Does annual variation in growth and sexual maturation of white sucker (*Catostomus commersoni*) confound comparisons between pulp mill contaminated and reference rivers?

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Abstract: A previous study on the effect of pulp and paper effluents on white sucker (*Catostomus commersoni*), conducted in 1991 and 1992, in both effluent-exposed and reference rivers showed that fish grew faster at downstream sites than at upstream sites. However, in contrast with fish from a reference river, fish exposed to effluent showed no decrease in age or size at first maturity or increase in gonad size or fecundity in response to greater growth. The objective of the present study, conducted in 1993, was to test if differences in measures of growth and sexual maturation between fish populations in exposed and reference rivers would vary from year to year and whether such variation would affect conclusions concerning the effects of pulp mill effluents. Although size at age, fecundity, and age at first maturity varied between the two studies, patterns of demographic responses to pulp mill effluents, relative to reference populations, remained the same, i.e., conclusions about effects of pulp mill effluents did not change despite variation in demographic variables between years and sites. This study reaffirmed the view that only by including the fish populations in a reference river could effects due to bleached kraft mill effluent be separated from effects due to nutrient gradients.

Résumé :Une étude antérieure concernant l'effet des effluents d'usine de pâte et papier sur les meuniers noirs (*Catostomus commersoni*), menée en 1991 et 1992 dans des cours d'eau exposés aux effluents et des cours d'eau témoins, a montré que les poissons croissaient plus rapidement aux sites d'aval qu'aux sites d'amont. Toutefois, à la différence des poissons d'un cours d'eau témoin, il n'y a pas eu chez les poissons exposés aux effluents de diminution de l'âge ou de la taille à la première maturité ni d'augmentation de la taille des gonades ou de la fécondité liées à leur taux de croissance accrue. L'objectif de la présente étude, menée en 1993, était de vérifier si les différences dans les mesures de la croissance et de la maturation sexuelle entre les populations de poissons de cours d'eau exposés et témoins variaient d'année en année, et si cette variation pouvait avoir un impact sur les conclusions relatives aux effets des effluents d'usines de pâte. Bien que la taille selon l'âge, la fécondité et l'âge à la première maturité aient varié d'une étude à l'autre, les profils de réponses démographiques aux effluents d'usines de pâte, par rapport aux populations témoins, sont demeurés les mêmes; c'est-à-dire que les conclusions concernant les effets des effluents des usines de pâte n'ont pas changé malgré une variation dans les variables démographiques entre les années et les sites. Cette étude confirme l'idée suivant laquelle on ne peut distinguer les effets dus aux effluents d'usine de pâte kraft blanchie des effets dus aux gradients de nutriants qu'en prenant en considération les populations de poissons d'un cours d'eau témoin.
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Introduction

Recent North American studies of the effects of pulp and paper mill effluents discharged to the aquatic environment have revealed a variety of effects on fish, from biochemical disturbances to changes in population dynamics. These effects include bioaccumulation of chlorophenolic compounds (Gagnon et al. 1994), induction of the mixed function oxygenase (MFO) system (Adams et al. 1992; Ahokas et al. 1993; Gagnon et al. 1994), lowered steroid sex hormone concentrations (Munkittrick et al. 1992; Gagnon et al. 1994), disrupted fecundity–weight relationships (Gagnon et al. 1994), delayed age at maturity and increased size at maturity (Munkittrick et al. 1991; Gagnon et al. 1994, 1995*a*), and increased growth rates (Adams et al. 1992; Gagnon et al. 1994, 1995*a*; Haley et al. 1995). Although observed in many case studies, the pattern and extent of these responses appear to be site specific and may not be easily extrapolated to all situations.

In 1989, an extensive survey of the St. Maurice River, Québec, was initiated to investigate the validity of different parameters to be used in the Canadian Federal Environmental Effects Monitoring (EEM) program on pulp and paper mill

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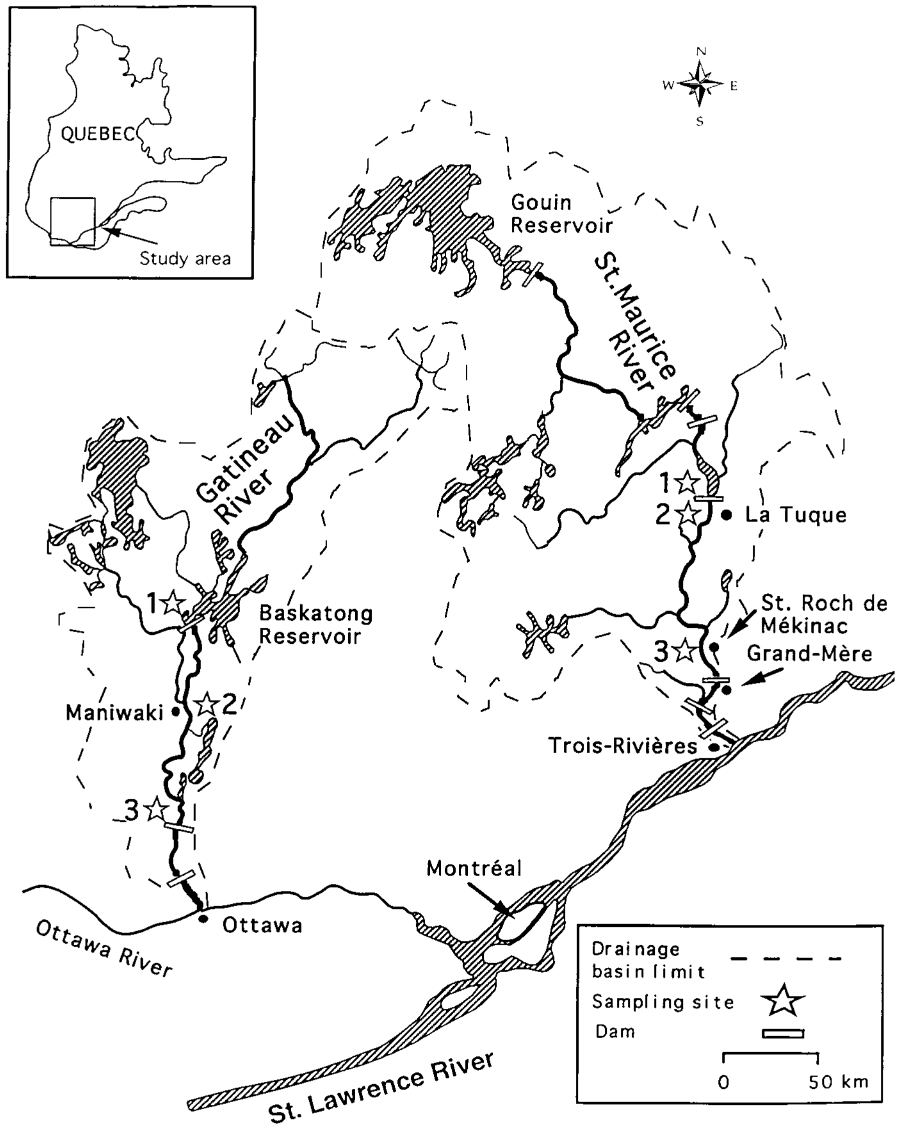
Fig. 1. Stations sampled on the St. Maurice and Gatineau rivers. On the St. Maurice River, white sucker populations are separated by hydroelectric dams at La Tuque and Grand-Mère. A pulp mill located at La Tuque is the major industry discharging effluent to the river. On the Gatineau River, dams were also located immediately downstream of stations 1 and 3, but no major industries occur in the study area. (Adapted from Gagnon et al. 1995*a*.)



effluents (Environment Canada 1992). At the beginning of the study, the St. Maurice River received more than 10 t of chlorinated organic chemicals per day from a bleached kraft mill situated at La Tuque (Fig. 1) (Hodson et al. 1992). The mill adopted a new sequence of bleaching in September 1988, changing from C_DNE_HD to C_DE_O(DED) (mill manager, Cartons St-Laurent, La Tuque, Québec, personal communication). In September 1992, the mill converted to chlorine dioxide substitution to reduce elemental chlorine use.

In earlier studies, we sampled white sucker (*Catostomus commersoni*), one of the most widespread and abundant fishes in North America (Scott and Crossman 1973), from the St. Maurice River in 1991 at three sites extending over 100 km of river. The purpose was to assess the impact of the effluent on white sucker demographics and the spatial extent of that impact. A gradient of productivity was expected over such a distance (Vannote et al. 1980), and river morphology varied from reservoir (lake) to riverine conditions among sites. The river was also used for log driving. A second, uncontaminated river, the Gatineau River, Québec, was chosen as a reference river. It had a similar morphology and distribution of sampling sites as well as a log drive. White sucker were sampled from the Gatineau River in 1992 on similar dates and under similar conditions as for the St. Maurice River (Gagnon et al. 1995*a*).

In both rivers, we observed accelerated growth of white sucker that occurred between 2 and 10 years of age at downstream stations relative to upstream stations, suggesting gradients of nutrient enrichment independent of bleached kraft mill effluent (BKME) contamination (Gagnon et al. 1995*a*, 1995*b*). Despite enhanced growth at downstream stations in both rivers, the reproductive response was markedly different. Gatineau River fish exhibited increased reproductive effort in response to enhanced growth, as shown by reduced length and age at first maturity, and increased gonad size and fecundity relative to body size (Gagnon et al. 1995*a*). The impacts of BKME exposure in the St. Maurice River were expressed as reduced reproductive effort in spite of enhanced growth at downstream stations, as revealed by greater length at maturity, reduced gonad size of females, and more variable fecundity relative to body size (Gagnon et al. 1995*a*). The reduction in potential reproductive performance was not obvious in simple upstream–downstream comparisons of the St. Maurice River, but became evident by comparison with fish from the uncontaminated Gatineau River which showed increased reproductive performance in response to enhanced growth rates (Gagnon et al. 1995*a*).

The EEM program for the pulp and paper industry requires each mill to study the impacts of its activities on the receiving environment. The EEM program is a series of monitoring and interpretation cycles, including field sampling repeated every 3 years, with comparisons of a recent cycle with previous cycles to assess temporal trends in environmental quality. The BKME-contaminated St. Maurice River and the uncontaminated Gatineau River provided an opportunity to test whether annual variations in demographics of white sucker populations would obscure effluent-associated changes that the EEM program wishes to detect. Both rivers exhibited very similar physicochemical and biotic characteristics, but interannual variations in demographic parameters among stations could affect previous conclusions. Although the mill changed its bleaching process in 1992, we did not anticipate new patterns in downstream fish population demographics in 1993 relative to 1991. Given the age of fish sampled (generally 4 years or older), the demographics in 1993 would likely reflect conditions from the previous 4–6 years.

The objective of this study was to determine if patterns of responses within rivers and between rivers previously documented were sufficiently strong to transcend the “noise” of natural annual variability and support the same conclusions about the effect of effluent exposure. Were the changes in demographics attributed to effluent exposure real and repeatable, or were they simply coincidental? We simultaneously sampled the Gatineau and St. Maurice rivers in 1993 during the spawning season of white sucker. Our previous results were based on data from the St. Maurice River in 1991 and from the Gatineau River in 1992. We compared these data sets to see if conclusions about the effect of effluent exposure would be altered by annual variation in fish demographics.

Materials and methods

Study areas

The St. Maurice and Gatineau rivers, located in the province of Québec (Fig. 1), exhibit similar watershed characteristics in terms of vegetation, soil types, weather conditions, and fish communities (Gagnon et al. 1995*a*). Overall, the St. Maurice River differs from the Gatineau River primarily in the discharge of BKME and a greater average flow rate of water associated with a greater watershed area. Fish communities were dominated by white sucker in both rivers.

The uncontaminated reference station 1 of the St. Maurice River was 10 km upstream of the mill and isolated from downstream stations by a hydroelectric dam situated beside the mill. Station 2 was located immediately downstream of the mill and next to the town of La Tuque, and station 3 was located 95 km downstream of the mill in a reservoir created by a second dam at Grand-Mère (Fig. 1). The primary sources of contamination in the study area were the pulp mill (chemicals, nutrients) and the town of La Tuque (nutrients). The effluent was diluted in the river to about 1% (v/v), and mixing was complete within 2 km of the discharge due to the hydroelectric dam and rapids downstream. At this rate of dilution, there were no measurable temperature differences among sites (Hodson et al. 1992). The 1993 sampling was performed 7 months after the conversion to chlorine dioxide substitution. However, because white sucker are long-lived, any significant demographic alterations observed in this study most likely reflect longer term exposure to effluent. There was continuous log floating at all three stations during the 2 years of sampling.

Three stations were also sampled on the Gatineau River (Fig. 1). The upstream station 1 was located in the Baskatong reservoir. The second station was located 30 km downstream of the dam near the town of Maniwaki. Station 3 on the Gatineau River was in a second reservoir located 105 km downstream from station 1. Most log floating was stopped during the summer of 1992, but some log floating persisted in 1993 while river banks were being cleared of logs.

In 1993, white suckers were collected simultaneously by two teams using gill nets in the two rivers immediately prior to spawning from May 3 to 13. The sampling procedure was similar for the two teams, following the methods used in 1991 and 1992 (Gagnon et al. 1995*a*). In the St. Maurice River, 1007 white sucker were collected in 1993 compared with 1301 in 1991, and in the Gatineau River, 854 white sucker were collected in 1993 compared with 723 in 1992.

Sample collection and analyses

For all fish, the fork length and the weights of the whole body, gonads, viscera, and carcass (whole body minus gonads and viscera) were recorded. Female gonads were preserved in Gilson’s fluid and fecundity was measured by the method described in Gagnon et al. (1994) (egg counts of a dried subsample). For all fish, the first fin ray of the right pectoral fin was taken for age determination (Beamish 1973). Age was determined by the method described in Gagnon et al. (1995*a*). Validation of age estimates from fin rays with fish of known age has been established for white sucker (Chalanchuk 1984).

Statistical analyses

Five fish were considered the minimum number necessary to calculate a representative value for statistical analyses of any parameter at a given station in a given year. When a parameter did not satisfy the minimum sample requirement, we excluded that year and station from the statistical analysis. Normality and homogeneity of variances of all data sets were tested with a Shapiro–Wilk test and a Bartlett test, respectively. Log-transformation was used to correct for normality and heteroscedacity (Zar 1984).

For each river, an analysis of covariance (ANCOVA) with two classification factors (station, year) was used to compare fish size, gonad size, and fecundity, with age as the covariate of fish size and carcass weight (body weight minus gonads) as the covariate of gonad size and of fecundity (SAS 1988). The homogeneity of slopes relating the dependent variable and the covariable was tested and found to be similar ($P > 0.05$) in all cases. Therefore, the subsequent ANCOVAs were repeated excluding the interaction term (station × year × covariable) between the factors and the covariable (SAS 1988). We used contrast tests as a posteriori hypotheses to locate which station was significantly different from the others. In the case where there was a significant effect between the station and year (station × year), we analysed each station separately for year comparisons and each year for station comparisons. For all the analyses, we used a significance level of 0.05. The ANCOVA tables are summarized in the Appendix.

Age and size at maturity were determined by visually inspecting age – percent maturation curves as recommended by Trippel and Harvey (1991), since white sucker populations showed an abrupt transition from immaturity to reproductive maturity. Age and size at first maturity were defined as that age or size at which 50% or more

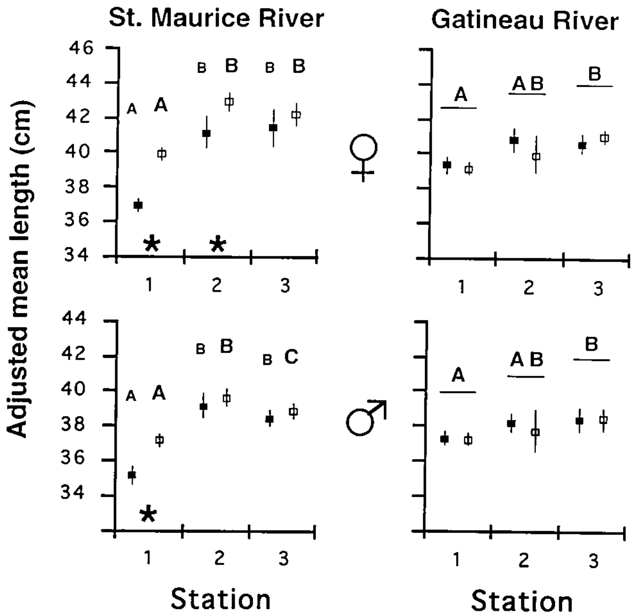


Fig. 2. Interannual and interstation comparisons of age-adjusted mean length of female and male white sucker captured during the spawning run in the Gatineau and St. Maurice rivers. Open squares, 1993 sampling (both rivers); solid squares, 1991 (St. Maurice River) or 1992 (Gatineau River) sampling. Asterisks indicate a significant difference between years ($P < 0.05$). Different letters indicate a significant difference among stations ($P < 0.05$). Horizontal lines indicate that interstation comparisons are based on pooled annual data. When annual data cannot be pooled (because of a significant year × station interaction), differences among stations are expressed by two different sizes of letter representing annual comparisons. Vertical bars indicate confidence limits.

of fish examined were mature. Statistical analyses were precluded because analytical methods for binomial data, such as probit analysis, require partial responses (i.e., >0 but <100% mature); in about 50% of comparisons, there were no partial maturities at one or more sites. Comparisons between years and among stations were limited by the low numbers of younger and smaller fish captured in 1993. In both years, most fish captured were aged 4 years or older.

Results

Growth

In the St. Maurice River, the results of the ANCOVA for females aged between 5 and 10 years revealed that the changes in length among stations varied between years as shown by the significant difference ($P = 0.0037$) of the interaction term (station × year). The contrast test on adjusted mean length indicated that female white sucker at stations 1 and 2 were significantly longer ($P < 0.01$) in 1993 than in 1991 whereas those captured at station 3 were of similar length during the 2 years (Fig. 2). Despite these annual differences, female white sucker were smaller at the upstream station relative to those sampled downstream in both sampling years. For male white sucker, fish aged between 5 and 10 years also varied in length among stations between years as shown by the significant difference ($P = 0.0152$) of the interaction term (station × year). The contrast test on adjusted mean length indicated that only male white sucker at station 1

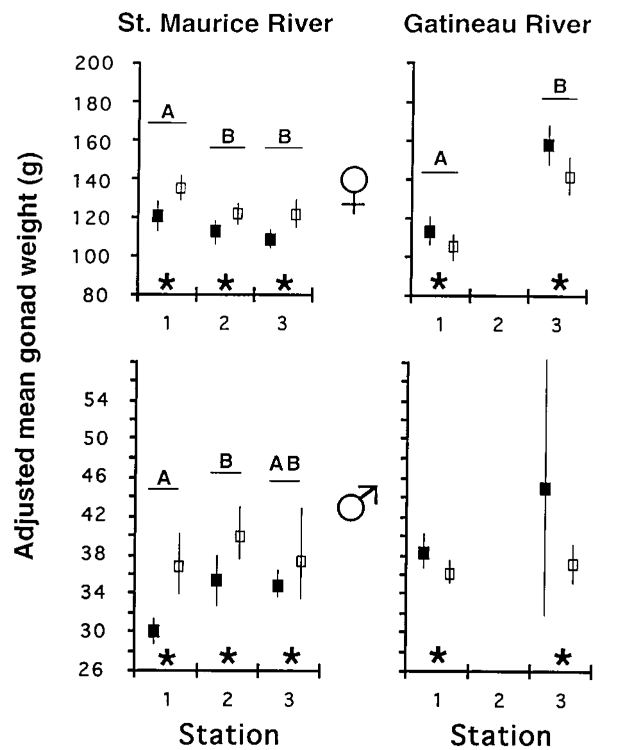


Fig. 3. Interannual and interstation comparisons of weight-adjusted mean gonad weight of female and male white sucker captured during the spawning run in the Gatineau and St. Maurice rivers. Open squares, 1993 sampling (both rivers); solid squares, 1991 (St. Maurice River) or 1992 (Gatineau River) sampling. Asterisks indicate a significant difference between years ($P < 0.05$). Different letters indicate a significant difference among stations ($P < 0.05$). Horizontal lines indicate that interstation comparisons are based on pooled annual data. Vertical bars indicate confidence limits.

were significantly ($P < 0.05$) longer in 1993 relative to 1991 (Fig. 2). As in the case of females, males from the upstream station were significantly ($P < 0.05$) smaller than those from the two downstream stations in both sampling years despite annual differences in length at age.

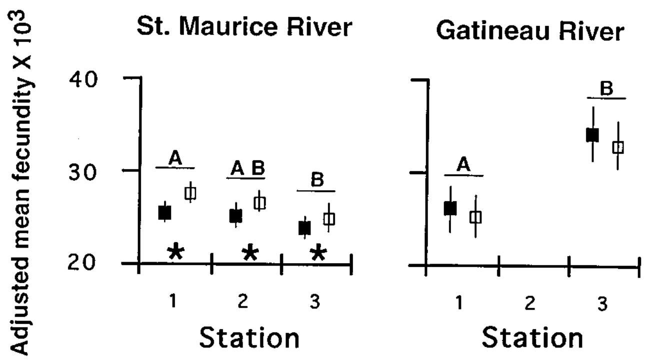
In the Gatineau River, female and male white sucker aged 5–10 years were not significantly different in length ($P > 0.05$) between 1992 and 1993 at all stations. White sucker were significantly smaller ($P < 0.05$) at the upstream station relative to at least one downstream station in both sampling years (Fig. 2). The magnitude of changes in length among stations was smaller than observed in the St. Maurice River.

Gonad size

In the St. Maurice River, mature female and male white sucker exhibited greater gonad weights in 1993 than in 1991, relative to carcass weight. Females from the upstream station had bigger gonads per unit carcass weight than those from downstream stations (Fig. 3). In contrast, the gonad weights of male fish sampled at station 2 in 1993 were higher ($P < 0.05$) than those of fish located at the upstream reference station (Fig. 3).

In the Gatineau River, the gonad weights of mature female white sucker relative to carcass weight were lower ($P <$

Fig. 4. Interannual and interstation comparisons of weight-adjusted mean fecundity of female white sucker captured during the spawning run in the Gatineau and St. Maurice rivers. Open squares, 1993 sampling (both rivers); solid squares, 1991 (St. Maurice River) or 1992 (Gatineau River) sampling. Asterisks indicate a significant difference between years ($P < 0.05$). Different letters indicate a significant difference among stations ($P < 0.05$). Horizontal lines indicate that interstation comparisons are based on pooled annual data. Vertical bars indicate confidence limits.



0.0001) in 1993 relative to 1992, and in both years, females from the downstream station 3 had higher ($P < 0.0001$) gonad weights than those sampled at station 1 (Fig. 3). The statistics for male white sucker indicated that the testis weights were lower ($P = 0.0385$) in 1993 relative to 1992 at stations 1 and 3, but in both years, no differences ($P > 0.05$) were observed among stations.

Fecundity

Females from the St. Maurice River produced a larger ($P <$ 0.001) number of eggs per unit carcass weight in 1993 relative to 1991, and females from the upstream reference station had a higher fecundity ($P < 0.001$) relative to at least one downstream station in both sampling years (Fig. 4).

In the Gatineau River, the number of eggs produced was similar between 1993 and 1992 for all sites ($P = 0.091$). Females sampled at the upstream station 1 produced fewer eggs ($P < 0.0001$) than females from station 3 in both sampling years (Fig. 4).

Age and size at maturity

In the St. Maurice, the youngest females and males captured in 1993 at the upstream reference station were 5 years old and all were sexually mature (Figs. 5 and 6). Therefore, age at first maturity would be 5 years of age or less. At the downstream stations 2 and 3, females reached first maturity at 5 and 6 years, respectively (Fig. 5), and males reached first maturity at 4 and 6 years, respectively (Fig. 6). There were too few fish from stations 1 and 2 in 1993 to establish size at maturity for females or males, but it is clear that male fish at station 3 reaching first maturity at length class 36–37 cm were longer relative to males at first maturity captured at station 1 (Fig. 6). While size at maturity of males and females could not be measured at stations 1 and 2 in 1993, the trend was similar to that seen in 1991, where fish of both sexes from the reference station 1 matured at a much smaller size.

Compared with 1991, female and male white sucker from the reference station of the St. Maurice River appeared to mature at least a year earlier in 1993. At the downstream station 3, the age (6 years) and size (38–39 cm) at first maturity of females were the same for the two sampling years (Fig. 5). Males at station 3 reached first maturity at the same age (6 years), but were slightly longer in 1993 compared with 1991 (Fig. 6). There were too few male fish captured at station 2 to compare between years.

In the Gatineau River, females sampled in 1993 at stations 1 and 2 reached first maturity between 5 and 6 years of age. At the downstream station 3, the youngest females captured were 4 years old and 100% were mature (Fig. 7). Female white sucker at station 1 reached first maturity at length class 34–35 cm (Fig. 7). Although there were too few fish from stations 2 and 3 to make a valid comparison, it appears that mature fish from station 1 were longer than mature fish sampled at the downstream station 3. Male white sucker from the upstream station 1 and downstream station 3 were spawning at 5 and 3 years of age, respectively, in 1993 (Fig. 8). Male fish from the downstream station 3 were smaller at first maturity relative to fish from upstream station 1 (Fig. 8). There were too few male fish from station 2 to compare age at maturity among stations and between years.

Compared with 1992, sampling in 1993 in the Gatineau River revealed that females were mature at the same age (station 1) or a year older in 1993 (station 2) (Fig. 7) whereas males from stations 1 and 3 matured a year earlier (Fig. 8). Males from stations 2 and 3 were longer in 1993 compared with males captured at the same station in 1992. Most importantly, the pattern of station-to-station differences remained the same: fish at downstream station 3 matured earlier and at a smaller size than fish from the upstream reference station.

Overall, the fish from the St. Maurice River showed little variation among stations in age at maturity, but matured at a greater length at downstream stations in 1993. In contrast, white sucker of both sexes in the Gatineau River were spawning at younger ages and smaller sizes at the downstream stations in 1992, and there were variations in the age and size at first maturity for both sexes and stations in 1993 relative to 1992.

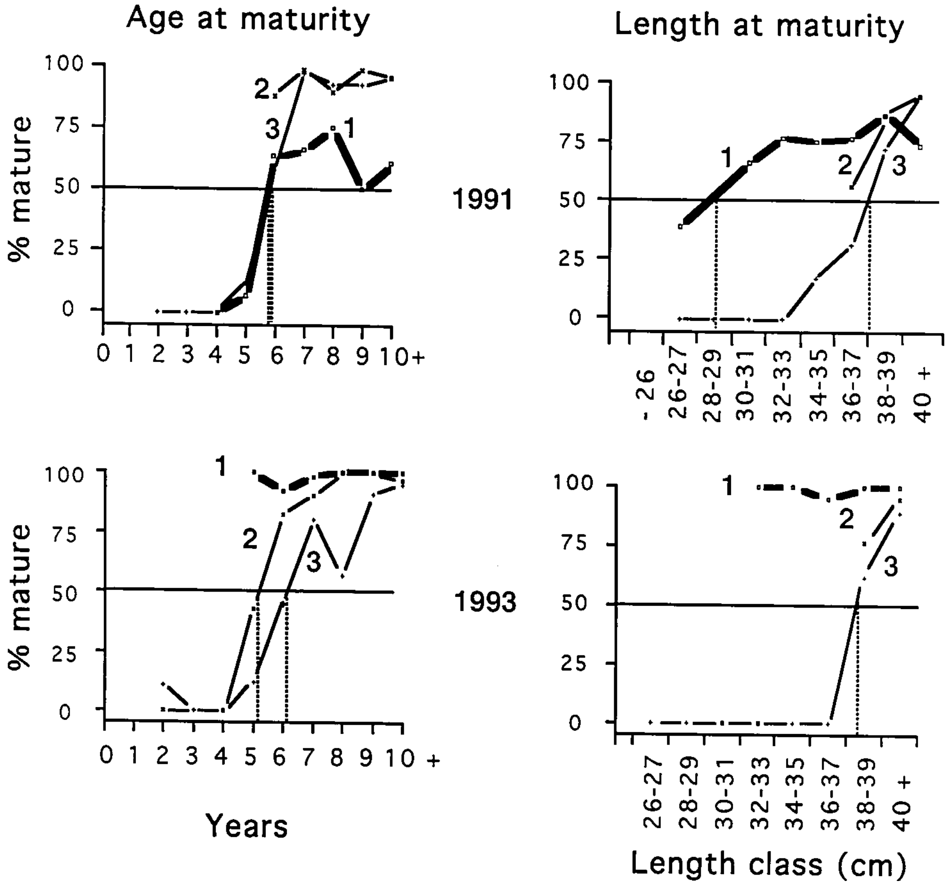
Discussion

Interstation variability

The results of the 1993 sampling campaign led us to the same conclusions as reached in the previous study (Gagnon et al. 1995*a*) concerning gradients of fish growth and reproductive effort as a function of river gradient and BKME exposure. The trends within the St. Maurice River remained the same over 2 years of sampling: white sucker from upstream (*i*) grew slower relative to white sucker from downstream as shown by size at age, (*ii*) exhibited greater reproductive effort (females only) as shown by greater gonad size and fecundity relative to body size, and (*iii*) matured at a younger age (in 1993) or at the same age (in 1991) relative to downstream sites. In comparison, white sucker from the upstream station of the Gatineau River (*i*) grew slower relative to white sucker from downstream as shown by size at age, (*ii*) exhibited reduced reproductive effort (females only) as shown by reduced gonad size relative to body size and fecundity, and (*iii*) matured at an older age relative to downstream sites.

In accordance with better growth, female fish from the

Fig. 5. Age and length at first maturity for female white sucker from the St. Maurice River. The numbers represents the station, and the thick line represents the upstream station 1. The vertical dotted lines indicate age and size at maturity. Samples sizes for each point ranged from 5 to 52 fish.



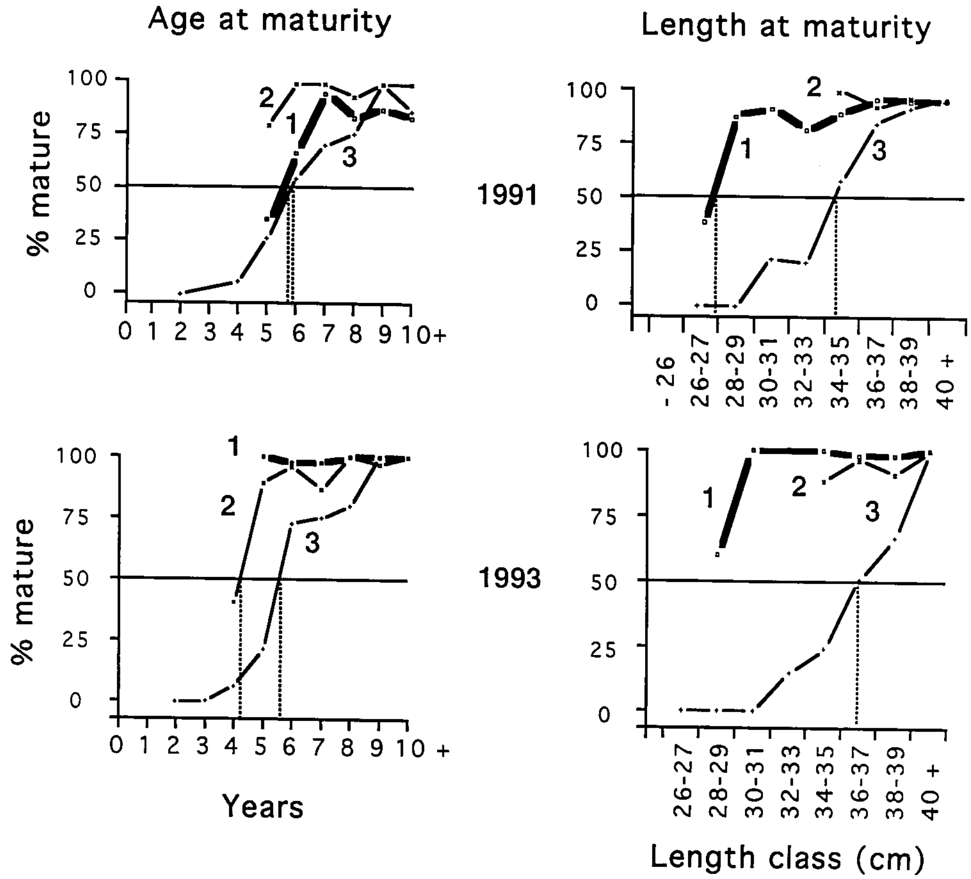
downstream stations of the Gatineau River had bigger gonads and higher fecundity relative to females of a similar carcass weight from the upstream station. This was consistent with a larger investment of energy in egg production because of greater nutrient availability at downstream stations. The fact that female white sucker from the downstream stations of the St. Maurice River did not develop bigger gonads and higher fecundity despite their larger size supports previous conclusions of negative impacts of BKME exposure on female gonad development (Munkittrick et al. 1991; Gagnon et al. 1994, 1995*a*). Only male fish from the St. Maurice River exhibited a bigger gonad weight relative to carcass weight at the BKME-exposed downstream station 2.

While age at first maturity exhibited great variability, fish from the BKME-exposed stations exhibited the same (1991) or delayed (1993) age at maturity relative to the reference upstream station of the St. Maurice River. In comparison, fish from the downstream stations of the Gatineau River reached maturity precociously relative to fish from the upstream station.

In the St. Maurice River, BKME may have also contributed to faster growth either directly or indirectly. Even the very low nitrogen and phosphorus levels of secondary-treated kraft effluent can be sufficient to alter the river's trophic status and cause algal blooms in receiving waters (Bothwell 1992). Rainbow trout (*Oncorhynchus mykiss*) exposed to secondary-treated effluents in experimental streams demonstrated increased growth relative to control rainbow trout, which is believed to result from a stimulation of benthic invertebrate biomass in effluent-exposed habitats (Haley et al. 1995). Similarly, recent experiments concluded that mayflies (*Eatis tricaudatus* Dodds) exposed to pulp mill effluent had 20–50% greater body weights than control benthic invertebrates (Lowell et al. 1995). The presence of juvabione-type compounds (juvenile hormone) in woody plants such as pine, fir, and spruce trees used by the pulp and paper industry could be responsible for stimulating the growth of benthic invertebrates. The juvenile hormone inhibits morphogenesis and differentiation of reproductive organs, allowing continued somatic growth of the insects (Lowell et al. 1995), resulting in an increased food biomass available to fish. The potential effects of juvabione-like compounds on fish growth are presently unknown, but may contribute to the increased growth of BKME-exposed fish.

Nevertheless, increased growth at downstream stations relative to the upstream station observed in both contaminated and reference rivers indicates gradients of productivity, and hence food availability, independent of BKME. Nitrogen and phosphorus contents of municipal effluents located along the rivers are expected to be higher than those associated with BKME and are the most likely cause of greater fish growth at downstream stations. In both rivers, growth of fish was better at downstream stations, indicating gradients of productivity independent of BKME contamination.

Fig. 6. Age and length at first maturity for male white sucker from the St. Maurice River. The numbers represents the station, and the thick line represents the upstream station 1. The vertical dotted lines indicate age and size at maturity. Samples sizes for each point ranged from 5 to 66 fish.



Annual variability within stations

The similarity in trends within and between rivers observed in the present and former studies was evident despite significant annual variability in demographic variables within stations. In the St. Maurice River, there was a significant enhancement in growth rates and reproductive effort in 1993 compared with 1991 at the upstream reference station. Female and male white sucker at station 1 (*i*) grew faster in 1993 as shown by direct observation of size at age, (*ii*) exhibited greater reproductive effort in 1993 as shown by greater gonad size and fecundity relative to body size, and (*iii*) were younger at first maturity. At stations 2 and 3 located downstream of the mill, females and males (*i*) did not grow faster in 1993 as shown by direct observation of size at age (except station 2, females), (*ii*) exhibited better reproductive effort in 1993 than in 1991 as shown by greater gonad size and fecundity relative to body size, and (*iii*) exhibited the same age at first maturity. Therefore, groups of white sucker sampled in the St. Maurice River exhibited significantly different within-station variability in growth and gonad investment in 1993 relative to 1991.

The enhanced gonad size and fecundity observed in 1993, associated with enhanced growth rates, resulted in a reduced age at maturity at the upstream station 1 of the St. Maurice River. Improved growth conditions may have led to greater energy allocation to reproduction and maturation at a younger age, in concordance with the findings of Trippel and Harvey (1989), Chen and Harvey (1994), and Gagnon et al. (1995*a*). But this was not the case at the downstream stations 2 (except females) and 3. Despite overall enhanced gonad size and fecundity, the growth and age at first maturity of the exposed fish did not change.

In comparison, growth rates and reproductive effort of white sucker from the reference Gatineau River demonstrated a different pattern of variation between years. Female and male white sucker located at the upstream station in 1993 (*i*) grew at the same rate as in 1992 as shown by no interannual difference in size at age, (*ii*) exhibited reduced reproductive effort as shown by reduced gonad size relative to body size, and no variation in fecundity, and (*iii*) matured at the same age and size. At the stations located downstream (Fig. 1), females and males (*i*) grew at the same rate as in 1992 as shown by no difference in growth at age, (*ii*) exhibited reduced reproductive effort as shown by reduced gonad size relative to body size (station 3), and no variation in fecundity (station 3), and (*iii*) were mature at a younger (station 3) or older (station 2, females only) age and at a larger size (station 3, males).

Thus, in the Gatineau and St. Maurice rivers, we observed annual differences within stations in growth rate, gonad investment, and age at first maturity. But these variations were not sufficient to alter our previous conclusions about the effects of BKME exposure. This demonstrates that the impact of BKME discharge on the reproductive investment of white sucker was evident despite the "noise" of natural annual

Fig. 7. Age and length at first maturity for female white sucker from the Gatineau River. The numbers represent the station, and the thick line represents the upstream station 1. The vertical dotted lines indicate age and size at maturity. Samples sizes for each point ranged from 5 to 84 fish.

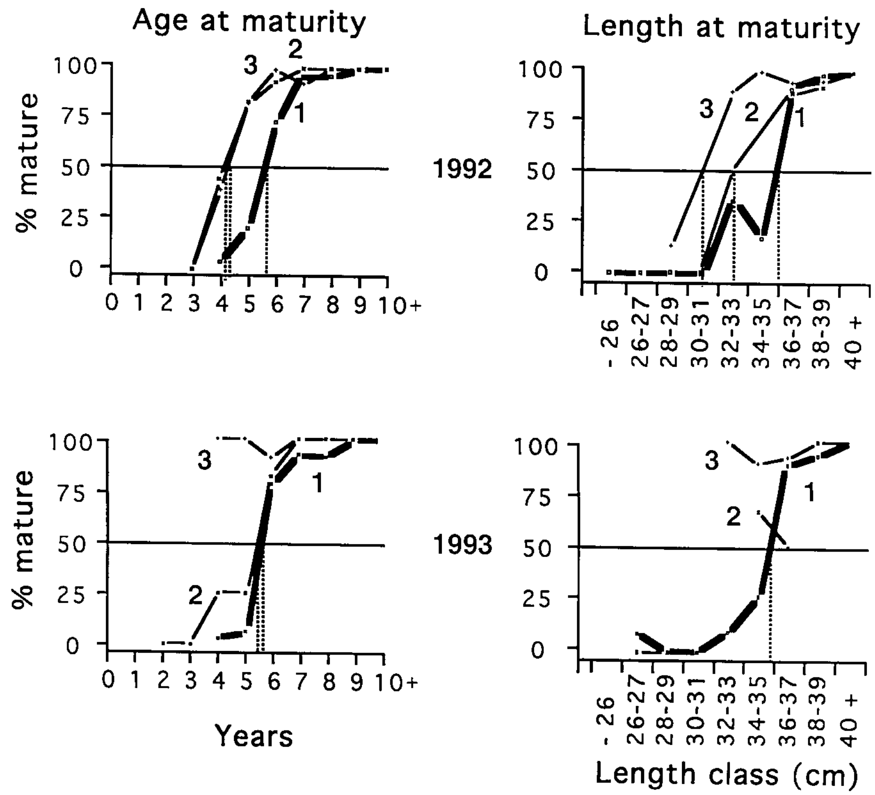
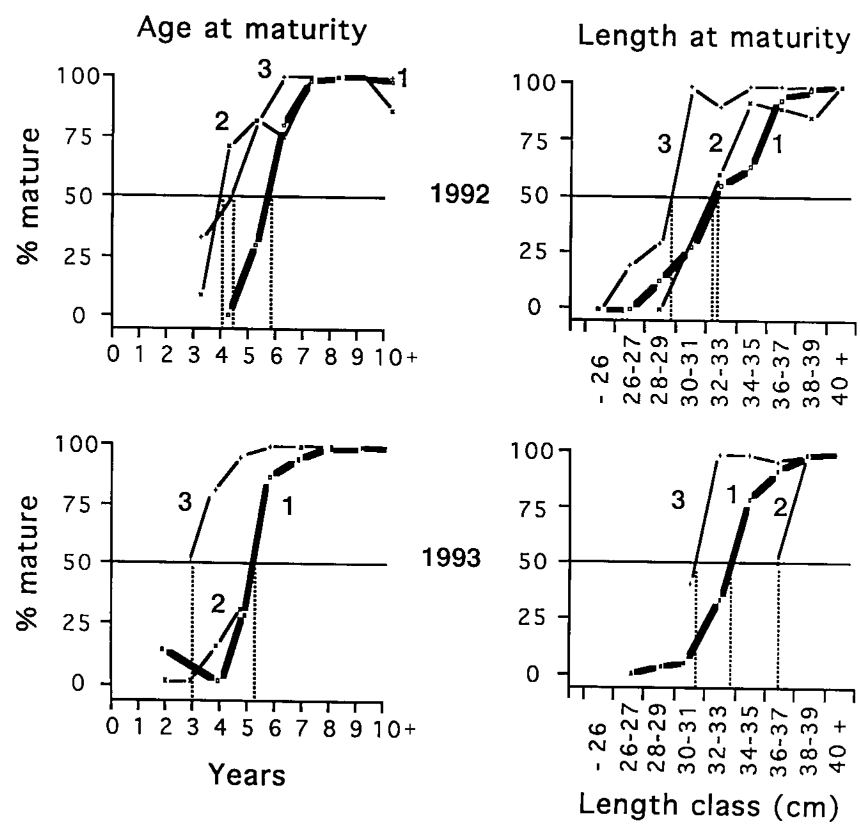


Fig. 8. Age and length at first maturity for male white sucker from the Gatineau River. The numbers represent the station, and the thick line represents the upstream station 1. The vertical dotted lines indicate age and size at maturity. Samples sizes for each point ranged from 5 to 60 fish.



variability. This study suggests that in cases where BKME has a significant impact on reproductive investment, the multiple sampling cycles of the EEM program should detect such an impact despite naturally occurring variability in growth and reproduction.

These results also illustrate a useful statistical tool for EEM programs. The ANCOVAs showing the distribution of relative variability among main factors demonstrate significant differences in responses attributable to years. However, the “year effect” was generally smaller than effects due to site and fish size. Most importantly, there were no significant site × year interactions in any factor except growth, indicating that the main effects of site had not changed between years. For monitoring, the interactive term provides a very useful way to identify significant temporal changes in the effects of pulp mill effluents on fish populations. In this particular case, the lack of year × site interactions indicates that chlorine dioxide substitution, implemented in 1992, had no effects on population demographics in 1993, as might be expected considering the relatively long life of white sucker.

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Appendix. ANCOVA tables

Table A1. ANCOVA for comparisons of white sucker length in the St. Maurice River.

Source of variance	df	Sum of squares	*F* ratio	*P*
Female				
Station	2	1096	69.9	0.0000
Year	1	231	29.6	0.0000
Age (covariable)	1	1048	133	0.0000
Station × year	2	89.1	5.69	0.0037
Males				
Station	2	849	68.5	0.0000
Year	1	96.9	15.63	0.0001
Age (covariable)	1	1502	242	0.0000
Station × year	2	52.3	4.217	0.0152

Table A2. ANCOVA for comparisons of white sucker length in the Gatineau River.

Source of variance	df	Sum of squares	*F* ratio	*P*
Female				
Station	2	199	13.56	0.0000
Year	1	4.824	0.6561	0.4183
Age (covariable)	1	1971	268	0.0000
Station × year	2	13.56	0.9221	0.3983
Males				
Station	2	70.1	6.353	0.0019
Year	1	2.241	0.4059	0.5243
Age (covariable)	1	758	137	0.0000
Station × year	2	2.522	0.2284	0.7959

Table A3. ANCOVA for comparisons of gonad weight of white sucker in the St. Maurice River (CW, carcass weight).

Source of variance	df	Sum of squares	*F* ratio	*P*
Female				
Station	2	0.1913	12.27	0.0000
Year	1	0.2029	26.02	0.0000
log CW (covariable)	1	9.364	1201	0.0000
Station × year	2	0.0054	0.3459	0.7077
Males				
Station	2	0.1895	5.822	0.0031
Year	1	0.2807	17.25	0.0000
log CW (covariable)	1	4.970	305	0.0000
Station × year	2	0.0442	1.358	0.2578

Table A4. ANCOVA for comparisons of gonad weight of white sucker in the Gatineau River (CW, carcass weight).

Source of variance	df	Sum of squares	*F* ratio	*P*
Female				
Station	1	0.010	164	0.0000
Year	1	0.1121	1823	0.0000
log CW (covariable)	1	5.065	823	0.0000
Station × year	1	0.0022	0.3645	0.5464
Males				
Station	1	0.0338	2.121	0.1463
Year	1	0.0688	4.319	0.0385
log CW (covariable)	1	5.273	330	0.0000
Station × year	1	0.0202	1.271	0.2605

Table A5. ANCOVA for comparisons of fecundity of female white sucker in the St. Maurice and Gatineau rivers (CW, carcass weight).

Source of variance	df	Sum of squares	*F* ratio	*P*
St. Maurice River				
Station	2	0.0663	5.187	0.0060
Year	1	0.0794	12.42	0.0005
log CW (covariable)	1	2.763	432	0.0000
Station × year	2	0.0153	1.196	0.3035
Gatineau River				
Station	1	0.6926	105	0.0000
Year	1	0.0189	2.882	0.0910
log CW (covariable)	1	2.487	378	0.0000
Station × year	1	0.0001	0.0116	0.9143