AN EVALUATION OF THE SURVIVAL OF CAPTIVE-REARED ATLANTIC SALMON (*SALMO SALAR*) EGGS IN INCUBATION BASKETS IN TWO INNER BAY OF FUNDY RIVERS

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by

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In-field egg incubators have been used worldwide for many years to study survival in the earliest life stages of salmonids. Their use is multi-dimensional in that the physical attributes of the incubating environment (e.g. fine sediments) can be measured concurrently with fish survival, allowing researchers to relate survival to habitat or environmental characteristics. Resource managers can distribute fish at their earliest life stage, which is not only cost effective, but also exposes offspring to more natural conditions earlier on, which may have important genetic and ecological implications.

In this two year (2004-05 and 2005-06) study, Atlantic salmon (*Salmo salar*) eggs from captive-reared adults of Big Salmon River origin were placed in egg incubation baskets in the Big Salmon and Point Wolfe rivers in New Brunswick. Salmon populations in both rivers are part of the endangered inner Bay of Fundy salmon population complex.

The study identified a period of early rearing mortality that occurred prior to the eyed stage, when survival is typically the highest. In the two study years, mean survival to the eyed stage was 34% (2004-05) and 18% (2005-06) in the Big Salmon River, and 35% (2004-05) and 4% (2005-06) in the Point Wolfe River. By emergence, survival had further decreased to 12% in 2004-05 and 2005-06 in the Big Salmon River, and to 2% in 2004-05 and 1% in 2005-06 in the Point Wolfe River. In comparison, survival to emergence of control eggs subjected to transportation effects was significantly higher in both years, at 76% in 2004-05 and 77% in 2005-06. The number of accumulated degree-days was closely related to emergence timing in the Big Salmon River. Exposure of eggs to colder temperatures early in development (December) and the fact that eggs originated from captive-reared salmon may have had a combined negative effect on egg survival. Until comparisons with eggs from wild, sea-run parents are made, these results indicate that the use of egg baskets may not be a very effective conservation strategy in the recovery of inner Bay of Fundy salmon.

Résumé

Flanagan, J.J., R.A. Jones, R. Wissink, and A. Caissie. 2008. An evaluation of the survival of captive-reared Atlantic salmon (*Salmo salar*) eggs in incubation baskets in two inner Bay of Fundy rivers. Can. Tech. Rep. Fish. Aquat. Sci. 2775: viii + 27 p.

Les incubateurs à œufs de saumon sont utilisés dans le monde entier depuis de nombreuses années pour étudier sur le terrain la survie des salmonidés à leurs premiers stades de vie. Leur utilisation revêt un aspect multidimensionnel, puisque les caractéristiques physiques du milieu d'incubation (p. ex. les sédiments fins) peuvent être mesurées en même temps que la survie du poisson, grâce à quoi les chercheurs peuvent établir des liens entre la survie et l'habitat ou les caractéristiques de l'environnement. Les gestionnaires de la ressource peuvent disséminer le poisson dès ses premiers stades biologiques, façon de procéder qui, en plus d'être économique, expose les juvéniles plus tôt au milieu naturel, ce qui est susceptible d'avoir des répercussions génétiques et écologiques importantes.

Dans l'étude sur deux ans (2004-05 et 2005-06) décrite ici, des œufs de saumon atlantique (*Salmo salar*) provenant d'adultes originaires de la rivière Big Salmon et élevés en captivité ont été placés dans des incubateurs à œufs dans les rivières Big Salmon et Point Wolfe, au Nouveau Brunswick. Les populations de saumon des deux rivières font partie du complexe de populations de saumon de l'arrière-baie de Fundy, en voie de disparition.

L'étude à mis en évidence une période de mortalité précoce survenant avant le stade embryonnaire, stade où la survie est habituellement à son plus haut niveau. Dans les deux années d'étude, la survie moyenne jusqu'au stade embryonnaire était de 34% (2004-05) et 18% (2005-06) dans la rivière Big Salmon, et de 35% (2004-05) et 4% (2005-06) dans la rivière Point Wolfe. Au stade de l'éclosion, la survie avait encore diminué et était tombée à 12% en 2004-05 et 2005-06 dans la rivière Big Salmon, et à 2% en 2004-2005 et 1% en 2005-06 dans la rivière Point Wolfe. Par comparaison, la survie jusqu'à l'éclosion d'œufs témoins soumis aux effets du transport était bien plus élevée les deux années considérées, atteignant 76% en 2004-05 et 7% en 2005-06. Il y avait un lien étroit entre le nombre de degrés-jours cumulé et la période d'éclosion. L'exposition des œufs à des températures froides au début de leur période de développement (en décembre) et le fait que les œufs provenaient de saumons élevés en captivité ont pu avoir un effet négatif sur la survie du saumon. En attendant qu'on puisse faire des comparaisons avec des œufs provenant de saumons sauvages qui ont séjourné en mer, les résultats révèlent que l'utilisation d'incubateurs à œufs n'est peut-être pas une stratégie très efficace pour le rétablissement du saumon de l'arrière-baie de Fundy.

Introduction

Egg incubation baskets (EIB) and variations thereof have long been used to estimate the in-stream egg-to-fry survival of many salmonid species (Rubin 1995). They have also been proposed as a possible resource or fisheries management tool for enhancement or supplementation to existing wild salmonid populations (Rubin 1995). Given that distributing eggs in EIBs would eliminate the costs associated with raising juveniles in typical rearing facilities (Aprahamian et al. 2003), the methodology may offer a cost-effective strategy for use in recovery planning. From an ecological standpoint, the EIB method allows fish to be exposed to a more natural environment at their earliest life stages, thereby lessening possible domestication effects associated with captive-rearing (Dempson et al. 1999, Jokikokko et al. 2006). The EIB method may also have important embryological development and epigenetic effects for eggs (P. O'Reilly, Department of Fisheries and Oceans, Maritimes Region, pers. comm.). Although the EIB method is promising, it must first be evaluated in different rivers and with different origins of salmon eggs to determine suitability, since studies using similar methods have shown variable results (Scrivener 1988).

This report discusses the results of a study conducted on two rivers in 2004-05 and 2005-06. This study evaluated the survival of eggs from captive-reared salmon of Big Salmon River origin and the potential to use EIB's to rear eggs in the Big Salmon and Point Wolfe rivers. If successful, the EIBs could be used in efforts to conserve Atlantic salmon (*Salmo salar*) of inner Bay of Fundy origin where the populations are critically low (Amiro 2003; Anon. 2002) and are designated as "endangered" (COSEWIC 2001).

Methods

In November 2004-05 and 2005-06, egg incubation baskets were installed in the Big Salmon River and Point Wolfe River. Both rivers flow into the inner Bay of Fundy from southeastern New Brunswick, Canada. Two locations in each river were chosen, denoted as upper (most upstream) and lower (most downstream) sites (Figure 1). The location of the upstream site in both rivers was changed in 2005 to further separate the sites within each river and to determine if differences in egg survival existed between sites within a river.

The physical attributes of the EIBs were similar to those used by Flanagan (2003), yet had a larger, more tapered opening for emergent fry. The deployment methods used were described in detail in Flanagan (2003), whereby EIBs (Figure 2) were filled with pre-sieved gravel >2mm in diameter before a known quantity of fertilized eggs was placed in the baskets and the baskets were capped and buried in the river's substratum. Eight EIBs per site were installed in 2004 and twelve per site in 2005 (Figure 3). Each site represented, to the best of our knowledge, suitable spawning habitat and conditions, yet allowed for access to the location to ensure retrieval of baskets and to facilitate daily monitoring of emergence traps in the spring.

Atlantic salmon of Big Salmon River origin - collected as wild parr and/or smolts and captive-reared to maturity at the Mactaquac Biodiversity Facility (MBF) - were spawned on November 09, 2004 and November 08, 2005. Ten different mating pairs (1:1 sex ratio) were used in each year and equal numbers of eggs (n = 15) from all pairings were represented in each egg incubation basket in the study (32 baskets in 2004-05, 48 baskets in 2005-06). The mated adults came from a complex mating strategy designed to avoid crosses of full and half siblings; hence maintaining greater genetic diversity within this spawning population (P. O'Reilly, Department of Fisheries and Oceans, Maritimes Region, pers. comm.). All egg batches (n = 150 eggs per batch/basket) were held in separate 1L water-filled plastic containers, transported and kept overnight in ambient river water to prevent freezing and to acclimatise the eggs. The following day eggs were installed in the gravel-filled incubation baskets using a funnel and plastic tubing. In 2004-05, the pre-sieved gravel used to fill the baskets had frozen overnight, so the gravel-filled baskets were placed in the river for a minimum of 15 minutes prior to installing the eggs to help acclimatise the gravel to river conditions. This was not required in 2005-06. The baskets were capped and buried with sieved gravel (>2mm in diameter) in pre-dug, artificial redds. Any remaining batches of eggs were returned to the Mactaquac Biodiversity Facility to be reared in hatching trays and serve as a control experiment to identify potential effects from transportation and handling. In 2004-05 four batches of eggs and in 2005-06 six batches of eggs (three from the Big Salmon River installations and three from the Point Wolfe River installations) were returned to Mactaquac. Egg batches brought to the river and back to Mactaquac are herein referred to as the 'transportation' controls. All remaining eggs from the ten mating pairs were placed directly in hatching trays at Mactaquac and thereby exposed to virtually no handling effects. These controls are herein referred to as the 'direct plant' controls. Comparisons of these two control groups in each year allowed us to account for any egg mortality in EIBs resulting from transportation or handling.

Survival rates in both groups of controls were determined to the fry stage (i.e. after the yolk sac was absorbed), where calculations accounted for all normally occurring mortalities as well as those resulting from 'shocking', a common practice used by hatchery managers to eliminate unfertilized and weak or poor condition eggs. Direct plant controls represented the best-case scenario in terms of survival in a controlled environment, with eggs being subjected to minimal negative influences. In-river survival of eggs for all egg stages was calculated as the number of live salmon recovered (i.e. egg, alevin or fry) from the number of live eggs installed per basket and then adjusted using the transportation control mortality constant (determined in both years). This accounts for egg viability, which is otherwise assumed to be 100% (see Cunjak et al. 2002, Flanagan 2003). In 2005-06, the transportation control mortality constants were calculated for each stage of evaluation and separately for the Big Salmon and Point Wolfe rivers.

$$\text{S (adjusted)} = \left(\frac{\text{number of live eggs recovered}}{\text{initial number of eggs in basket} \times (1 - \text{control egg mortality})} \right) \times 100$$

It is rarely the case that there would be 100% viability of eggs or that there would be no loss resulting from transporting eggs. If these sources of mortality were not accounted for, it would lead to an overestimation of in-river mortality (Peterson 1978 and Rubin 1995). All references to survival from here forth are thus 'adjusted' egg survivals.

Egg incubation baskets were left in-river for the winter to allow eggs to incubate. The EIB placements at each site were staggered, covered the width of the river, and were sufficiently separated to avoid effects to other baskets during removals. A random selection of baskets was applied at each site for the removals, which differed between the 2004-05 and 2005-06 experiments. In 2004-05, two EIBs at each site were removed in late-March and late-April to determine survival to the eyed and hatch stages, respectively, and in mid-May four remaining EIBs at each site were equipped with an emergence basket (Figure 4) to monitor daily emergence of fry. In 2005-06, two additional EIB removals in December and February were added to more accurately determine when mortality occurred. March EIB removals and May to June emergence monitoring were also completed, while the April EIB removal (hatch stage) was eliminated in the 2005-06 study. Peak fry emergence in both years was determined as the day on which 50% of the total fry catch was achieved or exceeded.

Stage	Removal Dates (by year, river and stage)			
	2004-05		2005-06	
	Big Salmon River	Point Wolfe River	Big Salmon River	Point Wolfe River
green*	n/a	n/a	Dec. 13	Dec. 13
green2	n/a	n/a	Dec. 23	Dec. 22
green3	n/a	n/a	Feb. 07	Feb. 08
eyed	Mar. 22	Mar. 23	Mar. 16	Mar. 17
hatch	Apr. 27	Apr. 27	n/a	n/a
emergence	Jun. 28	Jun. 05	Jun. 16	Jun. 16

- *'green' stage was omitted from study due to experimental errors during EIB removal.*
- *Note: 'green' stages are arbitrary names given to distinguish between the different removals.*

At all four sites in 2004-05, two EIBs were coupled with a Minilog[1] data logging thermometer to monitor intragravel water temperatures on an hourly basis. Just one EIB per site was equipped with a thermometer in 2005-06.

For EIB removals in 2004-05, all contents were emptied into a bucket, transferred to a plastic bag and transported to the lab at the Department of Fisheries and Oceans, Gulf Fisheries Center for analysis. In 2005-06, the December (green2) and February (green3) EIB removals were analysed immediately on-site in order to minimize mortality caused by transportation of eggs at the earlier, more sensitive life-stages. In both years, all EIB contents were examined for live eggs, alevin or fry. At the emergence stage, basket contents were examined immediately upon removal and any live fry recovered from within a basket was added to the emergence total. After all eggs, alevin and fry were removed from the baskets, the remaining substrate was kept in plastic bags and eventually analysed for fine particle (<2mm diameter) accumulation.

Egg survival data (percentages) were normalized by log transformation prior to statistical analyses. Based on an adaptation of the model for instantaneous mortality rate from Ricker (1975):

$$\ln\left(\frac{N_t}{N_o}\right) = \alpha + \beta \times \text{year} \times \text{site}$$

ANOVA of the adjusted means (LSMeans; SAS Institute Inc. 1999) was used to test the differences in survival between rivers, sites within a river, as well as the year and interaction effects.

Results

<u>2004-05 Egg Survival</u>

The direct plant controls had an overall mean survival of 79%, while the transportation controls had a slightly lower mean survival of 76% (n = 4) that suggests there were no negative effects

[1] Vemco Division, Amirix Systems Inc., Halifax, Nova Scotia, Canada

from transporting and holding eggs overnight for burial the next day (Table 1).

At the March EIB removals (eyed stage), all baskets were still present at three of the four sites. However, the upper site in the Point Wolfe River had been affected by an early freshet and substantial ice scour was evident. Only three of the eight baskets installed at this location were found after extensive digging in the gravel. Each of the three baskets had been damaged and had shifted within the gravel (i.e. were no longer oriented downstream as they were when installed). Included in the lost EIBs were the two minilog thermometers, so no intragravel water temperatures were obtained from this site. Given the extensive disturbance observed, it was obvious the intragravel environment and the conditions experienced by the EIBs at the upper Point Wolfe River site were much different than the conditions experienced by eggs at the other three sites. For this reason, data from the upper site on the Point Wolfe River were not included in the analyses.

Mean survival to the eyed stage for eggs in the lower Point Wolfe River site was 35% (n = 2) and did not differ (p = 0.90) from the overall mean survival rate of 34% (n = 4) in the Big Salmon River (Figure 5). However, it is not possible to conclude that overall survival rates were similar between rivers given that the upper Point Wolfe River site was removed from the analysis and survival varied significantly between sites in the Big Salmon River. Mean survival to the eyed stage for eggs at the lower Big Salmon River site was significantly higher (p = 0.01) than at the upper site in 2004-05 (Table 2). This was not the case for either the hatch (p = 0.24) or emergence stages (p = 0.83), where differences between sites were less obvious, most likely due to the variability in survival of individual baskets within a site (Table 2). Overall, egg survival declined to 26% (n = 4) and 23% (n = 2) at the hatch stage for the Big Salmon and Point Wolfe rivers, respectively, and continued to decline to 13% (n = 8) and less than 2% (n = 4) respectively at emergence (Figure 5). For the Point Wolfe River, the overall survival rate at emergence was significantly lower than that recorded on the Big Salmon River (p = 0.05; Figure 5).

A total of eight fry emerged from the four EIBs at the lower Point Wolfe River site in 2004-05, which was an insufficient number to determine the emergence timing distribution for that river (Appendix 1). In the Big Salmon River, a total of 61 and 53 fry emerged from the four EIB's at the upper and lower sites, respectively. Emergence timing between the upper and lower Big Salmon River sites was virtually the same with peak emergence occurring on June 14 and 15 (Figure 6). For the most part, fry did not begin to emerge until June 07 and emergence had ended by approximately June 25 (baskets were removed on June 28). Ten live fry were present in one EIB (at the lower site) upon removal from the gravel, the only basket to have more than one fry present at removal. With the exception of one other emergent fry, these were the only live fry recorded from this particular basket, which suggests that emergence was impeded for some reason (i.e. a possible basket effect).

<u>2005-06 Egg Survival</u>

The cumulative, inter-stage mean survival for the transportation control eggs was determined on December 20 (green2), February 04 (green3) and March 17 (eyed and emergence). Mean survival was 93% and 95% to the green2 stage for the Big Salmon and Point Wolfe rivers, respectively, and 77% for both rivers to the green3 stage (Table 1). Similarly, the mean survival to eyed and emergence was 77% for Big Salmon River eggs and 76% for Point Wolfe River eggs, while the overall mean survival for direct plant controls was 78% (Table 1). There was no difference in mean survival at any stage for the egg batches brought to the Big Salmon River and back and those brought to the Point Wolfe River and back.

During lab analysis of eggs from baskets removed on December 13, 2005 it was found that egg mortality had increased as the analysis progressed (i.e. the last basket analysed had the highest mortality, the first had the least). Therefore, egg survival rates for the green stage could not be considered in further analyses, but nevertheless demonstrated the sensitivity of eggs to handling in the early stages of incubation. Mean survival rates to the green2 stage were 88% in the Big Salmon River and 86% in the Point Wolfe River (Figure 5), with no significant difference between the two ($p = 0.88$). In both rivers, higher survival to this point was observed at the lower site, although statistically this was not significant ($p = 0.37$ for the Big Salmon River and $p = 0.34$ for the Point Wolfe River; Table 2). By the green3 removals, a substantial decrease in mean survival to 12% in the Point Wolfe River was observed (Figure 5); significantly less ($p < 0.04$) than the mean survival at the same time in the Big Salmon River (mean = 70%; Figure 5). Comparing the upper and lower sites on each river, survival rates at all stages tended to be greater in the lower sites on both rivers, yet this difference was only statistically significant for the green3 removals on the Point Wolfe River ($p = 0.04$; Table 2). As development progressed overall mean survival rates declined significantly at the eyed stage ($p = 0.03$) and at emergence in 2005-06 ($p = 0.02$) for the Point Wolfe and Big Salmon rivers, respectively (Figure 5).

Similar to 2004-05, so few fry (n = 5 in total) emerged from the Point Wolfe River baskets that it was not possible to establish an emergence timing distribution (Appendix 1). In the Big Salmon River, emergence began on May 19 (upper site) and was basically completed by the first week of June (Figure 6). The largest pooled catch of emerging fry was in the lower Big Salmon River site (n = 83), which peaked on May 27th. The catch at the upper Big Salmon River site (n = 37) did not peak until a few days later on May 31 (Figure 6). While the catch at the lower site seemed much larger than that at the upper site, it was weighted heavily by 58 fry that emerged from one basket, and did not actually differ from the upper site in terms of survival to this stage ($p = 0.21$). Overall, emergence in 2005-06 was much earlier than in 2004-05, which could possibly be attributed to warmer water temperatures throughout the winter (Figure 7; see below).

<u>Intragravel Water Temperatures and Degree Days</u>

In 2004-05, the mean intragravel water temperatures did not differ by more than 0.6°C between any two recorders at a site, so the daily average of the two was used (Figure 7). Mean intragravel water temperatures were virtually identical between the Big Salmon River sites (3.9°C (upper site) and 3.9°C (lower site); $R^2 = 1.00$) as well as between rivers (3.9°C (Big Salmon River and 3.6°C (Point Wolfe River); $R^2 = 0.98$). From December 07, 2004 to December 24, 2004 and March 21, 2005 to May 03, 2005 the Point Wolfe River intragravel water temperatures were slightly cooler (Figure 8). In contrast, control water temperatures were warmer for most of the incubation period, especially earlier on in development when rearing water was mixed with warmer ground water (mean = 3.0°C) from December 06, 2004 to January 11, 2005 (Figure 9). This translated into a faster accumulation of degree days and consequently, more rapid development to the eyed and hatch stages for control eggs.

Like 2004-05, intragravel water temperatures in 2005-06 were much the same between sites in the Big Salmon ($R^2 = 0.95$) and Point Wolfe rivers ($R^2 = 0.98$), as well as between the overall means for both rivers ($R^2 = 0.94$). The Point Wolfe River was coldest throughout the winter (December 21, 2005 – March 20, 2006) with overall mean temperatures of 0.1°C and 0.0°C for the lower and upper sites, respectively. In the Big Salmon River, the mean daily water temperature was 1.4°C for the upper site and 0.8°C for the lower site (Figure 7). Control water temperatures were warmer than in-river temperatures for much of December 2005. From December 22, 2005 to January 11, 2006, control water temperatures were influenced by ground water, which caused the rearing water to be warmed by an additional 0.8°C to 1.3°C daily during that time (Figure 9). After January 11, 2006 temperatures experienced by control eggs were more similar to in-river temperatures. All in-river temperatures were more variable during the second winter than in 2004-05 (Figure 7). The accumulation of degree days was faster for control eggs in 2005-06, yet the difference between control and in-river egg development was less drastic than in 2004-05, especially in the Big Salmon River. In the Point Wolfe River, in-river egg development was slower than control egg development, yet the difference in developmental rate varied little between years (Figure 8).

Fine Sediments

Comparing the four sampling sites, the lower Point Wolfe River site had the largest percent volume of fines in both years and at all removal stages but one (mean = 26.3%; Figure 10). The only exception was at the green3 removal in 2005-06, when the upper site on the Point Wolfe River had the highest level of accumulated fine sediments (mean = 9.8%). In 2004-05 the mean percent volume of fines in baskets from the Point Wolfe River exceeded 15% at the three removal stages (eyed, hatch, and emergence), whereas in 2005-06 fines did not surpass 12% and were usually below 10%. In the Big Salmon River, accumulated fines never exceeded a mean of 5% in either year (Figure 10). No obvious temporal trend in the accumulation of fines was observed in either river in this study.

Discussion

The objective of the current study was to assess the survival of Atlantic salmon eggs in EIBs planted in the Big Salmon and Point Wolfe rivers and to evaluate the potential to use the EIB method as an alternate strategy to help supplement iBoF salmon in rivers where the population is critically low.

The transportation and handling of eggs had no apparent effect on the total egg mortality observed in either year of this study. Similar survival rates were obtained for the 'transportation' controls (76% in 2004-05 and 2005-06) and the 'direct plant' controls (79% in 2004-05 and 78% in 2005-06) in both years. Still, the mortality rate from the 'transportation' controls was included in all survival rates to avoid improperly overestimating in-river egg mortality as suggested by Peterson (1978) and Rubin (1995).

In this study, we assumed the captive-reared environment was best for eggs to develop and the expected survival rate of controls to be highest, so the difference from the in-river egg survival rate represented the observed natural mortality within the baskets. During the first year of this study, we identified a considerable decline in survival prior to the removal of EIBs at the eyed stage. The magnitude of the decrease was unexpected and resulted in overall survival rates (34% and 35% in the Big Salmon and Point Wolfe rivers, respectively) which were considerably lower than the two sets of controls in 2004-05 (76% for 'transportation' controls and 79% for 'direct plant' controls). Early mortality reoccurred in 2005-06, but with more EIBs in place and earlier removals, it was determined that mortality occurred substantially earlier in the Point Wolfe River (between December 22, 2005 and February 08, 2006) than in the Big Salmon River (between February 07, 2006 and March 16, 2006). The reason for this difference in the timing of mortality between the two rivers in 2005-06 is unclear. It is possible that the eggs placed in the Big Salmon River had a selective advantage over those in the Point Wolfe River, which was attributed to adaptive traits passed on to the eggs by the parents whose river of origin was the Big Salmon River. The overall developmental rate when eggs were removed in February 2006, appeared slower in the Point Wolfe River (98 degree-days) compared to the Big Salmon River (127 degree-days). This may have prolonged the time that eggs remained sensitive during development in the Point Wolfe River, and as temperatures varied prior to the February 2006 removals, these less developed and perhaps more sensitive eggs experienced mortality sooner than the slightly more developed eggs in the warmer Big Salmon River. Salmon eggs are stenothermal, meaning they survive within a narrow range of temperatures, so small changes in water or incubation temperatures can have a direct impact on development and survival (Hamor and Garside 1976; Ojanguren et al. 1999; Peterson et al. 1977). Peterson et al. (1977) and Beacham and Murray (1985) have shown that colder temperatures early on in the development of salmon eggs can lead to increased mortality, albeit in a controlled environment where the lowest temperature tested was 4°C. Wallace and Heggberget (1988) studied the effects of temperatures <1°C on Atlantic salmon egg development in Norwegian rivers and found evidence that early egg mortality was related to low temperatures in standardized trials. Yet, there remains little definitive information on the effects of near zero temperatures on egg development and survival (Wallace and Hegberget 1988), especially in natural environments where these temperatures are most likely to occur. In particular, the physiological mechanism by which low temperatures cause mortality in developing embryos remains uncertain, though some researchers have suggested that low temperatures alter yolk absorption efficiency which ultimately affects overall development and fitness (Beacham and Murray 1985; Ojanguren et al. 1999).

It is possible that the in-river environment has the potential to be equally as good for incubation with comparable survival rates to the eyed stage as in a controlled environment. Studies in Catamaran Brook, New Brunswick over five years (1994-1997, 1998-2000) found that mean survival to the eyed stage was never <65% (Flanagan 2003), while studies completed in other North American rivers found that mean survival was even higher, at 89% (Mackenzie and Moring 1988) and 98% (Dumas and Marty 2006). An important difference from these other studies however, was that they used mature adults removed directly from the wild. In this study, the mature adults used had been removed from the wild as juveniles; thus partially reared in captivity. The time spent by the adults in controlled conditions may have altered their progeny's suitability for surviving in a natural river environment through epigenetic effects (Watters 2006); in other words, genetic effects resulting from environmental changes or influences passed on from the parents.

The possible effects of domestication selection are also worthwhile mentioning. It has been suggested that captive-reared salmon and their progeny are not particularly well suited in the wild (Fleming and Peterson 2001; Fleming et al. 2000) and that captive-rearing can potentially introduce traits conducive to a controlled, rather than a natural environment (Johnsson et al. 2001). This is not likely the cause for mortality in this study because eggs came from parents with only half a generation in captivity, and domestication selection probably would not have had enough time to have such an immediate impact on survival rate. Nevertheless, the use of future generations of captive-reared salmon could potentially have negative effects on existing wild populations (Mackey and Bean 2004) by suppressing overall fitness of the population (Bates and McKeown 2003, Araki et al. 2007, Jokikokko et al. 2006) if they carry or pass on such 'domesticated' traits.

Although steps are currently being taken to try and improve the viability and condition of eggs from captive-reared salmon (e.g. by changing captive-reared fish diet; T. Goff, DFO, Mactaquac, Maritimes Region, pers. comm.), a cautious approach to their use in natural river environments for population maintenance purposes and release through EIBs should be taken. Future research should compare survival rates in wild and captive-reared salmon eggs of the same origin (population) in EIBs to examine differential responses in-situ. One preliminary study that attempted to resolve this issue was done by Hallet (2006) in the Nashwaak River, New

Brunswick. Even though ice scour and flooding caused high EIB loss, there was faint evidence of higher survival rates from eggs of wild origin (67.4% ± 39.7, n = 5) than from captive-reared origin salmon (17.7% ± 16.0, n = 4) indicating the need for further study.

Previous research on salmonid development has shown that the accumulation of fine sediments (<2mm diameter) can significantly affect egg survival by inhibiting intragravel flow and eliminating oxygen delivery to eggs and the removal of wastes, as well as by preventing fry emergence (Chapman 1988, Hausle and Coble 1976, Young et al. 1990). Bjorn and Reiser (1991) and Lisle and Eads (1991) established a general value of 20% fines, beyond which the survival rate of eggs starts to deteriorate and mortality increases. With the exception of one site, fines were never greater than 12% in the two years of our study. It is possible that that the higher amount of fines (26%) within baskets in 2004-05 contributed to the extremely low fry emergence observed at the lower Point Wolfe River site; however, this appeared not to be a factor in 2005-06 and the accumulation of fines was not believed to have negatively affected the survival of incubating eggs in EIBs. The design of the EIBs used in this study (i.e. with a larger and more tapered opening to the emergence basket) was believed to be more beneficial to emerging fry (R. Cunjak, University of New Brunswick, pers. comm.). However, eleven fry counted from one basket at the lower Big Salmon River site in 2004-05, suggested that a basket effect might still exist.

Egg incubation baskets have the potential to be used successfully to incubate salmon eggs and to achieve high survival rates to the eyed stage (Flanagan 2003, Dumas and Marty 2006, MacKenzie and Moring 1988), but consistent results are difficult to achieve. The variability in survival rate is possibly nothing more than what occurs as a result of incubation in a natural environment (i.e. in the wild) and may also be a reflection of microhabitat differences within suitable spawning sites in rivers. Whichever the case, before the method is to be incorporated as an alternate means to distribute salmon to rivers where the population is critically low, the issues of egg viability and differential survival of eggs from captive-reared salmon versus wild parents, need to be addressed.

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Table 1. Mean survival (s.d. - standard deviation) of individual crosses of Atlantic salmon eggs used in the egg incubation experiment in the Big Salmon and Point Wolfe rivers in 2004-05 and 2005-06. Transportation effect control eggs were subjected to the same protocols as eggs placed in baskets, but were returned to Mactaquac, while direct plant controls were placed directly in trays in the rearing troughs.

2004-05

	tray #	total eggs	eggs for baskets	egg loss [a, b, c] December 20	egg loss February 04	egg loss February 28	egg loss total	alive	% S
Direct Plant Controls	1	2,117	570	76	97	14	187	**1,360**	**87.91**
	2	6,191	570	189	478	6	673	**4,948**	**88.03**
	3	3,971	570	157	3,244	0	3,401	**0**	**0.00**
	6	3,688	570	57	89	10	156	**2,962**	**95.00**
	8	3,122	570	21	85	23	129	**2,423**	**94.95**
	10	8,798	570	252	2,194	25	2,471	**5,757**	**69.97**
	11	5,799	570	566	231	13	810	**4,419**	**84.51**
	13	3,181	570	91	319	34	444	**2,167**	**83.00**
	14	5,544	570	92	159	7	258	**4,716**	**94.81**
	17	2,954	570	23	196	5	224	**2,160**	**90.60**
	cumulative mean survival:								**78.88 ± 28.72 (s.d.)**
Transport. Effect Controls	C-A	150		9	26	2	37	**113**	**75.33**
	C-B	150		19	27	3	49	**101**	**67.33**
	C-C	150		7	24	1	32	**118**	**78.67**
	C-D	150		2	26	1	29	**121**	**80.67**
	cumulative mean survival:								**75.50 ± 5.87 (s.d.)** (eyed, hatch, emergence)

2005-06

	tray #	total eggs	eggs for baskets	egg loss [c, d] December 20	egg loss February 04	egg loss March 17	egg loss total	alive	% S
Direct Plant Controls	1	5,126	810	176	661	0	837	**3,479**	**80.61**
	3	4,136	810	68	644	0	712	**2,614**	**78.59**
	4	4,260	810	7	555	0	562	**2,888**	**83.71**
	5	3,898	810	7	199	0	206	**2,882**	**93.33**
	6	4,571	810	58	1,574	0	1,632	**2,129**	**56.61**
	8	4,454	810	61	751	0	812	**2,832**	**77.72**
	9	4,136	810	234	63	0	297	**3,029**	**91.07**
	12	6,077	810	112	1,177	0	1,289	**3,978**	**75.53**
	13	5,707	810	214	2,043	0	2,257	**2,640**	**53.91**
	15	2,538	810	21	129	0	150	**1,578**	**91.32**
	cumulative mean survival:								**78.24 ± 13.61 (s.d.)**
Transport. Effect Controls	BSR TC1	150		10	22	1	33	**117**	**78.00**
	BSR TC2	150		7	22	0	29	**121**	**80.67**
	BSR TC3	143		12	27	1	40	**103**	**72.03**
	PW TC 1	150		7	26	0	33	**117**	**78.00**
	PW TC 2	150		12	14	2	28	**122**	**81.33**
	PW TC 3	150		5	38	3	46	**104**	**69.33**
	BSR Transportation Control mean:			**93.43**	**77.35**				**76.90 ± 4.42 (s.d.)**
	PWR Transportation Control mean:			**94.67**	**77.33**				**76.22 ± 6.19 (s.d.)**
				(green2)	(green3)				(eyed, emergence)

Notes: [a] inter-stage (i.e. green2 and green3) mean survivals not determined in 2004-05.
[b] Eggs shocked on January 05, 2005.
[c] Eggs treated with formalin.
[d] Eggs shocked on January 13, 2006.

Table 2. Mean, minimum and maximum survival rate (percentage) of Atlantic salmon eggs to green2 and green3 (2005-06 only), eyed, hatch (2004-05 only) and emergence, in the Big Salmon and Point Wolfe rivers, 2004-05 and 2005-06. P-value (significance = 0.05) for differences in mean survival rate by site are also shown.

2004-05					
River	**Site**	**n**	**Mean (%)**	**Range (%)**	**p-value**
eyed (March 22 and 23, 2005)					
Point Wolfe	lower	2	35	25 - 45	n/a
Big Salmon	upper	2	24	22 - 25	0.01
Big Salmon	lower	2	45	42 - 48	
hatch (April 27, 2005)					
Point Wolfe	lower	2	23	22 - 24	n/a
Big Salmon	upper	2	18	8 - 28	0.24
Big Salmon	lower	2	34	25 - 44	
emergence (June 05 and 28, 2005)					
Point Wolfe	lower	4	2	0 - 4	n/a
Big Salmon	upper	4	14	5 - 29	0.83
Big Salmon	lower	4	12	8 - 14	

2005-06					
River	**Site**	**n**	**Mean (%)**	**Range (%)**	**p-value**
green2 (December 22 and 23, 2005)					
Point Wolfe	upper	2	77	61 - 95	0.34
Point Wolfe	lower	2	96	95 - 97	
Big Salmon	upper	2	79	63 - 97	0.37
Big Salmon	lower	2	98	97 - 98	
green3 (February 07 and 08, 2006)					
Point Wolfe	upper	2	2	0 - 3	0.04
Point Wolfe	lower	2	24	17 - 32	
Big Salmon	upper	2	56	53 - 59	0.06
Big Salmon	lower	2	86	73 - 100	
eyed (March 16 and 17, 2006)					
Point Wolfe	upper	2	1	0 - 2	0.21
Point Wolfe	lower	2	8	5 - 10	
Big Salmon	upper	2	15	11 - 20	0.36
Big Salmon	lower	2	21	20 - 22	
emergence (June 16, 2006)					
Point Wolfe	upper[a]	2	1	0 - 2	0.98
Point Wolfe	lower	4	1	0 - 3	
Big Salmon	upper	4	8	3 - 15	0.21
Big Salmon	lower	4	16	3 - 48	

[a] - n = 2 (1 basket previously lost and 1 unknowingly removed from gravel and water)

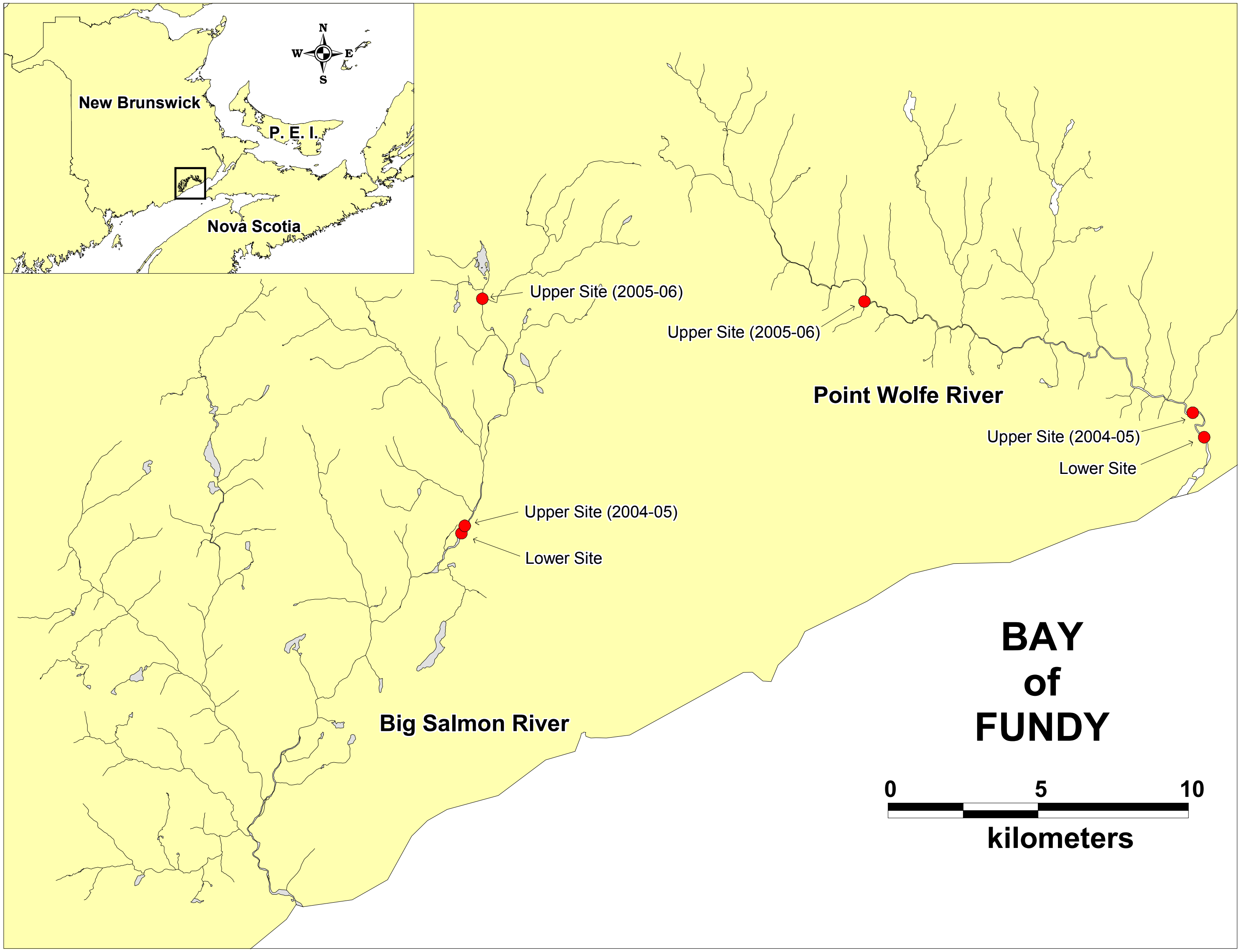


Figure 1. Map showing Big Salmon River and Point Wolfe River egg incubation basket locations in 2004-05 and 2005-06.

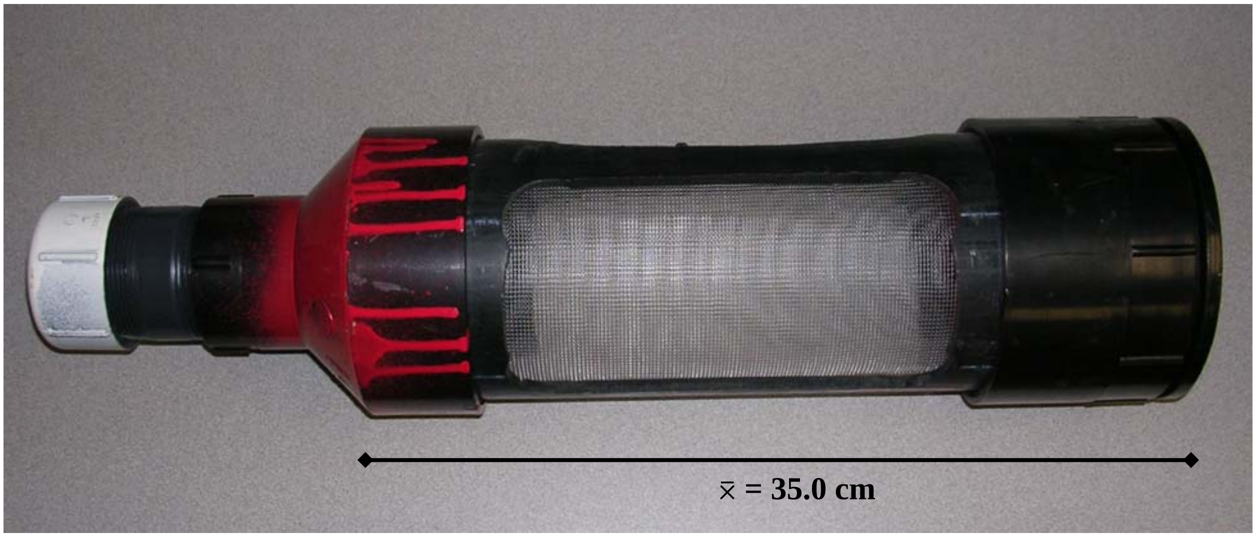


Figure 2. Egg Incubation Basket used in Big Salmon River and Point Wolfe River studies in 2004-05 and 2005-06.

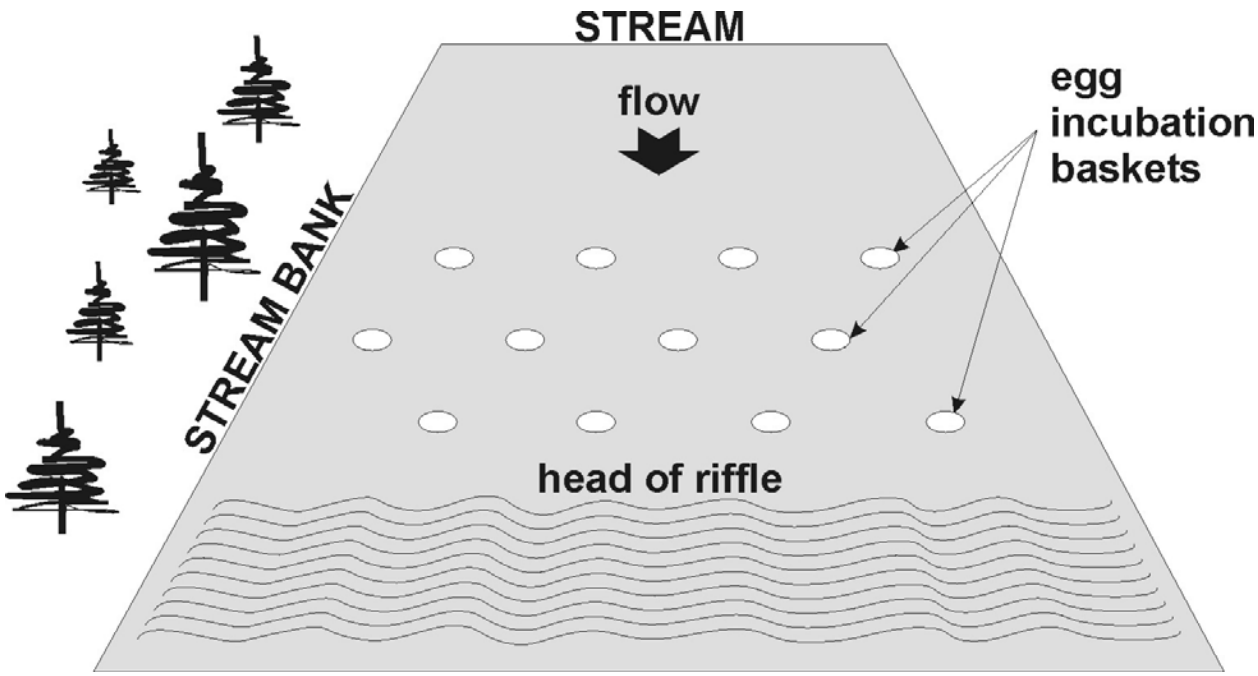


Figure 3. Typical, staggered arrangement of egg incubation baskets at sites in the Big Salmon and Point Wolfe rivers, 2004-05 and 2005-06. Only eight baskets per site were used in the 2004-05 study.

Figure 4. Photo of an egg incubation basket and emergence basket in-situ (photo taken from Flanagan 2003).

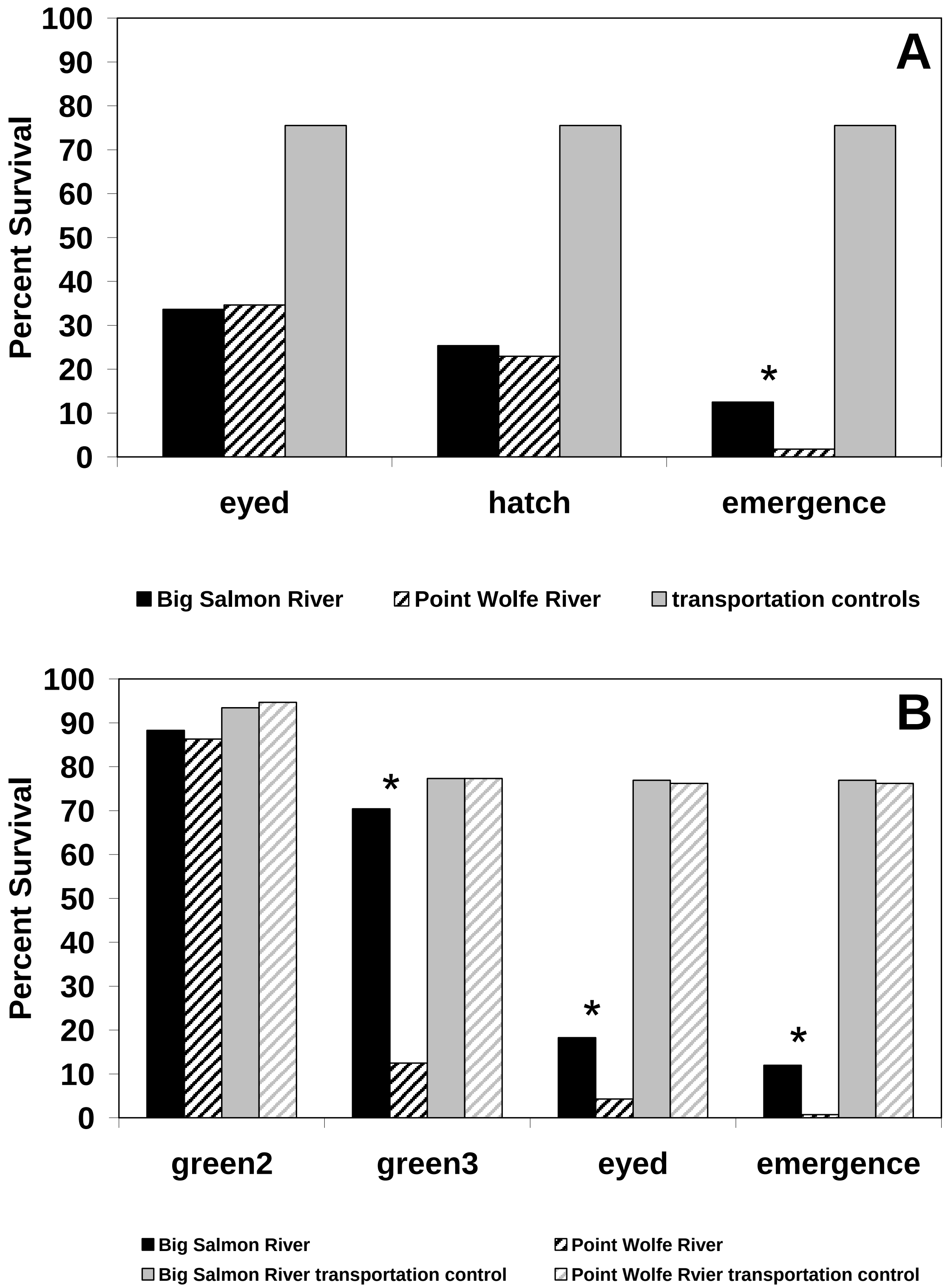


Figure 5. Mean survival of Atlantic salmon eggs in egg incubation baskets removed at various times during incubation in the Big Salmon and Point Wolfe rivers, 2004-05 (A) and 2005-06 (B). Mean transportation control survival is also shown for each year of the study. An asterisk indicates a significant difference in the mean survival between rivers.

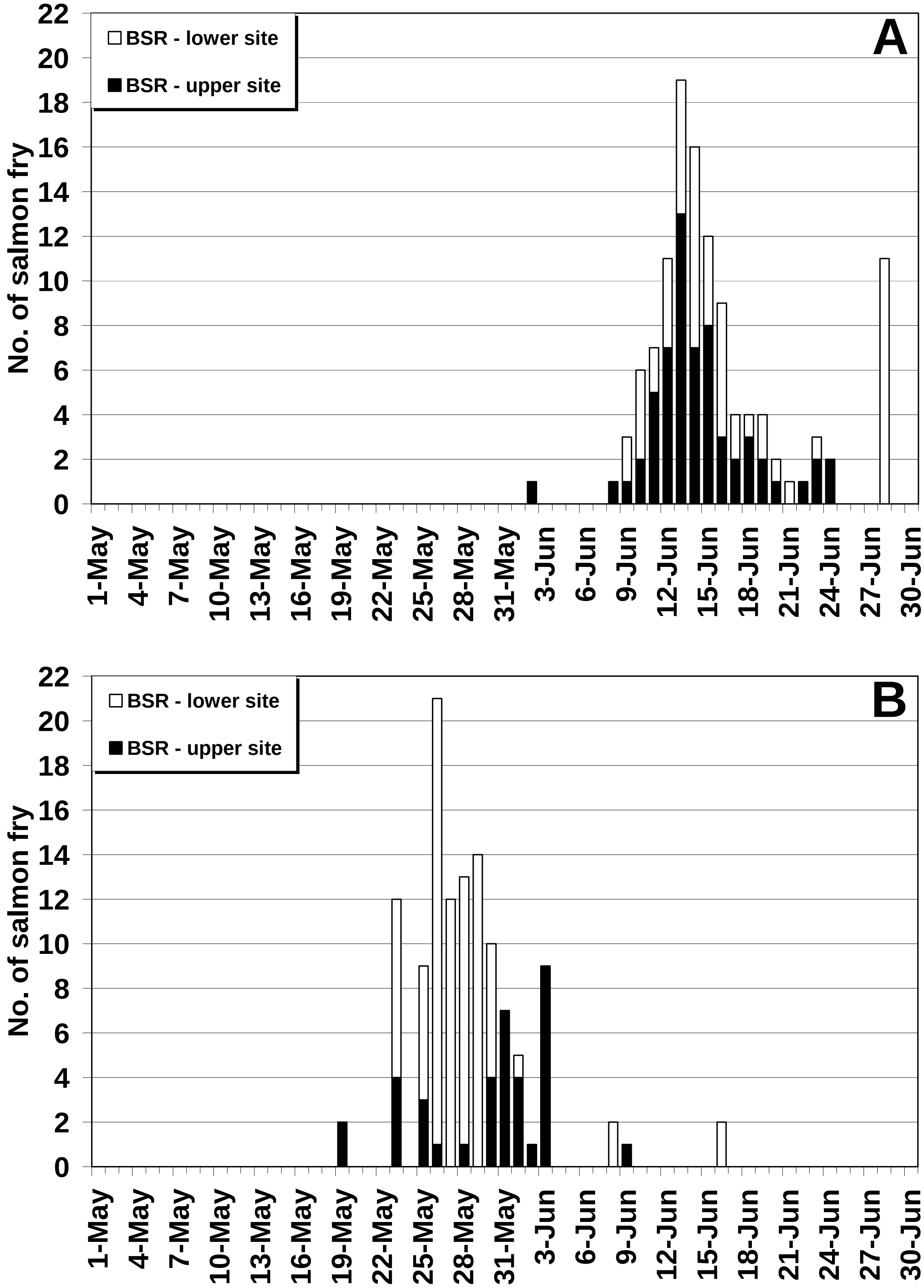


Figure 6. Emergence timing of fry from egg incubation baskets in the upper and lower sites in the Big Salmon River (BSR), 2004-05 (A) and 2005-06 (B).

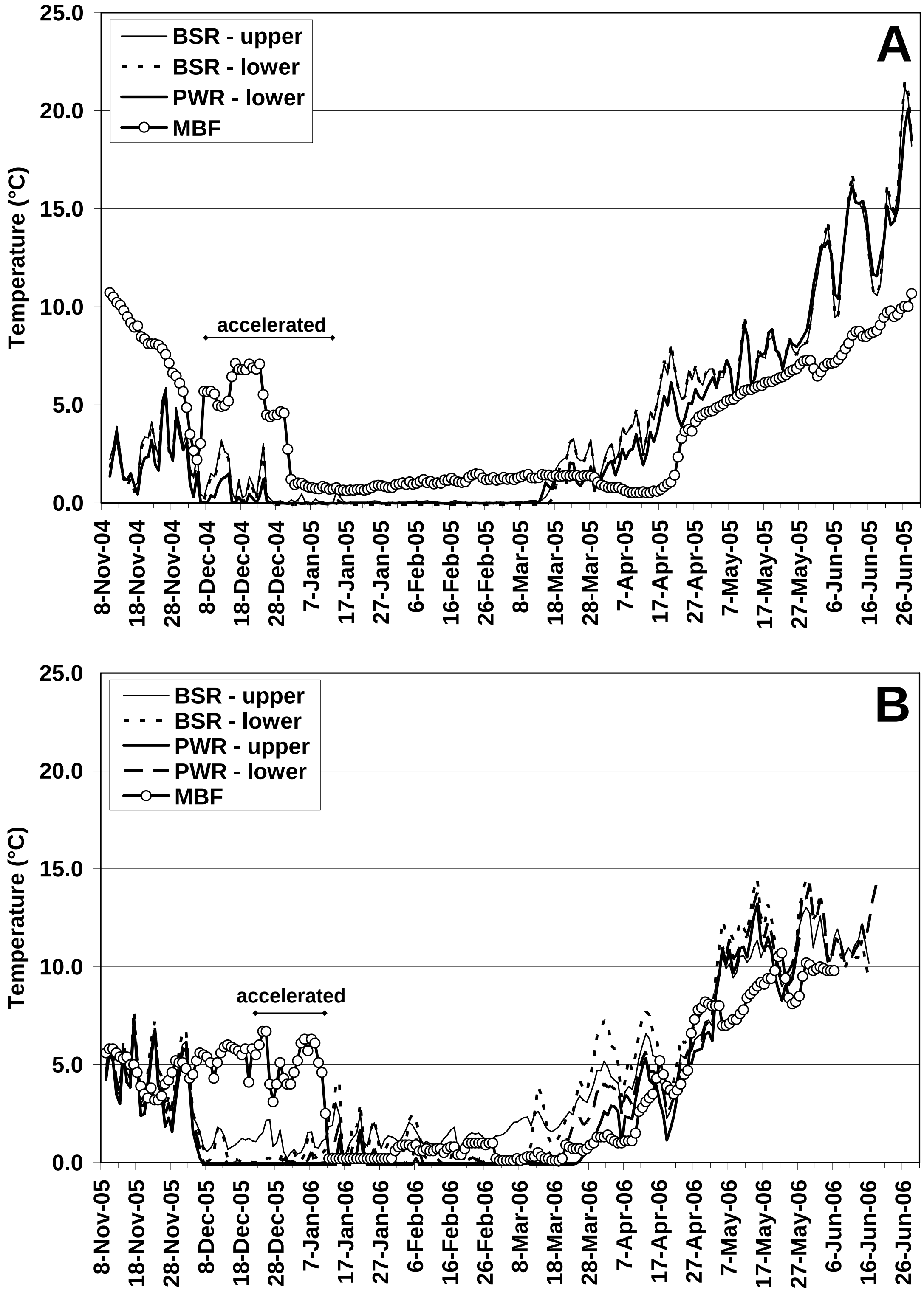
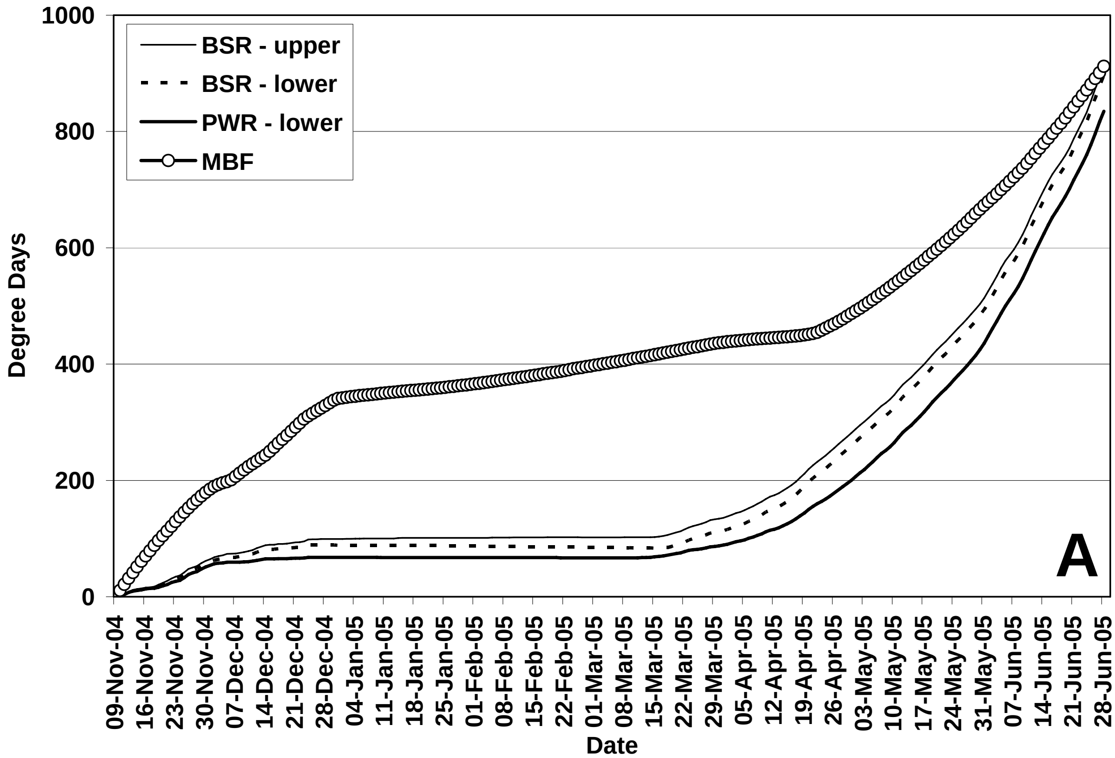


Figure 7. Mean daily intragravel water temperatures for the Big Salmon (BSR) and Point Wolfe (PWR) rivers and water temperatures for control eggs reared at the Mactaquac Biodiversity Facility (MBF), 2004-05 (A) and 2005-06 (B). "Accelerated" is the period of time when ground water was mixed with rearing water.



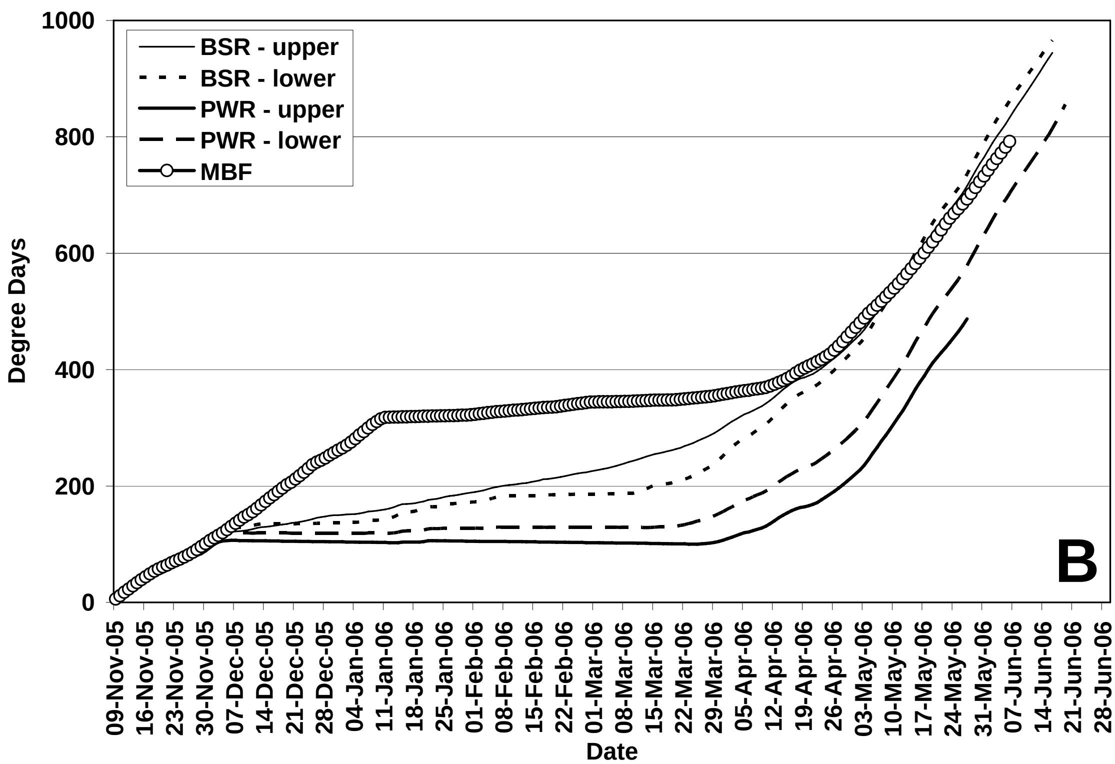


Figure 8. Accumulated Degree Days for the Big Salmon (BSR) and Point Wolfe (PWR) rivers, as well as for control eggs reared at the Mactaquac Biodiversity Facility (MBF), 2004-05 (A) and 2005-06 (B).

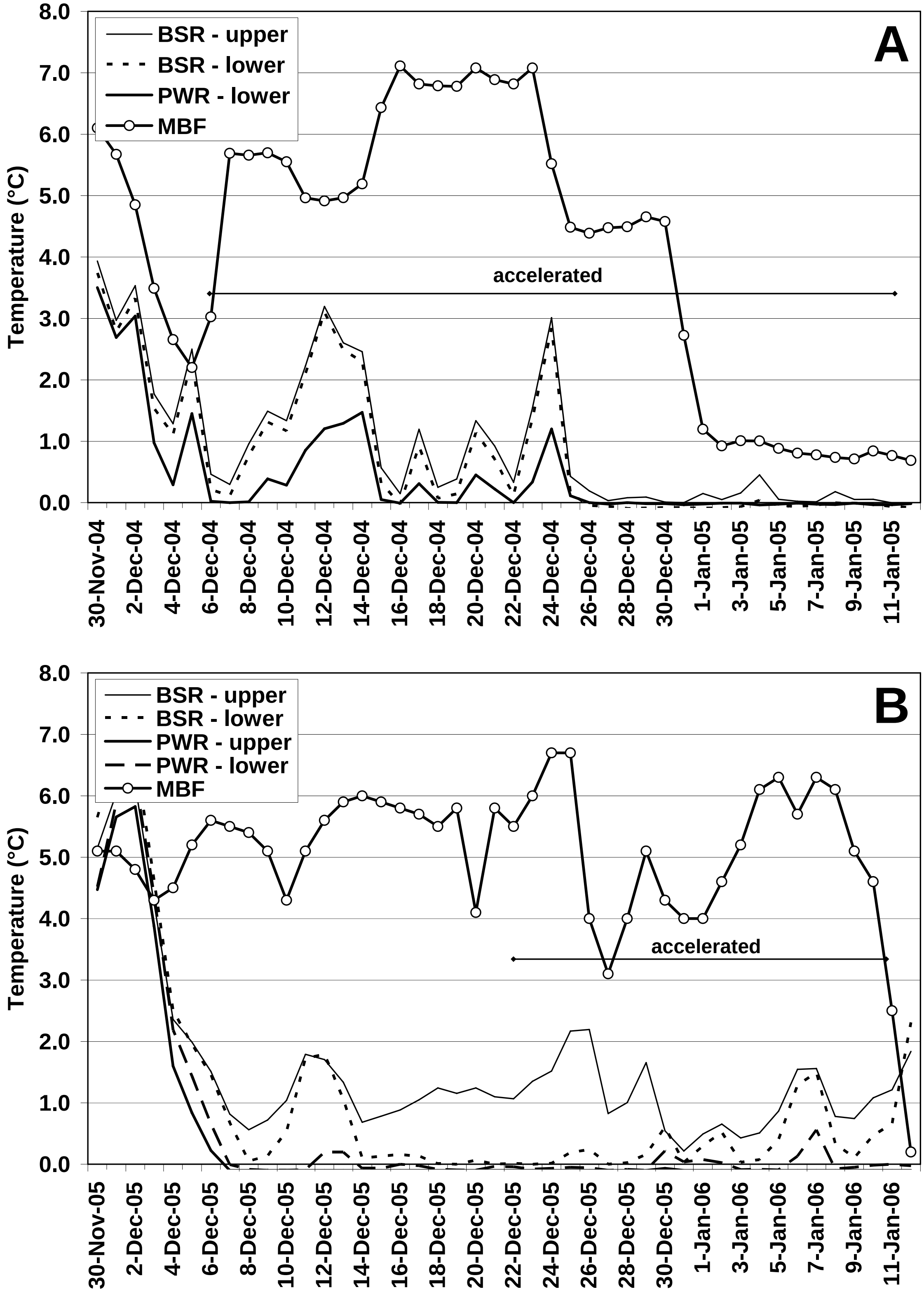


Figure 9. Mean water temperatures from November 30 to January 12 for eggs in the Big Salmon (BSR) and Point Wolfe (PWR) rivers, and in rearing troughs at the Mactaquac Biodiversity Facility (MBF), 2004-05 (A) and 2005-06 (B).

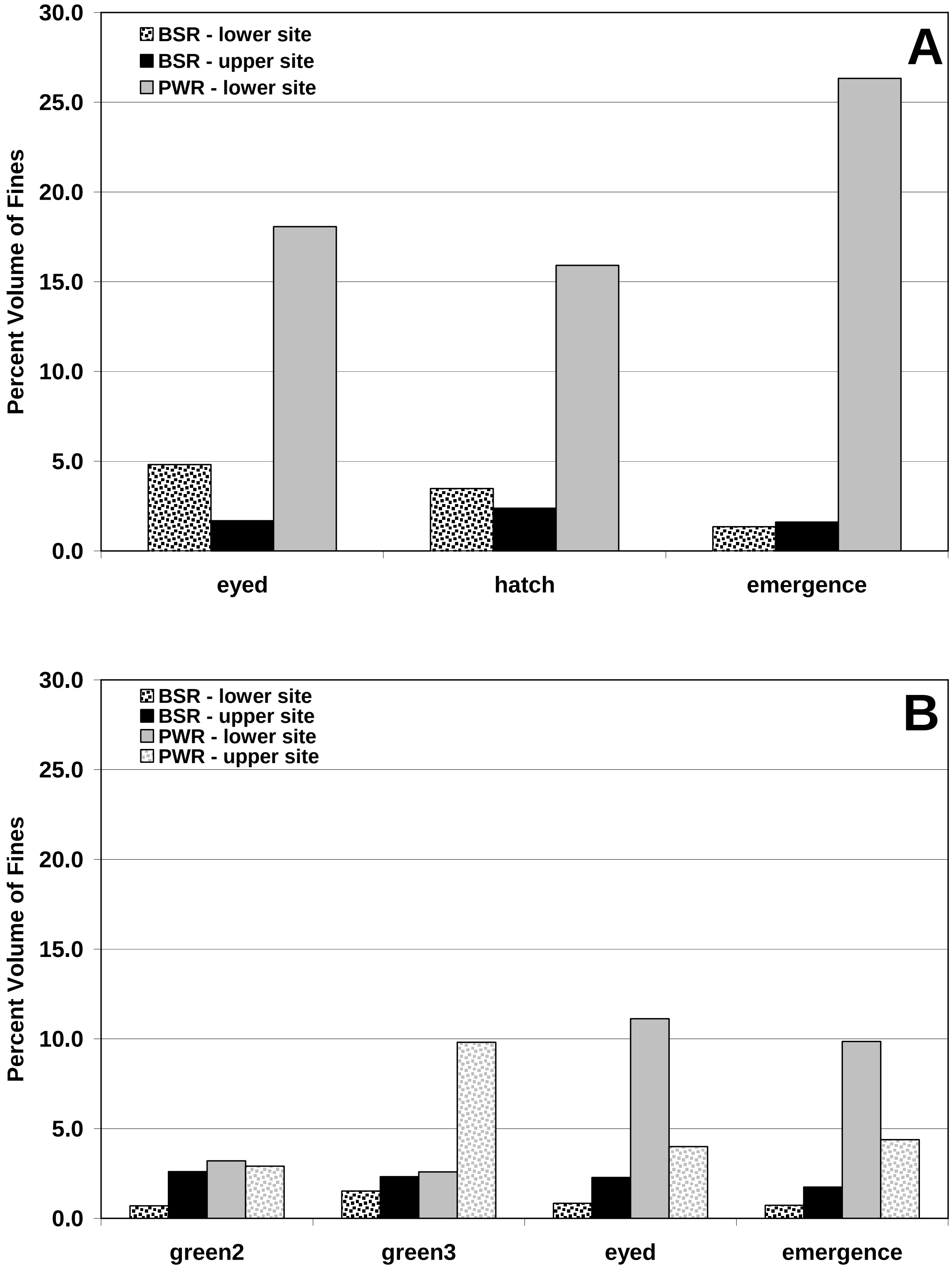


Figure 10. Mean percent volume of fine sediments from egg incubation baskets at the various stages of removal from the Big Salmon and Point Wolfe rivers, 2004-05 (A) and 2005-06 (B).

Appendix 1. Atlantic salmon egg survival data from egg incubation baskets installed and retrieved from the Big Salmon and Point Wolfe rivers, 2004-05.

River	Site	Install Date (mm/dd/yyyy)	Basket No.	Dead Eggs (at install)	Total Eggs (at install)	Removal Date (mm/dd/yyyy)	Stage	Live Eggs (recovered)	Dead Eggs (recovered)	Live Alevin (recovered)	Dead Alevin (recovered)	Live Fry (recovered)	Dead Fry (recovered)	Total (recovered)	Empty Shell	%S	%S (corrected)*
BSR	Lower	11/10/2004	9	0	150	3/22/2005	Eyed	54	74	0	0	0	0	128	0	36.0	47.7
BSR	Lower	11/10/2004	10	0	150	3/22/2005	Eyed	47	93	0	0	0	0	140	0	31.3	41.5
BSR	Lower	11/10/2004	11	1	149	4/27/2005	Hatch	4	72	29	16	0	0	121	0	32.9	43.7
BSR	Lower	11/10/2004	12	0	150	4/27/2005	Hatch	1	105	24	3	0	0	133	0	18.7	24.7
BSR	Lower	11/10/2004	13	2	148	6/28/2005	Emergence	0	54	0	0	15	0	69		10.1	13.5
BSR	Lower	11/10/2004	14	1	149	6/28/2005	Emergence	0	38	0	0	9	2	49		6.0	8.0
BSR	Lower	11/10/2004	15	0	150	6/28/2005	Emergence	0	69	0	0	13	0	82		8.7	11.5
BSR	Lower	11/10/2004	16	1	149	6/28/2005	Emergence	0	44	0	0	16	0	60		10.7	14.3
BSR	Upper	11/10/2004	2	0	150	3/22/2005	Eyed	25	103	0	0	0	0	128	0	16.7	22.1
BSR	Upper	11/10/2004	5	1	149	3/22/2005	Eyed	28	90	0	0	0	0	118	0	18.8	24.9
BSR	Upper	11/10/2004	1	0	150	4/27/2005	Hatch	2	77	3	4	0	0	86	16	6.0	7.9
BSR	Upper	11/10/2004	3	1	149	4/27/2005	Hatch	2	69	7	22	0	0	100	6	20.8	27.6
BSR	Upper	11/10/2004	4	1	149	6/28/2005	Emergence	0	18	0	0	33	0	51		22.1	29.4
BSR	Upper	11/10/2004	6	0	150	6/28/2005	Emergence	0	57	0	0	6	0	63		4.0	5.3
BSR	Upper	11/10/2004	7	0	150	6/28/2005	Emergence	0	52	0	0	11	0	63		7.3	9.7
BSR	Upper	11/10/2004	8	1	149	6/28/2005	Emergence	0	0	0	0	11	0	11		7.4	9.8
PWR	Lower	11/10/2004	18	0	150	3/23/2005	Eyed	51	45	0	0	0	0	96	0	34.0	45.0
PWR	Lower	11/10/2004	19	1	149	3/23/2005	Eyed	28	91	0	0	0	0	119	0	18.8	24.9
PWR	Lower	11/10/2004	20	0	150	4/27/2005	Hatch	26	46	1	0	0	0	73	2	18.0	23.8
PWR	Lower	11/10/2004	22	0	150	4/27/2005	Hatch	21	23	4	0	0	0	48	8	16.7	22.1
PWR	Lower	11/10/2004	17	1	149	6/5/2005	Emergence	0	56	0	0	2	0	58		1.3	1.8
PWR	Lower	11/10/2004	21	1	149	6/5/2005	Emergence	0	62	0	0	0	0	62		0.0	0.0
PWR	Lower	11/10/2004	23	0	150	6/5/2005	Emergence	0	36	0	0	2	0	38		1.3	1.8
PWR	Lower	11/10/2004	24	2	148	6/5/2005	Emergence	0	13	0	0	4	0	17		2.7	3.6
PWR	Upper	11/10/2004	25	1	149	3/23/2005	Eyed	30	72	0	0	0	0	102	0	20.1	26.7
PWR	Upper	11/10/2004	26	2	148	3/23/2005	Eyed	24	83	0	0	0	0	107	0	16.2	21.6
PWR	Upper	11/10/2004	30	2	148	3/23/2005	Eyed	31	58	0	0	0	0	89	0	20.9	27.9
PWR	Upper	11/10/2004	27	1	149	3/23/2005	Lost	-	-	-	-	-	-	0	-	-	-
PWR	Upper	11/10/2004	28	1	149	3/23/2005	Lost	-	-	-	-	-	-	0	-	-	-
PWR	Upper	11/10/2004	29	1	149	3/23/2005	Lost	-	-	-	-	-	-	0	-	-	-
PWR	Upper	11/10/2004	31	0	150	3/23/2005	Lost	-	-	-	-	-	-	0	-	-	-
PWR	Upper	11/10/2004	32	2	148	3/23/2005	Lost	-	-	-	-	-	-	0	-	-	-

* %S (corrected): [n/(i-m)]*100; where ***n*** is the number of live eggs retrieved; ***i*** is the initial number of eggs placed in the basket at installation and ***m*** is the mortality of the hatchery controls (in this case *(Σ all hatcery control morts) / 4)*

Appendix 1. (cont'd) Atlantic salmon egg survival data from egg incubation baskets installed and retrieved from the Big Salmon and Point Wolfe rivers, 2005-06.

River	Site	Install Date (mm/dd/yyyy)	Basket No.	Dead Eggs (at install)	Total Eggs (at install)	Removal Date (mm/dd/yyyy)	Stage	Live Eggs (recovered)	Dead Eggs (recovered)	Live Alevin (recovered)	Dead Alevin (recovered)	Live Fry (recovered)	Dead Fry (recovered)	Total (recovered)	Empty Shell	%S	%S (corrected)[a]
BSR	Lower	11/9/2005	29	0	150	12/13/2005	green	89	59	0	0	0	0	148	0	59.33	63.4
BSR	Lower	11/9/2005	37	1	149	12/13/2005	green	101	48	0	0	0	0	149	0	67.79	72.5
BSR	Lower	11/9/2005	30	0	150	12/21/2005	green2	138	8	0	0	0	0	146	0	92.00	98.3
BSR	Lower	11/9/2005	35	0	150	12/21/2005	green2	136	13	0	0	0	0	149	0	90.67	96.9
BSR	Lower	11/9/2005	33	0	150	2/8/2006	green3	85	61	0	0	0	0	146		56.67	73.1
BSR	Lower	11/9/2005	38	0	150	2/8/2006	green3	119	31	0	0	0	0	150		79.33	100.0
BSR	Lower	11/9/2005	36	0	150	3/17/2006	eyed	23	125	0	0	0	0	148	0	15.33	19.8
BSR	Lower	11/9/2005	39	0	150	3/17/2006	eyed	26	123	0	0	0	0	149	0	17.33	22.4
BSR	Lower	11/9/2005	28[b]	0	150	6/16/2006	emergence	56	33	0	0	2	0	91		37.33	48.3
BSR	Lower	11/9/2005	31	0	150	6/16/2006	emergence	16	114	0	0	0	0	130		10.67	13.8
BSR	Lower	11/9/2005	32	0	150	6/16/2006	emergence	5	103	0	0	0	0	108		3.33	4.3
BSR	Lower	11/9/2005	34	0	150	6/16/2006	emergence	4	102	0	0	0	0	106		2.67	3.4
BSR	Upper	11/9/2005	41	0	150	12/13/2005	green	75	75	0	0	0	0	150	0	50.00	53.4
BSR	Upper	11/9/2005	45	0	150	12/13/2005	green	76	74	0	0	0	0	150	0	50.67	54.2
BSR	Upper	11/9/2005	44	0	150	12/21/2005	green2	136	10	0	0	0	0	146	0	90.67	96.9
BSR	Upper	11/9/2005	51	0	150	12/21/2005	green2	89	59	0	0	0	0	148	0	59.33	63.4
BSR	Upper	11/9/2005	46	1	149	2/8/2006	green3	68	72	0	0	0	0	140		45.64	59.0
BSR	Upper	11/9/2005	50	0	150	2/8/2006	green3	62	74	0	0	0	0	136		41.33	53.3
BSR	Upper	11/9/2005	42	0	150	3/17/2006	eyed	13	131	0	0	0	0	144	0	8.67	11.2
BSR	Upper	11/9/2005	47	0	150	3/17/2006	eyed	23	117	0	0	0	0	140	0	15.33	19.8
BSR	Upper	11/9/2005	40[b]	0	150	6/16/2006	emergence	4	109	0	0	0	0	113		2.67	3.4
BSR	Upper	11/9/2005	43	0	150	6/16/2006	emergence	4	76	0	0	0	0	80		2.67	3.4
BSR	Upper	11/9/2005	48	0	150	6/16/2006	emergence	12	103	0	0	0	0	115		8.00	10.3
BSR	Upper	11/9/2005	49	0	150	6/16/2006	emergence	17	72	0	0	0	0	89		11.33	14.7
PWR	Lower	11/9/2005	3	0	150	12/13/2005	green	54	95	0	0	0	0	149	0	36.00	38.0
PWR	Lower	11/9/2005	7	0	150	12/13/2005	green	71	75	0	0	0	0	146	0	47.33	50.0
PWR	Lower	11/9/2005	4	0	150	12/22/2005	green2	138	10	0	0	0	0	148	0	92.00	97.2
PWR	Lower	11/9/2005	12	0	150	12/22/2005	green2	135	15	0	0	0	0	150	0	90.00	95.1
PWR	Lower	11/9/2005	5	0	150	2/7/2006	green3	20	126	0	0	0	0	146	0	13.33	17.2
PWR	Lower	11/9/2005	10	0	150	2/7/2006	green3	37	113	0	0	0	0	150	0	24.67	31.9
PWR	Lower	11/9/2005	2	0	150	3/16/2006	eyed	6	139	0	0	0	0	145	0	4.00	5.2
PWR	Lower	11/9/2005	9	0	150	3/16/2006	eyed	12	126	0	0	0	0	138	0	8.00	10.5
PWR	Lower	11/9/2005	1	1	149	6/16/2006	emergence	0	0	0	0	0	0	0		0.00	0.0
PWR	Lower	11/9/2005	6	0	150	6/16/2006	emergence	0	0	0	0	0	0	0		0.00	0.0
PWR	Lower	11/9/2005	8[b]	0	150	6/16/2006	emergence	3	0	0	0	0	0	3		2.00	2.6
PWR	Lower	11/9/2005	11	0	150	6/16/2006	emergence	0	0	0	0	0	0	0		0.00	0.0
PWR	Upper	11/9/2005	19	0	150	12/13/2005	green	45	101	0	0	0	0	146	0	30.00	31.7
PWR	Upper	11/9/2005	24	0	150	12/13/2005	green	57	93	0	0	0	0	150	0	38.00	40.1
PWR	Upper	11/9/2005	22	0	150	12/22/2005	green2	86	62	0	0	0	0	148	0	57.33	60.6
PWR	Upper	11/9/2005	23	0	150	12/22/2005	green2	135	14	0	0	0	0	149	0	90.00	95.1
PWR	Upper	11/9/2005	13	0	150	2/7/2006	green3	0	148	0	0	0	0	148	0	0.00	0.0
PWR	Upper	11/9/2005	17	0	150	2/7/2006	green3	4	137	0	0	0	0	141	0	2.67	3.4
PWR	Upper	11/9/2005	15	0	150	3/16/2006	eyed	2	144	0	0	0	0	146	0	1.33	1.7
PWR	Upper	11/9/2005	16	1	149	3/16/2006	eyed	0	145	0	0	0	0	145	0	0.00	0.0
PWR	Upper	11/9/2005	21	0	150	6/16/2006	emergence	2	133	0	0	0	0	135		1.33	1.7
PWR	Upper	11/9/2005	18	0	150	6/16/2006	emergence	0	122	0	0	0	0	122		0.00	0.0
PWR	Upper	11/9/2005	14	1	149	2/7/2006	emergence[c]	0	0	0	0	0	0	0		0.00	0.0
PWR	Upper	11/9/2005	20[b]	0	150	5/27/2006	emergence[c]	0	112	0	0	0	0	112		0.00	0.0

[a] - %S (corrected): [n/(i-m)]*100; where ***n*** is the number of live eggs retrieved; ***i*** is the initial number of eggs placed in the basket at installation and ***m*** is the mortality of the hatchery controls (in this case *(Σ all hatchery control morts) / 3; for each river)*

[b] - minilogs

[c] - baskets not included in analyses because removed prior to completion of emergence monitoring

Appendix 2. Accumulated fine sediments by weight and volume from egg incubation baskets retrieved from the Big Salmon and Point Wolfe rivers, 2004-05.

Weight:

Site	Basket	Stage	>2mm (g)	1mm (g)	0.5mm (g)	0.25mm (g)	0.125mm (g)	0.063mm (g)	Silt (g)	Tot. fines (g)
BSR - Lower	10	Eye	4502.6	1.6	1.0	6.1	6.5	1.8	2.2	19.2
BSR - Lower	9	Eye	4608.6	1.5	1.0	5.4	5.7	1.7	1.8	17.1
BSR - Lower	12	Hatch	4517.9	3.4	2.1	1.2	0.8	0.6	0.4	8.5
BSR - Lower	11	Hatch	4596.4	1.8	1.2	5.5	6.1	2.2	2.1	18.9
BSR - Lower	16	Emergence	4404.3	1.6	2.1	1.0	0.7	0.5	0.4	6.3
BSR - Lower	13	Emergence	4488.2	3.0	3.4	1.1	0.6	0.4	0.2	8.7
BSR - Lower	14	Emergence	4585.9	2.1	2.7	1.7	0.8	0.5	0.2	8.0
BSR - Lower	15	Emergence	4663.8	2.2	2.2	0.9	0.7	0.6	0.7	7.3
BSR - Upper	5	Eye	4575.7	2.2	0.9	0.5	1.0	2.5	3.3	10.4
BSR - Upper	2	Eye	4748.7	1.8	1.2	0.6	1.4	1.6	2.4	9.0
BSR - Upper	3	Hatch	4359.6	1.4	3.3	1.6	1.5	1.2	1.0	10.0
BSR - Upper	1	Hatch	4539.7	2.3	1.2	0.5	0.7	3.3	3.2	11.2
BSR - Upper	4	Emergence	4266.9	4.2	1.8	2.8	2.8	0.8	0.6	13.0
BSR - Upper	7	Emergence	4231.1	1.6	1.5	2.2	1.3	0.7	0.7	8.0
BSR - Upper	6	Emergence	4580.6	2.0	2.8	2.1	1.3	0.9	0.8	9.9
BSR - Upper	8	Emergence	4744.2	2.2	2.1	2.2	1.8	0.7	0.7	9.7
PWR - Lower	19	Eye	4616.0	360.3	305.8	41.0	10.4	4.4	3.4	725.3
PWR - Lower	18	Eye	4477.6	232.9	182.1	25.0	5.9	2.6	1.6	450.1
PWR - Lower	22	Hatch	4683.7	115.6	138.8	46.4	16.2	7.4	6.0	330.4
PWR - Lower	20	Hatch	4547.5	235.5	170.7	26.5	8.1	4.1	3.4	448.3
PWR - Lower	17	Emergence	4988.9	450.4	354.8	101.6	26.2	9.1	8.4	950.5
PWR - Lower	21	Emergence	4262.9	387.3	437.3	63.8	13.8	5.9	5.7	913.8
PWR - Lower	23	Emergence	4167.9	404.2	367.3	118.7	16.4	7.7	7.9	922.2
PWR - Lower	24	Emergence	4226.7	464.1	362.6	75.0	13.8	7.4	6.5	929.4

Volume:

Site	Basket	Stage	>2mm (cm^3)	1mm (cm^3)	0.5mm (cm^3)	0.25mm (cm^3)	0.125mm (cm^3)	0.063mm (cm^3)	Silt (cm^3)	Tot. fines (cm^3)
BSR - Lower	10	Eye	1650.0	2.8	2.1	26.0	29.0	8.5	7.4	75.8
BSR - Lower	9	Eye	1750.0	2.6	2.0	22.5	21.0	8.5	7.0	63.6
BSR - Lower	12	Hatch	1750.0	7.0	7.0	4.5	2.0	2.3	1.7	24.5
BSR - Lower	11	Hatch	1730.0	3.3	2.2	24.5	26.3	9.3	7.9	73.5
BSR - Lower	16	Emergence	1630.0	2.1	6.5	3.9	2.6	1.8	1.7	18.6
BSR - Lower	13	Emergence	1650.0	3.3	6.1	3.6	2.1	1.3	1.2	17.6
BSR - Lower	14	Emergence	1855.0	2.6	5.9	5.1	2.7	1.9	1.2	19.4
BSR - Lower	15	Emergence	1840.0	2.9	6.5	3.5	2.4	1.9	2.1	19.3
BSR - Upper	5	Eye	1650.0	2.2	1.0	1.0	2.0	9.5	12.0	27.7
BSR - Upper	2	Eye	1725.0	3.2	1.1	2.4	1.0	5.0	8.6	21.3
BSR - Upper	3	Hatch	1655.0	2.5	16.3	8.1	6.7	4.6	3.5	41.7
BSR - Upper	1	Hatch	1700.0	2.1	1.2	1.0	1.6	10.9	11.4	28.2
BSR - Upper	4	Emergence	1584.0	4.8	4.8	9.0	8.4	0.7	2.5	30.2
BSR - Upper	7	Emergence	1555.0	2.2	4.3	7.4	3.9	2.2	2.1	22.1
BSR - Upper	6	Emergence	1580.0	2.3	8.2	7.4	3.7	2.3	2.0	25.9
BSR - Upper	8	Emergence	1690.0	2.4	5.7	4.3	4.0	2.3	2.0	20.7
PWR - Lower	19	Eye	1673.0	135.0	135.0	31.0	11.0	5.5	5.5	323.0
PWR - Lower	18	Eye	1780.0	85.0	75.0	20.5	6.0	3.8	3.1	193.4
PWR - Lower	22	Hatch	1870.0	48.0	108.0	18.0	17.5	9.0	17.5	218.0
PWR - Lower	20	Hatch	1675.0	90.0	74.0	24.0	12.5	8.4	7.0	215.9
PWR - Lower	17	Emergence	1710.0	170.0	136.0	84.0	26.0	14.5	13.0	443.5
PWR - Lower	21	Emergence	1510.0	145.0	165.0	51.0	16.5	10.0	10.4	397.9
PWR - Lower	23	Emergence	1425.0	155.0	145.0	90.0	18.5	12.2	13.2	433.9
PWR - Lower	24	Emergence	1450.0	175.0	140.0	65.0	16.0	12.4	11.6	420.0

Appendix 2. (cont'd) Accumulated fine sediments by weight and volume from egg incubation baskets retrieved from the Big Salmon and Point Wolfe rivers, 2005-06. Sediment samples were not actually collected at the green2 removals; instead samples from the green removals taken a week prior to the green2 removals were used in their place. Sediment volumes for the emergence stage were calculated from regressions of weight and volume for each size fraction from the previous three removals.

				WEIGHT								VOLUME							
River	Site	Basket	Stage	>2mm (g)	1mm (g)	0.5mm (g)	0.25mm (g)	0.125mm (g)	0.063mm (g)	Silt (g)	Tot. fines (g)	>2mm (g)	1mm (g)	0.5mm (g)	0.25mm (g)	0.125mm (g)	0.063mm (g)	Silt (g)	Tot. fines (g)
BSR	Lower	29	green	4480.1	1.0	0.9	0.7	0.7	0.6	0.7	4.6	1725.0	1.0	0.5	2.0	1.9	1.8	1.3	8.5
BSR	Lower	37	green	4964.0	5.4	3.8	0.8	0.7	0.7	0.7	12.1	1930.0	2.0	1.5	1.7	1.9	1.7	1.4	10.2
BSR	Lower	30	green2								0.0								0.0
BSR	Lower	35	green2								0.0								0.0
BSR	Lower	33	green3	4759.8	9.8	11.0	3.1	1.5	1.4	1.4	28.2	1775.0	6.0	4.5	3.5	3.0	3.3	2.8	23.1
BSR	Lower	38	green3	4819.2	6.4	8.2	2.3	1.0	0.8	1.1	19.8	1810.0	5.0	3.0	3.1	2.0	2.2	2.6	17.9
BSR	Lower	36	eyed	4511.8	7.7	6.0	1.7	1.0	0.8	0.7	17.9	1685.0	1.5	2.5	2.9	2.4	2.1	1.3	12.7
BSR	Lower	39	eyed	4191.3	2.9	1.9	1.3	1.4	1.6	1.0	10.1	1540.0	1.0	1.0	2.7	2.9	3.5	1.9	13.0
BSR	Lower	28	emergence	4512.9	3.4	1.4	0.7	0.7	0.6	0.6	7.4	1685.7	1.8	0.7	1.7	1.8	1.8	1.2	9.0
BSR	Lower	31	emergence	4533.1	2.1	0.7	0.6	0.6	0.6	0.4	5.0	1695.3	1.3	0.5	1.6	1.6	1.8	0.8	7.5
BSR	Lower	32	emergence	4895.7	3.9	3.7	1.6	1.3	0.9	0.5	11.9	1867.2	2.0	1.5	2.6	2.8	2.3	1.0	12.2
BSR	Lower	34	emergence	4362.0	3.7	2.0	1.4	1.2	0.9	1.0	10.2	1614.2	1.9	0.9	2.4	2.7	2.3	2.0	12.2
BSR	Upper	41	green	4172.0	21.0	18.1	6.0	2.6	1.7	1.7	51.1	1545.0	8.5	6.5	7.7	5.2	3.5	3.0	34.4
BSR	Upper	45	green	4256.4	39.3	25.0	8.8	3.0	1.8	2.0	79.9	1525.0	15.5	9.0	10.0	6.1	4.2	4.3	49.1
BSR	Upper	44	green2								0.0								0.0
BSR	Upper	51	green2								0.0								0.0
BSR	Upper	46	green3	4593.6	23.9	9.4	5.0	2.2	1.4	1.4	43.3	1700.0	11.0	3.0	5.1	4.7	3.2	2.7	29.7
BSR	Upper	50	green3	4479.7	21.6	16.2	6.3	3.2	1.9	2.1	51.3	1670.0	10.0	6.0	7.8	6.2	3.9	4.3	38.2
BSR	Upper	42	eyed	4370.4	21.8	6.8	4.9	3.7	2.1	2.0	41.3	1610.0	6.5	3.0	5.7	7.0	4.5	4.0	30.7
BSR	Upper	47	eyed	4741.5	22.4	8.7	5.5	3.9	3.2	2.2	45.9	1800.0	7.0	3.0	6.1	7.7	6.0	4.3	34.1
BSR	Upper	40	emergence	4182.4	17.8	8.4	3.6	1.8	1.4	0.8	33.8	1529.0	7.2	3.2	4.6	3.8	3.2	1.6	23.5
BSR	Upper	43	emergence	4612.9	12.3	6.4	5.1	3.2	2.2	2.3	31.5	1733.1	5.1	2.5	6.1	6.3	4.5	4.6	29.1
BSR	Upper	48	emergence	4201.6	24.6	13.7	6.9	3.0	1.9	1.6	51.7	1538.1	9.7	5.0	7.9	5.9	4.0	3.2	35.8
BSR	Upper	49	emergence	4206.1	9.6	5.0	2.4	1.8	1.7	1.1	21.6	1540.3	4.1	2.0	3.4	3.8	3.7	2.2	19.1
PWR	Lower	3	green	4980.5	111.1	44.0	9.4	2.1	1.0	0.9	168.5	1835.0	41.0	17.0	6.6	2.1	1.4	1.5	69.6
PWR	Lower	7	green	4885.9	24.7	3.5	0.6	0.4	0.1	0.2	29.5	1900.0	11.0	1.1	0.9	0.5	0.2	0.2	13.9
PWR	Lower	4	green2								0.0								0.0
PWR	Lower	12	green2								0.0								0.0
PWR	Lower	5	green3	4835.0	68.8	26.5	5.2	1.8	0.9	1.0	104.2	1850.0	26.0	9.0	3.8	2.0	1.4	1.5	43.7
PWR	Lower	10	green3	4681.3	49.0	8.4	2.3	1.0	0.6	1.0	62.3	1740.0	18.0	2.0	1.9	1.1	0.8	1.5	25.3
PWR	Lower	2	eyed	4941.3	167.2	137.8	31.2	7.8	3.6	1.7	349.3	1870.0	65.0	50.6	20.0	9.4	5.7	2.5	153.2
PWR	Lower	9	eyed	4726.7	135.1	146.7	23.6	6.2	3.8	2.7	318.1	1790.0	52.0	54.5	14.7	7.0	6.1	4.0	138.3
PWR	Lower	1	emergence	5215.4	185.2	212.7	45.3	11.4	6.3	4.9	465.8	1982.4	71.1	78.8	29.1	13.5	9.9	6.8	209.3
PWR	Lower	6	emergence	5395.9	114.5	29.9	6.3	1.7	1.1	0.9	154.4	2056.6	43.9	10.9	4.5	2.0	1.8	1.4	64.3
PWR	Lower	8	emergence	4750.8	150.8	91.3	24.2	6.8	3.4	2.9	279.4	1791.5	57.9	33.7	15.8	8.1	5.4	4.1	124.9
PWR	Lower	11	emergence	4945.3	108.5	56.5	12.1	3.1	1.8	1.5	183.5	1871.4	41.5	20.8	8.2	3.6	2.8	2.2	79.2
PWR	Upper	19	green	4406.7	88.1	14.0	4.6	2.3	1.7	2.4	113.1	1640.0	30.0	4.8	3.5	2.5	3.0	3.1	46.9
PWR	Upper	24	green	4475.6	67.3	10.0	3.0	1.4	1.0	1.9	84.6	1685.0	25.0	4.0	2.7	2.0	2.0	2.9	38.6
PWR	Upper	22	green2								0.0								0.0
PWR	Upper	23	green2								0.0								0.0
PWR	Upper	13	green3	4681.8	220.4	125.9	25.6	5.9	2.9	4.0	384.7	1750.0	85.0	46.0	16.5	7.0	4.4	5.3	164.2
PWR	Upper	17	green3	4394.2	131.7	90.3	19.9	5.3	2.9	3.5	253.6	1650.0	52.0	34.0	15.0	6.5	4.5	5.3	117.3
PWR	Upper	15	eyed	4342.4	97.7	46.3	12.5	3.7	1.9	1.9	164.0	1620.0	37.0	17.5	7.9	4.5	3.1	2.7	72.7
PWR	Upper	16	eyed	4327.6	59.2	18.2	7.7	4.3	2.1	3.4	94.9	1620.0	25.0	6.5	4.9	5.0	3.0	4.6	49.0
PWR	Upper	18	emergence	4388.0	91.4	81.3	16.9	4.4	2.8	2.3	199.1	1642.4	34.9	30.0	11.2	5.2	4.4	3.3	89.0
PWR	Upper	21	emergence	4408.8	59.2	24.0	5.2	2.2	1.6	1.6	93.8	1650.9	22.5	8.7	3.8	2.6	2.5	2.3	42.5
PWR	Upper	14	emergence*								0.0								0.0
PWR	Upper	20	emergence*								0.0								0.0

* baskets prematurely removed, no sediment samples collected.