## Juvenile Salmon Survival in the Saint John River System

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May, 1980

## Canadian Technical Report of Fisheries and AquaticSciences No. 939

## Canadian Technical Report of

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# $C A 8040349$ 

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B3J 257
(C) Minister of Supply and Services Canada 1980 Cat. No. Fs 97-6/1980-0939 ISSN 0706-6457

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For the Saint John River system above Mactaquac Dam the number of actual virgin returns per female salmon spawner rose from 10 (per 8,000 eggs) for spawning year 1967 to a peak of 16 for 1969 and then declined to 3 for 1972. Most returns were in the fourth, fifth and sixth years after spawning. This rise and decline is attributed to a combination of poor juvenile survival. (Gue to pollution) in the main stem of the Saint John River and to changes in the relative proportions of spawning adults released into the main stem and into the Tobique River (a tributary). The adult return average for salmon spawners in Tobique River was high ( 16.8 per 8,000 eggs), while for fish released into the main stem (Woodstock) and not migrating to the Tobique, the return rate was not significantly greater than zero (2.8 per 8,000 eggs). To maximize the number of wild salmon returns, it is recommended that the first priority should be to ensure an adequate egg-deposition density in Tobique River.

Key words: Atlantic salmon, Saint John River system, Mactaquac Dam, Tobique River, juvenile salmon survival, rearing habitat, egg-deposition density, water quality.

## RÉSUME

Watt, W.D. and G.H. Penney. 1980. Juvenile salmon survival in the Saint John River system. Can. Tech. Rep. Fish. Aquat. Sci. No. 939. viit 13 p.

Pour le system fluviale de la rivière Saint-Jean en amont du barrage de Mactaquac le nombre de saumon reproducteurs vierges, issue de chaque femelle en fraye, s'est accru a partir de 10 (pour 8,000 oeufs) en 1967 jusqu'à atteindre un sommet de 16 en 1969 et décliner jusqu'à 3 en 1972. La pluspart des saumons reproducteurs qui retournerent a leur frayere d'origine au cours de ces années de reproduction étaient agés de quatre, cing ou six ans. Cet accroissement et le deciin qui suivit sont attribuable à l'effet combiné d'une mauvaise survie (a cause de la pollution) des saumoneaux dans le tronc principale de la riviere Saint-Jean et aux changements dans les proportions relatives des saumons reproducteurs libérés dans le tronc principale de la rivière Saint-Jean et dans la riviere Tobique (tributaire de la Saint-Jean). La moyenne des samons reproducteur vierges issue des saumon reproducteurs de la riviêre Tobique fut élevée (16.8 pour 8,000 oeufs), tandis que poux les saumons reproducteurs relaches dans le tronc principale (woodstock) et qui n'émigrèrent pas dans la riviere Tobique, le taux de retour ne fut pas significativement plus grand que zero (2.8 pour 8,000 oeufs). La "maximisation" du nombre de saumon reproducteurs natifs préconise que l'on donne priorícé à la déposition d'oeuf en densite suffisante dans la rivière Tobique.


FIG. I. Saint John River system map, indicating positions of dams and some major tributaries.

Since 1967, with the building of the Mactaquac Dam and hydroelectric station ${ }^{1}$, all anadromous fish moving up the saint John River (past Mactaquac) have been counted and sorted at the Mactaquac fishhandilng facility, and from here they have been carried in tank trucks to various uprivex release points. Atlantic salmon were, for the most part, trucked either to the main river at woodstock or to the Tobique River, a tributary (Fig. 1).

Salmon released at Woodstock have a choice of spawning sites; they may remain in the main stem, enter the Becaguimed River or some other small tributary, or pass over the fish lift at Beechwood Dam. Above Beechwood they may remain in the main sten between Beechwood and Grand Falls. pass into Salmon River or some other small tributary, or pass up through the fish Ladder at Tobique Narrows Dam on the Tobique River.

The areas of accessible juvenile salmon rearing habitat available above Mactaguac Dam are distributed as follows:

Estimated rearing
habitat
River section (units of $100 \mathrm{~m}^{2}$ ) Percent

| Saint John main stem <br> Mactaquac Dam to <br> Beechwood Dam <br> Beechwood Dam to <br> Grana Falls <br> Tobigue River | 25,810 | 24.1 |
| :--- | :--- | :--- |
| Other accessible <br> tributaries | 94,440 | 14.5 |
| Total | 11,950 | 54.5 |

Of the accessible (from Woodstock) tributaries other than the Tobique, the best for salmon production are the salmon and Becaguimec rivers, which are estimated to contain respectively 5,100 and 4,200 units (of $100 \mathrm{~m}^{2}$ ) of juvenile Atlantic salmon rearing habitat. A number of other small tributaries contain minor quantities of rearing habitat (approximately 2,650 units in all).

Atlantic salmon management policy on the Saint John River has attempted to maximize salmon production by aiming for a potential egg deposition in all accessible habitat of 240 eggs $/ 100 \mathrm{~m}^{2}$ as recommended by Elson (1957).

[^0]Upstream migrating anadromous fish are partially sorted (species) in the fishcollecting facility at Mactaquac Dam, and then all Atlantic salmon are carried by tank truck to the salmon-sorting facility at Mactaquac Hatchery.

Beginning in 1972 and continuing to the present, the age and life history of wild salmon and grilse returning to Mactaquac have been determined from readings of scale samples (Table l). Data from returns of hatchery releases were not used in this analysis. The wild-fish data indicate that juvenile salmon in the saint John River system smoltified after 2 (49.1复), 3 (49.30) or 4 (1.65) years in fresh water. The adults returned after one year at sea as grilse ( $39.2 \%$ ) or after two sea-years (51.4\%) or three sea-years (0.2\%) as virgin salmon. Also, on average, about 9.28 of the total were repeat spawnexs (non-virgin salmon).

Most virgin returns (98.2名) were in the life-history categories $2: 1$ (i.e., 2-year-old smolt and one year at sea, 18.98), $3: 1(23.6 \%), 2: 2(30.18)$ and $3: 2$ (25.6\%). Thus, most returns come in the fourth. fifth and sixth years aftex spawning, with the largest percent return (53.78) occuxring in the fifth year when $3: 1$ grilse and $2: 2$ salmon return together.

Egg depositions in the Saint Jonn River above Mactaquac Dam for the years 1967-77 have been estimated (Table 2). Sex ratios for estimation of potential egg deposition were taken as the overall means from a data series (1967-77) of visual sexing of the Mactaquac returns. These data vary considexably in accuracy from year to year, reflecting personnel changes and leaxning by experience. Hence, over-all mean values were considered preferable to the annual values. The female means axe $82.9 \%$ for salmon and 7.48 for the grilse. For egg-deposition estimation, it was assumed that female salmon produce 8,000 eggs $/$ Eish $(1,800 / \mathrm{kg})$ and that female grilse produce 3,200 eggs/fish. It is apparent (Table 2) that the grilse component, because of the small fish size and low proportion of Eemales, contributes relatively insignificant quantities of eggs to the total deposition in any given spawning.

The fish-return data (Table 1) can be used to assign the vaxious life-history classes to their spawning year. This arrangement (Table 3) allows comparison of the total annual returns to Mactaquac of progeny from spawning years 1967-72, with the corresponding estimates of egg-deposition densities for the river system above Mactaquac (Fig. 2). The general shape of the plot suggests a curved line, which could be interpreted as implying a lower survival at the high egg-deposition density of 1972. However, the 1972 stocking density is considerably below Elson's (1957) recommended optimum of 240 eggs/ $100 \mathrm{~m}^{2}$. When a least squares straight

TABLE 1. Numbers of wild grilse and salmon counted at the Mactaquac fish-passage facilities duxing the years $1972-78$ and estimated (from scale readings) composition of the various age groups.

| Age-class composition | Numbers of fish |  |  |  |  |  |  | Life cycle (years) |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 | 1978 |  |
| 2:1 | 110 | 1,413 | 1. 593 | 1,941 | 3,962 | 922 | 391 | 4 |
| 3:1 | 596 | 404 | 1,762 | 3,727 | 2,658 | 2,545 | 1,160 | 5 |
| 4:1 | 78 | 37 | 34 | 57 | 177 | 39 | 33 | 6 |
| Total grilse | 784 | 1,854 | 3,389 | 5,725 | 6.797 | 3,506 | 1.584 |  |
| $2: 2$ | 1,260 | $\begin{array}{r}549 \\ \hline \quad 551\end{array}$ | 3.806 377 | 3,566 | 2,110 | 4.236 1,858 | $\begin{array}{r}916 \\ \hline .817\end{array}$ | 5 |
| 3:2 | 3,144 | 1,551 | 377 | 2,208 | 2,999 | 1. 858 | 1.817 | 6 |
| 3:3 | 27 | 11 | 0 | 35 | 31 | 0 | 0 | 7 |
| 4:2 | 100 | 109 | 0 | 0 | 84 | 37 | 67 | 7 |
| Total virgin salmon | 4,531 | 2,220 | 4,183 | 5,809 | 5,224 | 6,131 | 2,800 |  |
| Repeat spawners | 300 | 147 | 592 | 391 | 287 | 1,116 | 234 |  |
| Total salmon | 4,831 | 2.367 | 4.775 | 6,200 | 5,511 | 7,247 | 3,034 |  |
| Total returns | 5,615 | 4,221 | 8,164 | 11,925 | 12,308 | 10,753 | 4.618 |  |

TABLE 2. Numbers of salmon and grilse in spawning escapements above Mactaquac Dam during 1967-77 and estimated egg depositions (per $100 \mathrm{~m}^{2}$ ). (The numbers have been corrected for the reported angling catch. The juvenile habitat accessible above Mactaquac is taken as $17,328,000 \mathrm{~m}^{2}$.)

| Year | Salmon (82.9\% female) | $\frac{\text { female) }}{\text { Eggs/l00 } \mathrm{m}^{2}}$ | Grilse (7.48 female) |  | $\begin{gathered} \operatorname{Total} \\ \operatorname{eggs} / 100 \mathrm{~m}^{2} \end{gathered}$ |
| :---: | :---: | :---: | :---: | :---: | :---: |
| 1967 | 487 | 18.6 | 682 | 0.9 | 19.5 |
| 1968 | 123 | 4.7 | 954 | 1.3 | 6.0 |
| 1969 | 640 | 24.5 | 1.885 | 2.6 | 27.1 |
| 1970 | 1,219 | 46.7 | 2.445 | 3.3 | 50.0 |
| 1971 | 1,383 | 52.9 | 1,425 | 1. 9 | 54.8 |
| 1972 | 4,631 | 177.2 | 729 | 1.0 | 178.2 |
| 1973 | 2,305 | 88.2 | 2.978 | 4.1 | 92.3 |
| 1974 | 5,043 | 193.0 | 6,142 | 8.4 | 201.4 |
| 1975 | 7,271 | 278.3 | 9,629 | 13.2 | 291.5 |
| 1976 | 6,003 | 229.8 | 12,578 | 17.2 | 247.0 |
| 1977 | 7,562 | 289.4 | 7,339 | 10.0 | 299. 4 |

TABLE 3. Actual returns to Mactaquac of wild virgin salmon progeny from spawing years 1967-72.

| Spawning year | Actual returns |  |  |  |  |  |  | Total |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Grilse |  |  | Salmon |  |  |  |  |
|  | $2: 1$ | 3:1 | $4: 1$ | 2:2 | 3:2 | $3: 3$ | $4: 2$ | actual return |
| 1967 | 6881 | 596 | 37 | 1,260 | 1.551 | 0 | 0 | 4,132 |
| 1968 | 110 | 404 | 34 | 549 | 377 | 35 | 0 | 1,509 |
| 1969 | 1,413 | 1,762 | 57 | 3,806 | 2,208 | 31 | 84 | 9,361 |
| 1970 | 1,593 | 3,727 | 177 | 3,566 | 2,999 | 0 | 37 | 1,209 |
| 1971 | 1.941 | 2,658 | 39 | 2,110 | 1,858 | 0 | 67 | 8,673 |
| 1972 | 3,962 | 2,545 | 33 | 4,236 | 1,817 | $15^{1}$ | $57^{1}$ | 12.665 |

[^1]Line is fitted to these data ( $y=5,340+$ 49. 45 x$)$, the Y - intercept is not significantly ( $p>0.05$ ) greater than 0 , as it should be if the relationship were significantly curved. Also, when fitted with a second-order polynomial, the curved line is not a significantly better fit than the straight line; hence it must be concluded that the apparent reduction in survival of the 1972 eggs is not significant.

The returns presented (Tables 1 and 3 are of fish that have escaped capture by commercial fishemen (i.e., incidental catches, since the comercial salmon fishery has been closed since 1972), poachers, the Indian food fishery at Kingsclear and anglers. Estimates of the relative (percent) impact on wild salmon and grilse returns by the various groups involved in the harvesting are depicted (Fig. 3). The values for angling catches have been derived from reported catches (New Brunswick Fish and Wildife Branch) ; catches in the Indian food fishery have been estimated from observations; and the combined levels of poaching and incidental catches in commercial gear set for other species have been roughly estimated at about $10 \%$ for the years 1972-75 and 208 for the years 1976-78.
since the closure of the commercial salmon fishery in 1972, the proportion of the salmon run reaching the Mactaquac fishhandling facilities has steadily declined as a result of increased harvesting by the Indian food fishery, and incidental commercial catches and poaching. The proportion of the salmon run taken by anglers has remained fairly constant. The grilse returns show a similar exploitation trend, with the exception that the proportion taken by the Indian food fishery is lower than for salmon.

Total potential returns (Table 4) were computed by applying the approximate cor-
rection values (above) for each return year to the actual return data (Table 3). A plot of these total potential returns for each spawning year versus the estimated egg-deposition density yields a curve (Fig. 4) which is similar in its appearance to the corresponding plot for actual returns (fig. 2). Superficially, a diminished rate of survival for potential returns in the year 1972 is suggested (Fig. 4). However, as was shown with the curve for actual returns (Eig. 2), the apparent reduction in survival is not statistically significant.

It is common to consider changes in survival rates in terms of returns per spawning female. A female salmon lays approximately 8,000 eggs (3,200 for a female grilse). Accordingly, the return rates (actual and potential) per 8,000 eggs deposited above Mactaquac Dam are depicted (Fig. 5). This histogram indicates that survival improved between 1967 and 1969 and then declined during 1970-72.

It was initially considered that this trend probably represented a mortality problem in downstream fish passage due to changes in curbine operation schedules. However, an examination of the history of hydropower generation and development yields nothing that could account for the trend. Possible changes in smolt predation rates (eg., by chain pickexel) have also been considered and discounted. The only known factor that appears to parallel the survival-rate trend is the proportion of the egg deposition in the fobique River (dashed line in Fig. 5). The variation in returns per 8,000 eggs would be largely accounted for if the juvenile salmon survival (egg-to-smolt) were substantially better for fish spawned in Tobique River than for fish spawned elsewhere in the Saint John Rivex system.

To test this hypothesis further,

TABLE 4. Total potential returns to Mactaquac for spawning years 1967-72. (Inclucies actual returns plus estimates of the numbers of fish taken by commercial fishermen, poachers, the Indian food fishery and anglers).

| Spawning year | Potential returns |  |  |  |  |  |  | Total |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Grilse |  |  | Salmon |  |  |  |  |
|  | $2: 1$ | 3:1 | 4:1 | $2: 2$ | 3:2 | 3:3 | $4: 2$ | potential return |
| 1967 | $800^{1}$ | 689 | 43 | 1,436 | 1,843 | 0 | 0 | 4,811 |
| 1968 | 128 | 469 | 41 | 652 | 482 | 44 | 0 | 1,816 |
| 1969 | 1.637 | 2,141 | 67 | 4,871 | 2,794 | 65 | 174 | 11,749 |
| 1970 | 1,935 | 4,383 | 245 | 4,515 | 6,231 | 0 | 74 | 17,383 |
| 1971 | 2,275 | 3,680 | 58 | 4,375 | 3,737 | 0 | 190 | 14,315 |
| 1972 | 5,487 | 3,857 | 57 | 8,521 | 5,143 | $42^{ \pm}$ | 1.581 | 23,265 |

${ }^{1}$ Number estimated from average proportion.
estimates were calculated (Table 5) of egg-deposition densities in the Tobique River. The relationship between total potential returns to Mactaquac and the estimated egg deposition in Tobique River is examined (Fig. 6). A least squares straight line regression of returns on deposition is significant to the $p<0.005$ level and accounts for $90.78\left(x^{2}\right)$ of the variation. The equation is $y=3.43+$ 0.182 x . The intercept is not significantly greater than 0 , and a second-ordex polynomial does not give a significantly better fit, thus indicating that the relationship is not significantly cuxved. This apparent direct relationship between the number of eggs stocked in Tobique River and returns to Mactaquac implies that the eggs produced by fish released on the main stem of the Saint John River at woodstock (excepting the few [118] that migrate into Tobique via the fishways) have a very low rate of survival.

TABLE 5. Tobique River salmon spawning escapement and estimated egg deposition. (The data have been corrected for fish entering the rivex via the Tobique Narxows Fishway and for the reported angling catch, but no reduction has been made for poaching. The available juvenile habitat is taken as 9,444,000 $\mathrm{m}^{2}$.)

| Year | Spaming escapement |  |  |
| :--- | :---: | :---: | :---: |
| No. of salmon | No. of grilse | Deposition <br> of eggeloom² |  |
| 1967 | 178 | 379 | 13.5 |
| 1968 | 78 | 352 | 6.4 |
| 1969 | 593 | 1,572 | 45.6 |
| 1970 | 932 | 1,850 | 70.1 |
| 1971 | 1,166 | 738 | 83.7 |
| 1972 | 2,140 | 249 | 150.9 |
| 1973 | 1,209 | 1,547 | 88.8 |
| 1974 | 3,538 | 3,728 | 257.8 |
| 1975 | 5,020 | 6,722 | 369.4 |
| 1976 | 4,055 | 7,919 | 304.6 |
| 1977 | 4,480 | 4,305 | 325.4 |

The corresponding regression of total potential returns to Mactaquac vs. egg deposition per $100 \mathrm{~m}^{2}$ for the entire Saint John Rivex system above Mactaquac (Fig. 4) accounts for $71.9 \%$ of the variam tion and is significant to the $p<0.05$ level. A regression of total potential retume to Mactaquac vs. estimated egg deposition in the Saint John River system exclusive of Tobique River is not statistically significant. Similar regressions on egg deposition in the main rivex sections from Woodstock to Beechwood and from Beechwood to Grand Falls are also not significant.

To estimate separate survival rates from spawners in Tobique River and those in the Saint John main stem and other tributaries (above Mactaquac) a series of simultaneous equations was set up in the form:

$$
\begin{aligned}
& R=S_{t} t_{t}+S_{j}{ }_{j} \\
& \text { where } R=\text { potential returns to } \\
& \text { Mactaquac. }
\end{aligned}
$$

R, Et and $E j$ have been estimated for spawning years $1967-72$, thus permitting six equations with two unknowns. Assuming St and $s j$ are reasonably constant from year to year, then from this set of oquations there are 15 possible combinations of 2; thus yielding 15 separate (though not independent) estimates of $S_{t}$ and $S_{j}$. The mean (and standard exror) potential adult return to Mactaquac per 1,000 eggs stocked in Tobique River (st) is 2.10 t 0.13 (16.8 returns per 8,000 eggs). For the fish in the Saint John main stem feleased at Woodstock) the mean rate of returns per 1,000 eggs ( $S_{j}$ ) is $0.35 \pm 0.23$ (2.8 per 8,000 eggs), which is not significantly greater than 0 .

## DISCUSSION

The analysis indicates very low survival rates for the progeny of fish released in the main stem of the saint John River at woodstock, and high wates of return ( 16.8 per female salmon) Erom Tobique River spawners.

The main stem of the Saint John River contains about 6,689,000 $\mathrm{m}^{2}$ of habitet that are physically suited to juvenile salmon rearing. however, an extensive water-quality survey reported by Environment Canada (1973) and ecological and chemical reports by Watt et al. (1973), Keachie and cote (1973), Watt (1973), MacDonald et al. (1970), Saunders (1969) and Sprague (1964) indicate that a severe pollution problem existed on the main stem of the Saint John River. It seems probable that poor watex quality would cause very low survival rates for salmon eggs deposited in the main stem. In fact, for spawning years 1967-72, the runs of wild salmon reaching Mactaquac may have been recruited almost exclusively from fish spawned in the Tobique River. This is not to imply that juvenile salmon survival is impossible elsewhere on the Saint John River system, but cather that fish released at Woodstock (excepting the 11.8 that migrate to Tobique) appear to have had negligible spawning success, which probably indicates that most of these fish attempted to spawn in the main stem of the Saint

Jonn River, where water quality was suitable for spawning activities in octoberNovember but unsuitable for juvenilesalmon survival during the mid-summer 10w-flow periods (Environment Canada 1973). Moreover, water toxicity problems have been reported by MacDonald et al. (1970) and Dominy (1973) in main stem Saint John River water at the Mactaguac salmon hatchery (usually during high spring flows).

Fish spawning in the smallex tributaries (Salmon, Becaguimec, etc.) would encounter suitable water quality, and these tributaries should be capable of providing at least a small proportion of the wildsalmon run. Unfortunately, it is impossible at Mactaquac to sort the adult fish according to their tributary of origin. Tnevitably, Eish from other tributaries were released in Tobique River and most of the fish released at Woodstock were Tobique River fish, and thus less inclined to spawn in any of the other tributaries.

Even so, some spawning must have taken place at least in the Becaguimec River, whose confluence is near the Woodstock release site. Electrofishing results (available since 1972) do indicate reasonably high juvenile populations in this tributary (Francis 1980). However, the entire juvenile-salmon rearing area available in the Becaguimec River is equivalent to only about $4 \%$ of the rearing area in the Tobique River. Hence even if this triblitary was producing to capacity, its contribution could not significantly alter the trends (Figs. 5 and 6).

The smolts from the Tobique River tributary have to pass through three headponds (possible predation) and over three power dams (possible spillway and turbine mortality) in their seaward migration. The possibility of increased downstream fish-passage mortality was initially advanced to explain the fall off in return rates to Mactaquac (Fig. 5). However, the high average return rate for fish spawned in the Tobique River virtually rules out any unusually high rates of downstream mortality.

In spawning years 1971 and 1972 , small numbers of hatchery-reared returns were included among the potential spawners released at Woodstock and Tobique. There is evidence (unpublished) that the migratory behaviour of these hatchery fish is rather different from that of wild fish, and thus there is some question as to their comparability in terms of potential egg deposition. The numbers involved were $2 \%$ of salmon in 1971 and 11\% in 1972, and the inclusions might have caused slightly reduced survivals in these years. The effect, if present, does not appear to be statistically significant.

The data points in Fig. 6 suggest that the relationship between egg deposition in the Tobique River and adult returns to Mactaquac may actually be curved, but the bend is not significant (p>0.05). However, at higher egg-deposi-
tion densities, the slope will inevitably flatten out. Elson (1957) suggested 240 eggs/ $100 \mathrm{~m}^{2}$ as near optimal for Maritimes salmon rivers. Elson (1975) has revised the figure downward to about $170 / 100 \mathrm{~m}^{2}$. Symons (1979) considers that the relation ship between smolt production and eggdeposition density should vary with the age at smoltitication. Thus a river producing mainly $2-y e a r-o l d$ smolts would require a lower egg density for maximum smolt production than would one producing 3-year-old or a-yearmold smolts. On this basis, a river such as the Saint John (Tobique) which produces roughly half and half $2-$ and 3 -year-old smolts can be expected to approach maximum smolt production at a spawning density of $150-200$ eggs/100 $\mathrm{m}^{2}$. Thus the Tobique River may already have reached its maximum production in 1972 at an egg density of $150.9 /$ $100 \mathrm{~m}^{2}$ 。

In any case, egg densities considerably in excess of this theoretical optimum (Table 5) occurred in Tobigue River in 1975-77. Returns from these spawning years (expected in 1981-83) should provide a fitted curve which calibxates the Tobique River for optimum smolt production.

## CONCLUSIONS

1. The adult-return potential of fish released in or successfully migrating into the Tobique River is high (averaging $16.8 \pm 1.0$ returns per female salmon).
2. The adult-return potential for fish released at woodstock and not migrating into the Tobique Rivex is low $(2.8 \pm 1.8$ returns per female).
3. To maximize the number of wild salmon returns to Mactaquac, the first priority should be to provide an adequate egg-deposition density in Tobique Rivex (currently estimated as $20 \times 10^{5}$ eggs or about 2,500 female salmon spawners).
4. The rise and decline in salmon return rates to Mactaquac for spawning years 1967-72 is attributed to a combination of poor juvenile survival (due to pollution) in the main stem of the Saint John River and changes in the relative proportions of returning adults released into the main stem and into Tobique River.
5. The evidence suggests that in the Saint John River system smolt mortality during the downstream migration is not unusually high.


FIG. 2. Total actual returns to Mactaquac of wild virgin salmon and grilse from spawning years 1967-72 vs. egg-deposition density above Mactaquac.


FIG. 3. Estimated relative distribution (\%) of wild salmon and grilse returns among the various harvesters, and actual returns counted at Mactaquac.


FIG. 4. Total potential returns to Mactaquac of wild virgin salmon and grilse from spawning years 1967-72 vs. egg-deposition density above Mactaquac.

$\square$Correction for angling, Indian fishery, poaching and incidental catches

## $\square$ Actual return rate

๑--® Percent ofeggs deposited in Tobique River


FIG. 5. Actual and potential returns to Mactaquac per 8,000 eggs (one female salmon) of wild virgin salmon and grilse progeny from spawning years 1967-72.


FIG. 6. Total potential returns to Mactaquac of wild virgin salmon and grilse from spawning years 1967-72 vs. estimated egg-deposition density in the Tobique River.

## REFERENCES

Dominy, C.L. 1973. Recent changes in Atiantic salmon (salmo salar) runs in the light of environmental changes in the Saint John River, New Brunswick, Canada. Biol. Conserv. 5:105-113.

Elson, P.F. 1957. Number of salmon needed to maintain stocks. Can. Fish. Cult. 21:7-17.

Elson, P.F. 1975. Atlantic salmon rivers, smolt production and optimal spawning: an overview of natural production. Int. Ati. Salmon Found. Spec. Publ. Ser. 6:96-119.

Environment Canada. 1973. Water quality data report submitted to the Saint John River Basin Board. Prepared by the Water Quality Division, Inland Waters Branch, Ottawa. 473 p .

Francis, A.A. 1980. Densities of juvenile Atlantic salmon and other species, and related data from electroseining studies in the Saint John River system, 1968-78. Freshwater and Anadromous Division, Dept. of Fisheries and Oceans, Halifax, Nova Scotia. Can. Data. Rep. Fish. Aquat. Sci. No. 178. 102 p.

Keachie, P.M. and R.P. Coté. 1973. Toxic pollutants in the Saint John River Basin. Report $\# 16$ from the Saint John River Basin Board, Fredericton, N.B. 179 p.

MacDonald, J.R., R.A. Row and J.R. Machell. 1970. Pollution survey Saint John River system, 1969. Unpublished report from the Resource Development Branch, Department of Fishexies and Forestry, Halifax, N.S. 103 P.

Ruggles, C.P. and w.D. Watt. 1975. Ecological changes due to hydroelectric development on the Saint John River. J. Fish. Res. Bd. Canada 32:161-170.

Saunders, D.E. 1969. Watex quality studies in the Mactaquac impoundment. UnpubIished thesis, Department of Civil Engineering, University of New Brunswick, Fredericton, N.B. 69 p.

Sprague, J.B. 1964. Chemical surveys of the Saint John River, tributaries, impoundments, and estuary in 1959 and 1960. Fisheries Research Board of Canada, Manuscript Report Series (O\&L) No. 181. 59 p .

Symons, P.E.K. 1979. Estimated escapement of Atlantic salmon (salmo salar) for maximum smolt production in rivers of different productivity. J. Fish. Res. Bd. Canada 36:132-140.

Watt, W.D., 1973. Aquatic ecology of the Saint John River - Volume 1. Report \#15f from the Saint John River Basin Board, Fredericton, N.B. 112 p.

Watt, W.D., G.H. Harding, J. Caldwell and A. McMinn. 1973. Sludgeworms (oligochaetes) as indicators of water poliution in the Saint John River. Report flyc from the Saint John River Basin Board, Fredericton, N.B. 31 p.


[^0]:    The history of hydroelectric developments on the saint John Rjver and the interactions of these developments with aquatic ecology and fisheries have been described by Ruggles and watt (1975).

[^1]:    ${ }^{1}$ Number estimated from average proportion.

