. 1991. *Methods to measure sedimentation of spawning gravels*. Research Note PSW-411. Pacific Southwest Research Station, Forest Service, US Department of Agriculture: Berkeley, CA 7.

Lisle TE, Lewis J. 1992. Effects of sediment transport on survival of salmonid embryos in a natural stream: a simulation approach. *Canadian Journal of Fisheries and Aquatic Sciences* **49**: 2337–2344.

MacKenzie C, Moring JR. 1988. Estimating survival of Atlantic salmon during the intragravel perid. *North American Journal of Fisheries Management* **8**: 45–49.

Petts GE, Thoms MC, Brittan K, Atkin B. 1989. A freeze-coring technique applied to pollution by fine sediment in gravel-bed rivers. *The Science of the Total Environment* **84**: 259–272.

Reiser DW. 1998. Sediment in gravel bed rivers: ecological and biological considerations. 199–228. In: PC Klingeman, RL Beschta, PD Komar, JB Bradley (eds). *Gravel-Bed Rivers in the Environment*. Water Resources Publications, High land Ranch, Colorado. 832p.

Reiser DW, White RG. 1988. Effects of two sediment size classes on survival of steelhead and chinook salmon eggs. *North American Journal of Fisheries Management* **8**: 432–437.

Rubin JF. 1995. Estimating the success of natural spawning of salmonids in streams. *Journal of Fish Biology* **46**: 603–622.

Scrivener JC. 1988. Two devices to assess incubation survival and emergence of salmonid fry in an estuary streambed. *North American Journal of Fisheries Management* **8**: 248–258.

Soulsby C, Youngson AF, Moir HJ, Malcolm IA. 2001. Fine sediment influence on salmonid spawning habitat in a lowland agricultural stream: a preliminary assessment. *The Science of the Total Environment* **265**: 295–307.

Walkotten WJ. 1976. *An improved technique for freeze sampling streambed sediments*. Research Note PNW-281. USDA Forest Service Pacific Northwest Forest and Range Experiment Station: Portland, Oregon.

Wesche TA, Reiser DW, Hasfurther VR, Hubert WA, Skinner QD. 1989. New technique for measuring fine sediment in streams. *North American Journal of Fisheries Management* **9**: 234–238.