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A Review of the American Shad *(Alosa sapidissima)* Stocks of the Saint John River, New Brunswick, With Particular Reference to the Adverse Effects of Hydroelectric Developments

by
B. M. Jessop

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Resource Development Branch
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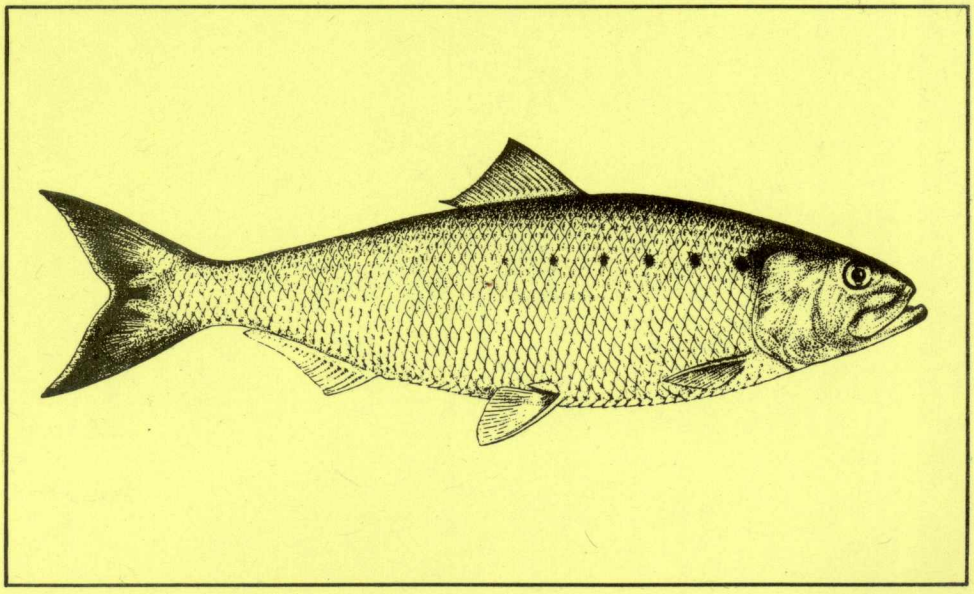

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A REVIEW OF THE AMERICAN SHAD *(ALOSA SAPIDISSIMA)* STOCKS OF THE SAINT JOHN RIVER, NEW BRUNSWICK, WITH PARTICULAR REFERENCE TO THE ADVERSE EFFECTS OF HYDROELECTRIC DEVELOPMENTS

B.M. JESSOP

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ABSTRACT

The commercial catch of American shad *(Alosa sapidissima)* in the Saint John River, New Brunswick, declined from approximately 1 million pounds to 56,000 pounds between 1953 and 1974. At Mactaquac Dam, the run of shad declined from 38,800 to 2,400 between 1968 and 1974. The relationship between the total shad population of the Saint John River and that portion which spawned above Mactaquac Dam is uncertain, and no satisfactory estimate can be made of the impact of the dam on the total shad population or commercial fishery. There is little doubt that Mactaquac Dam significantly affected the shad stock which formerly migrated beyond.

The major factors affecting shad returns to Beechwood and Mactaquac dams apparently are the biology of the population, difficulties in fish passage at the dams and the effect of adverse environmental conditions on reproductive success. Evidence is given for geographically distinct populations of shad differing in mean population fecundity, for substantial adult shad mortality during upstream passage at Mactaquac Dam, for poor attraction conditions at Beechwood Dam and for mortality during downstream migration at both dams.

Declining shad returns to Mactaquac Dam probably also reflect mortality of eggs, resulting from adverse water quality in the headponds and a reduction in suitable spawning area, as well as predation and mortality of juveniles at the dams during downstream passage.

Recommendations are made for the management and rehabilitation of the shad returning to Mactaquac Dam.

RÉSUMÉ

La prise commerciale de l'alose américaine *(Alosa sapidissima)* dans la rivière Saint-Jean, Nouveau Brunswick, est tombée de un million de livres en 1953, à 56,000 livres, en 1974. Le nombre d'aloses qui sont passées par le barrage de Mactaquac est tombé de 38,800, en 1968, à 2,400, en 1974. L'apparentement entre la population totale d'aloses de la rivière Saint-Jean et la colonie qui frayait en aval du barrage de Mactaquac est indéterminé, de ce fait, l'on ne peut arriver à une estimation satisfaisante de l'effet du barrage sur la population totale d'aloses ni sur la pêche commerciale. Il y a tout lieu de croire que le barrage de Mactaquac a profondément dérangé le stock d'aloses migratrices qui autrefois se déplacaient au-delà du barrage.

Les facteurs principaux qui influent sur les retours d'aloses aux barrages de Beechwood et de Mactaquac sont apparemment la biologie de la population, les difficultés pour le poisson de passer le barrage et l'effet des facteurs negatifs du milieu écologiques sur le succes de la reproduction. Des données de base sont fournies sur des populations d'aloses provenant de secteurs géographiques distincts sur la mortalité considérable de la population adulte d'aloses lors du passage en amont du barrage Mactaquac, sur les conditions peu attrayantes qui se trouvent au barrage Beechwood et sur la mortalité lors de la migration en aval aux deux barrages.

La diminution du nombre d'aloses au barrage de Mactaquac reflète probablement la mortalité des oeufs provoquée par la qualité nuisible des eaux des étangs d'amont et une réduction des secteurs propres au frai ainsi que la predation et la mortalité du poisson juvénile lors du passage en aval du barrage.

Nous recommandons que des dispositions soient prises en vue de la gestion et la réhabilitation de l'alose qui retourne au barrage Mactaquac.

INTRODUCTION

The annual commercial catch of American shad *(Alosa sapidissima)* in the Saint John River, New Brunswick, has declined irregularly from a peak of approximately one million pounds in 1953 to 56,000 pounds in 1974 (Table 5). The decline is attributed to several factors, such as existence of hydroelectric dams, water pollution and heavy fishing pressure.

This report reviews the available information on the shad population migrating to the Saint John River system and particularly to the Mactaquac Dam, assesses those factors possibly responsible for the declining abundance, and recommends measures which may increase the run.

HYDROELECTRIC DEVELOPMENT

Three hydroelectric dams have been constructed on the main stem of the Saint John River (Fig. 1). These plants are "run-of-the-river" types, with limited power-generation fluctuations in response to peak demand, but largely governed by the natural river flow (Ruggles and Watt 1975).

The uppermost dam, constructed in 1928 at Grand Falls, (349 km from the river mouth and approximately 212 km from the head of tide near Fredericton) is located at a natural waterfall, impassable to upstream migrating fish. No fish passage facilities are provided.

The Beechwood Dam, constructed in 1957, is located 59 km downstream from Grand Falls and 153 km above the head of tide. It is operated as a peak-load plant during low-flow periods (winter and late summer to early fall) and as a base-load plant during high flow periods (spring runoff and rainfall floods) (Ruggles and Watt 1975). A mechanical elevator passes fish upriver.

Mactaquac Dam was completed in 1967. It is located 18 km upstream of Fredericton and the powerhouse is operated in a manner similar to that at Beechwood Dam. Fish passage facilities include both a mechanical elevator and tank trucks, which in combination relay fish to release points above the dam.

In 1953, a hydroelectric dam was constructed near the mouth of the Tobique River, a tributary to the Saint John River midway between the Beechwood and Grand Falls dams. This structure was provided with a pool-and-weir fishway.

AMERICAN SHAD, LIFE HISTORY

American shad are anadromous and ascend their parent river to spawn in the spring, the precise time depending upon water temperature. In the Saint John River, the run generally begins in May, peaks in June and tapers off in July. Shad do not normally travel as far upstream as do alewife *(Alosa pseudoharengus)*, and

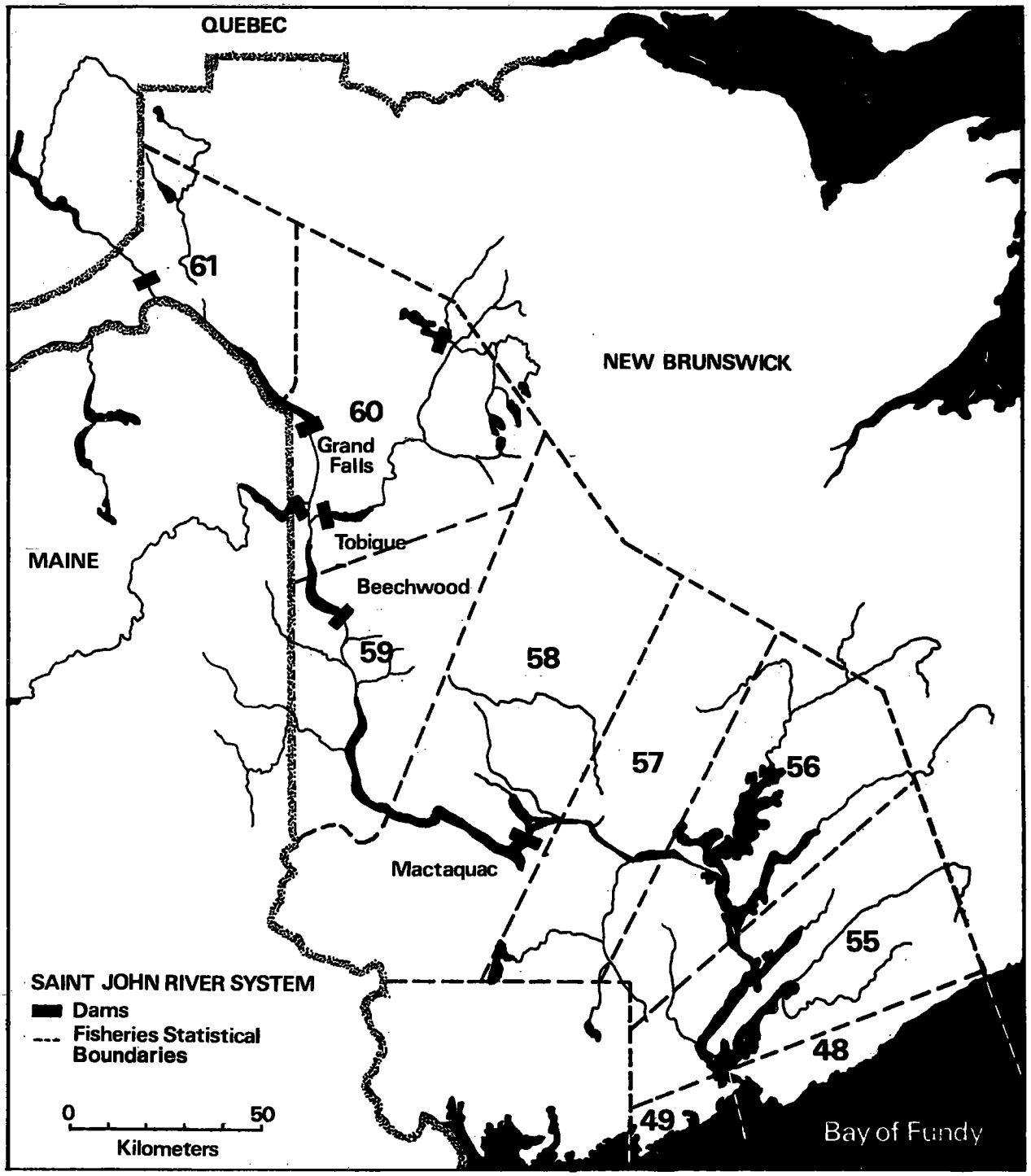

FIG. 1. Map of the Saint John River system, New Brunswick, showing Fisheries and Marine Service Statistical Districts and locations of hydroelectric developments.

Perley (1852) noted "...that the gaspereau and shad rarely ascend the Saint John higher than Fredericton, four miles above which the swift water and strong rapids commence." Later reports state that small numbers of shad have been observed below Grand Falls (Leim 1924) and that a small population existed in the Tobique River prior to dam construction. Shad have recently been counted at Beechwood and Mactaquac dams, being most numerous at Mactaquac Dam.

Spawning occurs in rivers, rarely in lakes (Scott and Crossman 1973), over sandy or pebbly bottoms (Bigelow and Schroeder 1953), in water depths of 1-3 m (Walburg and Nichols 1967). Shad may spawn in areas of tidal influence. Spawning commences when the water temperature reaches approximately 12°C and continues as long as the temperature does not drop much below this point (Leim 1924).

Carscadden and Leggett (1973) conclude that discrete populations of shad exist in the Saint John River system. No consistent or significant differences were observed between the various populations in mean lengths or weights of fish at a given age (Tables 1 and 2). Within each shad population the growth increment from year to year appeared to be similar. In all populations, male fish were smaller than female fish at similar ages.

The age composition (Table 3) of the populations differs slightly, with the upstream populations (Washademoak Lake and Mactaquac Dam) having a greater percentage of younger fish than the downstream populations (Saint John Harbour and Kennebecasis River). The lower proportion of older fish in the upstream populations may indicate a higher mortality rate, which could reflect the intensive fishing activity in Washademoak Lake and the existence of unsatisfactory environmental conditions for spawners at and above the Mactaquac Dam. A significant difference in mean age at maturity also exists between males from the Kennebecasis River and those of both Washademoak Lake and Mactaquac Dam (Carscadden and Leggett 1973). For females, significant age differences at maturity were found only between the Kennebecasis River and Washademoak Lake populations. In all populations, males matured at a significantly younger age than females. Significant inter-population differences were found in age at maturity between years, which Leggett (1969) notes is common in Atlantic coastal shad populations.

A few Saint John River shad spawn first at age-3 but most are age-4 and average 41.0 cm in length (Carscadden and Leggett 1973). Repeat spawners are abundant (77% of run in 1972) and shad up to age-10 have been sampled (Table 3).

Shad fecundity varies with the size of the female but the largest females do not necessarily produce the greatest number of eggs. Roy (1969) reported a mean of 125,166 eggs per female (range 58,534-390,633) in a study of shad from the St. Lawrence River. Within the Saint John River, distinct populations have been identified which differ in mean population fecundity - total annual egg production of the average female - ranging from 131,767

TABLE 1. Summary of mean fork lengths (cm) of male and female shad from sampling locations in Saint John River, New Brunswick, 1972.[1]

Age (yr)	Saint John Harbour		Kennebecasis River		Washademoak Lake		Mactaquac Dam	
	Length	No.	Length	No.	Length	No.	Length	No.
Male								
2	-	0	-	0	34.9	2	37.1	1
3	41.6	3	40.2	1	39.7	52	38.7	23
4	41.0	11	42.6	14	40.3	77	40.9	22
5	43.0	11	43.8	26	42.6	30	42.6	10
6	44.8	23	45.4	24	45.1	10	45.0	9
7	47.1	21	46.4	27	46.1	18	46.5	5
8	48.2	16	47.6	14	46.9	4	-	0
9	49.3	3	48.5	1	-	0	-	0
10	47.8	1	-	0	-	0	-	0
Female								
3	41.6	4	-	0	41.6	6	42.0	11
4	43.7	12	43.8	9	43.5	32	43.6	35
5	46.7	16	46.6	26	44.8	27	46.3	29
6	49.1	22	48.0	43	46.7	14	48.7	24
7	51.1	14	50.1	39	50.4	10	49.4	9
8	52.3	8	51.2	16	51.2	2	51.8	3
9	51.5	3	52.9	2	51.2	1	-	0
10	-	0	52.8	1	-	0	-	0

[1]From Carscadden and Leggett 1973. Length values rounded to nearest millimeter.

TABLE 2. Summary of mean weights (g) of male and female shad from sampling locations in Saint John River, New Brunswick, 1972.[1]

Age (yr)	Saint John Harbour		Kennebecasis River		Washademoak Lake		Mactaquac Dam	
	Weight	No.	Weight	No.	Weight	No.	Weight	No.
Male								
2	-	0	-	0	725	2	875	1
3	1,183	3	1,200	1	1,087	52	1,053	23
4	1,157	11	1,321	14	1,131	77	1,124	22
5	1,350	11	1,417	26	1,301	30	1,328	10
6	1,521	23	1,498	24	1,543	10	1,492	9
7	1,795	21	1,641	27	1,583	18	1,600	5
8	1,930	16	1,713	14	1,719	4	-	0
9	2,042	3	1,900	1	-	0	-	0
10	1,850	1	-	0	-	0	-	0
Female								
3	1,306	4	-	0	1,333	6	1,275	11
4	1,471	12	1,544	9	1,373	32	1,436	35
5	1,831	16	1,687	26	1,476	27	1,844	29
6	2,085	22	1,879	43	1,707	14	1,959	24
7	2,396	14	2,171	39	2,048	10	1,983	9
8	2,491	8	2,245	16	1,850	2	2,333	3
9	2,300	3	2,550	2	2,150	1	-	0
10	-	0	2,325	1	-	0	-	0

[1]From Carscadden and Leggett 1973. Weight values rounded to nearest gram.

TABLE 3. Age composition (sexes combined) of shad populations in the Saint John River, 1972.[1]

Age (yr)	Saint John Harbour		Kennebecasis River		Washademoak Lake		Mactaquac Dam	
	No.	%	No.	%	No.	%	No.	%
2	0	0.0	0	0.0	2	0.7	2	1.1
3	7	4.2	1	0.4	58	20.4	34	18.6
4	23	13.7	23	9.5	109	38.2	57	31.1
5	27	16.1	52	21.4	57	20.0	39	21.3
6	45	26.8	67	27.6	24	8.4	34	18.6
7	35	20.8	66	27.2	28	9.8	14	7.7
8	24	14.3	30	12.3	6	2.1	3	1.6
9	6	3.6	3	1.2	1	0.3	0	0.0
10	1	0.6	1	0.4	0	0.0	0	0.0
Total	168		243		285		183	

[1]Data adapted from Carscadden and Leggett, 1973.

to 165,127 eggs per female for the Mactaquac and Kennebecasis River populations, respectively (Carscadden and Leggett 1973). After spawning has occurred, the semi-buoyant eggs drift with the current. Hatching occurs after 8-12 days at a water temperature of 11-15°C (Leim 1924). Spent fish return to the sea immediately after spawning.

The larvae, about 9-10 mm long when hatched, grow to 50-75 mm during their summer residence in the river. By autumn, the young shad have drifted to brackish water, then entered the sea where they remain until sexual maturity.

More comprehensive discussions of shad biology are found in Leim (1924), Bigelow and Schroeder (1953) and, with reference to the Saint John River, Carscadden and Leggett (1973).

FISHWAY COUNTS

No estimates are available of the number of shad that once moved upstream past the present site of the Beechwood Dam, although historical records suggest they were few (Perley 1852; Leim 1924). Between 1957 (completion of the dam) and 1967, an average of 364 shad (range 0-1,490) was counted annually at the

fishway (Table 4). In the first two years of operation, the fishway attraction conditions were unsatisfactory during most of the shad runs, and numerous shad which failed to ascend were observed below the dam (Smith 1957, 1958). After completion of the Mactaquac Dam in 1967, still fewer shad arrived at Beechwood (1968-74 average of 6 fish), and escapement to this section of the river is now virtually non-existent.

Between 1968 and 1974, the passage of shad at the Mactaquac Dam averaged 20,100 fish (range 1,500-39,000), with a pronounced decline beginning in 1971 (Table 4).

TABLE 4. Estimated numbers of American shad passed at Beechwood and Mactaquac dams, 1957-74.

Year	Estimated numbers of shad	
	Beechwood Dam	Mactaquac Dam
1957	0	-
1958[1]	55	-
1959	1,155	-
1960	1,490	-
1961	251	-
1962	209	-
1963	43	-
1964	103	-
1965	139	-
1966	199	-
1967	0	0
1968[2]	0	38,843
1969	17	37,449
1970	9	36,437
1971	16	16,817
1972	1	1,497
1973	0	7,363
1974	0	2,400

[1]First year Beechwood fishway was fully operational during shad run.

[2]First year of Mactaquac fishway operation. In 1967, the river was obstructed to shad passage at this site by dam construction.

The shad run to Mactaquac Dam begins in mid-May, peaks in mid-June and continues until mid-July or early August. In recent years, the lower return of shad has shortened the migration to the mid-June to late July period.

COMMERCIAL FISHERY

The history of shad fishery protection is essentially one of

regulations devised and enforced by the Conservation and Protection Branch of the Fisheries and Marine Service. The New Brunswick Fishery Regulations in their various editions specify: the type of gear permitted to fish for shad, the requirement for a license to fish other than by angling, the mesh size and length of gill net permitted, and limitation of the degree of gear obstruction of the river. Within this framework, regulations defined the locations and seasons for legal fishing.

In general, the gear types used have been: weirs in the Saint John Harbour, set or drift gill nets in the tidal waters above the Reversing Falls, and dip nets in non-tidal waters. Previous to 1965, a limited amount of gill-net fishing was permitted at Lower Basin, Grand Falls, but fishing ceased with the construction of Beechwood Dam in 1957. In 1971, the Fishery Regulations were amended to prohibit the use of drift nets above the Reversing Falls. Since then, set nets have been employed in this area. Incidental catches of some magnitude are made by alewife trap nets throughout the tidal waters.

Leim (1924) reported that between 1871 and 1921 the commercial shad catch in the Saint John River and waters of the Bay of Fundy adjacent to the river mouth varied from approximately 100,000 lb to over 900,000 lb, while within the river itself the catch ranged from less than 10,000 lb to over 300,000 lb. Between 1950 and 1974, the commercial shad catch varied from 39,000 lb to over 1 million lb (Table 5). The catch peaked in 1953, then declined irregularly to a low in 1968, and has slowly recovered to 56,000 lb in 1974.

Shad fishing has been confined to the Saint John Harbour and river system proper since before 1950. Assuming, as Leim (1924) theorized, that those shad caught adjacent to the river mouth were destined for the Saint John River, then a comparison of the commercial catches for the 1871-1921 and 1950-1974 periods indicates that they were of similar sizes and fluctuated in comparable ranges.

The shad catches recorded in each Fishery District are actually the totals reported landed in that District, whether or not the fish were caught there. Fishermen may transport catches between Fishery Districts or dispose of portions or all of them in ways that are not reported. The extent of these activities is unknown but undoubtedly varies between years and Fishery Districts, making the reported landing statistics a crude indicator of the actual catch.

Between 1950 and 1974, approximately 59% of the annual Saint John River shad catch was taken in Fishery Districts 48 and 49 (Fig. 1), consisting of Saint John Harbour and a small area above the Reversing Falls. This distribution might be expected, since all migrating shad have to move through these districts and the major market for fresh shad is nearby. Districts 55 and 56 were less productive, accounting for approximately 14% and 16% of the 1950-74 average yearly total catch. Only 9% of the catch was taken in District 57. Historically, the shad catch was minor in those districts farthest upstream and now above the dams, i.e.,

TABLE 5. Commercial landings of American shad in Fisheries and Marine Service Statistical Districts on the Saint John River, 1950-74 (thousands of pounds).

Year	Statistical district								Total
	48	49	55	56	57	58	59	60	
1950	8	109	41	90	9	5	0	4	266
1951	8	542	66	53	33	8	0	8	738
1952	5	625	68	57	37	6	0	11	809
1953	5	716	60	124	83	12	0	9	1,009
1954	4	180	57	100	82	8	0	7	438
1955	0	163	43	50	43	6	0	8	313
1956	0	126	33	60	45	1	0	1	266
1957	0	76	92	60	40	5	0[1]	1[1]	273
1958	0	62	44	44	20	8			178
1959	0	42	43	20	30	5			140
1960	0	135	41	32	35	5			248
1961	243	0	20	33	22	2			300
1962	82	0	24	14	14	4			138
1963	93	2	15	8	6	1			125
1964	36	2	8	6	6	2			62
1965	37	1	20	29	7	3			97
1966	24	0	27	9	7	4			71
1967	28	0	8	4	2	3			45
1968	5	0	15	9	5	5			39
1969	6	0	27	165	4	2			155
1970	25	0	25	65	2	5			122
1971	72	0	18	24	2	1			117
1972	24	0	18	13	3	0			58
1973	0	13	14	28	3	0			58
1974	14	16	26	0	0	0			56

[1]Commercial fishery ceased following construction of Beechwood Dam.

less than 3% of the total average annual catch was taken in Districts 58, 59 and 60 combined.

About 97% of the average shad catch occurred downstream of Mactaquac Dam, the farthest downstream of the dams. If a correspondingly high proportion of the average total reproduction also takes place below the Mactaquac Dam site, it might be assumed that the dam has had little effect on total shad reproduction in the river. However, the effect on the population which migrated above the dam has been severe.

There is evidence of homing by discrete populations of shad in the Saint John River (Carscadden and Leggett 1973) and therefore, it is likely that a part of the shad catch in District 57 and below was destined to spawn farther upriver. Statistics are unavailable on the number of nets fished and their locations within the districts, so that determination of the proportion of fish destined for upstream areas and caught in the main stem of

the river is impossible. Also, it is unknown whether shad populations native to upstream tributaries enter the river as discrete groups within a short time span, or whether they mix and ascend over the entire run.

RETURN OF SHAD TO MACTAQUAC AND ABOVE

It is difficult to determine the proportion of the total Saint John River shad population that returns to the Mactaquac Dam. Likewise, no estimate of the total Saint John River shad population is available. However, if the commercial shad catches for all Fishery Districts (Table 5) are used as a minimum crude estimate, then the shad population declined irregularly from a high of 238,100 fish in 1953 to a low of 9,300 fish in 1968, and has since recovered to 10,900 fish in 1974 (based on a mean weight of 1.92 kg/fish [Carscadden and Leggett 1973]). Since the shad fishery is often influenced as much by market conditions as by abundance - and no effort data are available to separate the two factors - the catch as a proportion of the total run will vary from year to year.

Between 1958 and 1967, an average of 364 shad (range 0-1,490) was counted annually at the Beechwood Dam fishway but, since completion of the Mactaquac Dam, this escapement has virtually ceased. Estimates of the return to the river between Beechwood and Mactaquac dams prior to completion of Mactaquac Dam in 1967 must be based on the commercial catch statistics for District 58 (the area largely blocked by the dam) and the counts of fish at the Mactaquac Dam (ignoring any effects of fishing downstream of District 58). As Carscadden and Leggett (1973) note, the annual totals of shad arriving at the Mactaquac Dam from 1968 to 1970 are approximately equal, which suggests that the population was maintaining itself at a constant level, assuming constant fishing effort below the dam. The commercial catch of District 58 between 1950 and 1971 remained relatively constant at about 1,220 fish per year (range 240-2,860), and, again assuming constant fishing effort, the population size must have been relatively constant. Since the Mactaquac Dam received an average of 37,580 shad annually between 1968 and 1970, the estimated annual return to District 58 and above between 1950 and 1971 would be 37,600 fish.

It is impossible to determine accurately what proportion of the total Saint John River stock was contributed by the area above Mactaquac Dam (Districts 58-60). Different methods produce conflicting estimates of the proportion of the total shad return destined for Mactaquac. In 1968, the 38,800 shad ascending Mactaquac Dam exceeded the entire commercial catch (9,532 fish) by over 300%. By 1973, the trend had reversed and the Mactaquac count of 7,400 fish represented about 54% of the commercial catch.

The importance of the Mactaquac return is evident if it plus the commercial catch is considered a minimal estimate of the total population. The efficiency of the commercial fishery is unknown but is probably low. Evidence for this is provided by the age structure and the high frequency of repeat spawners in the various

shad populations within the river (Carscadden and Leggett 1973).

The commercial catch in District 58 between 1950 and 1971 averaged 1.7% of the total Saint John River catch (range 1%-7%). The shad counts at Mactaquac Dam between 1968 and 1971 indicate that an average of 3.1% (range 0.6%-7.4%) of the estimated total return to District 58 was caught by the commercial fishery of that district. Use of this estimate of fishing efficiency applied to the catches of districts below Mactaquac Dam would produce a large estimate of the total Saint John River shad population, with the return to Mactaquac being only a minor part. This calculation may not be wholly valid, however, since the yearly catches of the other districts have varied markedly and probably the fishing effort was influenced to a greater degree by marketability. The difficulty here is in separating the interactions of market forces with fishing effort, of fishing effort with catch, and the effects of environmental change on reproduction. Whatever the exact figure, it seems evident that the presence of Beechwood and Mactaquac dams has had a negative effect on the Mactaquac Dam shad run. The run to Beechwood has been virtually eliminated, and the return to Mactaquac Dam has declined greatly since its construction. Generally, the catches in all districts have declined, particularly in those farthest upriver, i.e., Districts 57 and 58.

FACTORS AFFECTING DECLINE IN ABUNDANCE

Great changes in shad commercial catches over time appear to be quite common (Walburg and Nichols 1967) and the shad fishery of the Saint John River is no exception. These changes, most notably long-term declines in catch, have been attributed to many factors: physical and chemical alteration of the environment, which render it unsuitable for spawning or which affect the survival of eggs and larvae; the presence of dams, which prevent upstream movement of fish; over-exploitation, which reduces the spawning escapement below required limits; and natural cycles of abundance.

Physical and Chemical Changes

Natural or man-made physical changes to the Saint John River - changes in stream flow, siltation, and water quality and temperature - have been considerable, particularly those related to the presence of hydroelectric dams, which will be discussed later. Dredging and the release of dredged materials have occurred at a few locations in the lower part of the river. These locations are not known to be spawning or nursery areas. Talbot (1954) concluded that extensive dredging of the Hudson River produced no measurable adverse effects on shad abundance.

Industrial, agricultural and domestic pollutants have frequently been shown to have adverse effects on fish populations. Serious pollution from these sources exists in the Saint John River and has adversely affected aquatic life (Dominy 1973; Elson 1967). High BOD's, resulting in dissolved oxygen levels below 5 mg/l (the minimum acceptable level for salmonid fishes), are often

encountered in the Beechwood and Mactaquac headponds (Dominy 1973; Ruggles and Watt 1975), particularly in the former. Oxygen levels are lowest during periods of reduced flow. Summer oxygen levels are critical since shad migration, spawning and larval development occur during this period. However, repeat-spawning shad are known to return to Mactaquac Dam (Carscadden and Leggett 1973). Also, large numbers of alewives, whose spawning produces abundant young-of-the-year, survive in the headpond, so conditions must generally be tolerable for young and adult shad. Lack of data prevents a full assessment of the effect of pollution on shad reproduction in the main Saint John River. Talbot (1954) reports that serious pollution may have been a factor in the decline of shad abundance in the Hudson River.

Dam Installation

The alteration of rivers by dams has been recognized as an important factor in the decline of shad populations on the Atlantic coast (Walburg and Nichols 1967). It is evident that this has also been a factor in the reduced returns of shad to the upper reaches of the Saint John River. The potential for increased adult mortality to the Mactaquac shad population seems reflected in the reduced proportion of repeat spawners (38.9% vs 67.6%) and the smaller average number of spawnings per fish (2.1 vs 2.8) as compared with the other pppulations (Carscadden and Leggett 1973).

Fishway facilities

The major effect of dams is the prevention of upstream migration of fishes. To some degree, this effect has been remedied by the provision of fish passage facilities. However, the passage of fish other than Atlantic salmon was given relatively little consideration in the design of fish passage facilities at the Mactaquac, Beechwood and Tobique Narrows dams, and part of the decline in shad returns can be attributed to this deficiency.

Prior to entering the fishway, shad are exposed to potentially lethal nitrogen supersaturation in the waters below Mactaquac Dam, particularly on weekends when power demands are reduced and flow rates through the turbines are minimal (MacDonald and Hyatt 1973). Although death by gas-bubble disease has been positively identified only in Atlantic salmon and American eels *(Anguilla rostrata)*, undesirable effects on shad are very likely. Nitrogen supersaturation has not yet been identified as a potential problem at the Beechwood or Tobique Narrows dams, but no one has investigated conditions there. Sub-lethal effects on fish may be experienced.

Shad are known to be reluctant users of traditional fishways and few of the early installations were successful (Whitney 1961; Walburg and Nichols 1967). On the West Coast, shad successfully pass through fishways on the Columbia River. At the Hadley Falls Dam on the Connecticut River at Holyoke, Massachusetts, shad utilize a fish-lift similar in principle to that used at Mactaquac Dam (Whitney 1961). Fishways of the pool-and-weir, vertical-baffle and elevator types, as well as fish locks, have also been used to

pass shad successfully (Walburg and Nichols 1967).

One of the greatest problems to overcome is the difficulty of attracting fish from a large river into a relatively small fishway collection system. At the Tobique Narrows Dam, few of the shad observed in the tailrace entered the fishway and, during the first years of operation of the Beechwood fish-lift, shad did not readily enter that facility because attraction conditions were unsuitable during much of the run (Smith 1957, 1958). Improvements in the attraction conditions were subsequently made at Beechwood Dam but shad still do not enter the fishway readily, except for relatively short periods when attraction conditions are optimum (J.H. Ingram, pers. comm.). Attraction at Mactaquac Dam is much better, largely because of the sophisticated flow-control facilities which automatically adjust the attraction-water flow in relation to the tailrace water level. General specifications for collection-system entrance width, depth, and flow suitable for shad are given by Walburg and Nichols (1967).

Once in the fishway, shad encounter another set of obstacles. For a pool-and-weir fishway, as at the Tobique Narrows Dam, Walburg and Nichols (1967) suggest that the optimum difference in pool elevations should be 0.23 m (0.75 ft), with water velocities of 0.61-0.91 m/sec (2-3 ft/sec). Although shad can negotiate velocities of up to 4.1 m/sec (13.4 ft/sec) for very short distances, such high velocities can be a serious barrier (Weaver 1965). At the Tobique Narrows Dam, the head between pools is 0.3 m (1 ft) and the water velocity is approximately 1 m/sec (3.3 ft/sec), conditions which are more suitable for salmon than for shad.

The fish-lift systems at Beechwood and Mactaquac dams present differing problems. Shad utilizing the fish lift at Beechwood may experience lengthy delays once inside the gallery and rest pool, but neither crowding by other species nor mortality are significant. At Mactaquac, however, shad are often badly scaled and sometimes abraided on the snout by confinement with thousands of alewives in the holding pool for several days. Shad apparently do not enter the brail pools as readily as do alewives. Stevenson (1899) stated that "shad cannot or will not run up through fishways that are readily used by alewives." At the successful Holyoke fish lift, alewives and blueback herring *(Alosa aestivalis)* are not present in any great numbers (W.C. Leggett, pers. comm.). Once the shad are in the Mactaquac hopper, the vibrations accompanying its upward movement apparently excite them and they thrash about, losing additional scales. Shad mortalities during lifting and transportation to the release site average 25% per year, of which the greater part follows transportation and release. This figure is minimal, since recovery of all fish which die in the headpond following release is unlikely.

The difficulties encountered in transporting adult shad are possibly a reflection of the difficulties experienced in handling and transporting juvenile shad as reported by Sykes (1950). Chittenden (1971) states that the mortality frequently encountered in handling young shad can be attributed mainly to stress arising

from excitement. Intensity of excitement is important since low level stress may lead to delayed mortality and severe stress causes rapid mortality. Stress levels in the Mactaquac operations evidently range from moderate to severe. Whitney (1961) reported 12-18% mortality of the adult shad captured and trucked above the Conowingo Dam on the Susquehanna River, Pennsylvania. The absence of trucking at the Holyoke Dam (the fish are released from the fish hopper directly into the headpond) may have contributed to the steady increase since 1955 in the numbers of returning shad (W.C. Leggett, pers. comm.). The use of brackish water as a transportation medium in the tank trucks apparently minimizes the effects of stress (Sykes 1950; Chittenden 1971).

Headpond conditions

Water conditions in the headpond and passage of adult shad downstream following spawning are also potential sources of mortality. At Beechwood, the heterotrophic headpond contains very low dissolved oxygen levels in summer and may occasionally become anaerobic (Watt 1972). During periodic sampling, a low of 2.4 mg/l of dissolved oxygen was recorded in August of 1968 (Cullen 1968) but conditions have improved such that levels of 3.5 mg/l and 4.6 mg/l were the lowest recorded in July and August of 1971 and 1972 respectively (Watt 1973). Chittenden (1969) reports that at dissolved oxygen levels below 3.0 mg/l, loss of equilibrium would occur in shad; at levels below 2.0 mg/l, heavy mortality would occur; and at less than 0.6 mg/l, an immediate, complete kill would occur. In combination with the sometimes high, but sublethal, concentrations of toxic constituents such as lignosulphonates and pesticides (Dominy 1973), the low oxygen levels surely have a negative effect upon shad survival and spawning success in the Beechwood headpond. There are no reports of shad kills, although an extensive kill of suckers (*Catostomus* sp.) occurred in the Hartland area in 1969, due apparently to a lack of dissolved oxygen (Ruggles and Watt 1973). The extent of headpond mortality or impaired spawning success has not been investigated.

Water quality conditions in the Mactaquac headpond are much better than those at Beechwood (Watt 1972), but still must be of concern since dissolved oxygen levels below 5 mg/l are occasionally recorded in the epilimnion (Dominy 1973). Dissolved oxygen levels in the hypolimnion can become severely reduced; they ranged from 3.0 to 0.4 mg/l during the summer of 1972 (Watt 1973). Whitney (1961) attributes shad mortalities of 4-40% to headpond conditions and passage through turbines on their return to sea from the Connecticut River.

Downstream passage

Since little use of dam spillways occurs after the end of May, downstream-migrant adult shad must pass through the turbines at Mactaquac and Beechwood dams. Mortality rates are unknown since no studies of shad mortality in turbines have been made at these sites. Some Atlantic salmon are known to successfully pass the turbines at Mactaquac (Annual Report 1972), but it is doubtful that shad could survive passage as readily as the more hardy

salmon.

Since spillage is unusual during the August-October period of downstream migration of young shad, the likelihood of mortality as they pass through the turbines at Mactaquac Dam should not be overlooked. A limited study of juvenile shad passage through low-head turbines indicated little fish mortality (Walburg and Nichols 1967). However, mortality of the alewife was estimated at 50% during passage at the Tusket River Dam, Nova Scotia (Smith 1961).

Juvenile shad and alewives gather in the gatewells of the turbine intakes at Beechwood Dam and probably do so at Mactaquac Dam, since such behaviour is typical of these and other species of fish (Marquette and Long 1971). The tendency to rise in the gatewells probably results from the fish swimming upward, seeking relief from higher water pressures at the gatewell entrance (Marquette and Long 1971). This response has been demonstrated in laboratory experiments with juvenile chinook salmon (Tarrant 1964). However, the early young of fish possessing a swim-bladder, e.g., salmonids and clupeids, are more sensitive to pressure drop than are older individuals. Large numbers of young fish passing through turbines at dams can perish as a result of changing hydrostatic pressure (Isvetkov et al. 1972). This phenomenon applies particularly to fish entering the turbines from deeper layers of water. Isvetkov et al. (1972) noted the profusion of seagulls feeding on injured fish at turbine outlets, and this observation can be made at Mactaquac at certain times.

The behavioural response of young spring salmon *(Oncorhynchus tshawytscha)* and steelhead trout *(Salmo gairdneri)* at gatewell entrances to hydroelectric dams has been advantageously used to provide safe downstream passage. Laboratory experiments with a simulated turbine intake, gatewell, and stationary screen at the gatewell entrance produced a maximum guiding efficiency of 87% (Marquette and Long 1971). After entering the gatewells, the fish pass through an orifice in the side of the gatewell into an ice or trash sluiceway and then into the tailrace of the dam (Bentley and Raymond 1969). Implementation of a similar collection and bypass system at Mactaquac and Beechwood might benefit the maintenance of shad and alewife runs above these dams. Park and Farr (1972) conclude that the benefits of this type of system to downstream migrant adult fish would not be great for Columbia River shad.

Reproductive Potential

Shad populations in the Saint John River differ little in terms of mean virgin and mean population fecundity (mean virgin fecundity is defined as the total fecundity of the average virgin female in the population; mean population fecundity is the total annual egg production of the average female in the population). Differences in the incidence of repeat spawning result in great differences in mean lifetime fecundities (Table 6).

Carscadden and Leggett (1973) suggest that lifetime fecundity,

TABLE 6. Fecundity and spawning history of shad populations in the Saint John River, 1971-72.[1]

Population	Mean virgin fecundity	Mean population fecundity	Mean lifetime fecundity	Percent repeat spawning[2]
Kennebecasis River	170,142	165,127	461,228	92.2
Washademoak Lake	136,387	138,640	242,660	47.9
Mactaquac	132,590	131,767	204,821	36.7

[1]Data from Carscadden and Leggett 1973.

[2]Females only.

defined as the total egg production of the average female in a population during its reproductive life, is possibly the most important parameter for long-term population success. On the average, each female of a population must produce during her lifetime at least two mature recruits to maintain a stable population.

Two scenarios can be constructed concerning the reproductive success of shad in the Saint John River, both of which suggest that the Mactaquac population is particularly sensitive to adverse environmental conditions.

(a) Leggett (1969) states that approximately 100,000 eggs are required to produce one mature recruit in various Atlantic Coast shad populations. Given comparable egg-recruit survivals in the Saint John River, then the number of mature recruits produced differs between tributary populations, such that one Kennebecasis River female would produce 4.6 and one Washademoak Lake female would produce 2.4 (Carscadden and Leggett 1973). In the Mactaquac population, one female would produce 2.0 mature recruits and it must, therefore, be regarded as a marginal population.

(b) The approximately equal yearly returns of shad to Mactaquac just after its construction (Table 4) suggest that the population was stable at that time; returns destined for areas above Beechwood Dam had largely been eliminated by then (Carscadden and Leggett 1973). Also, the assumption must be made that the shad in Washademoak Lake and Kennebecasis River are maintaining a constant population level. In combination with the values for mean lifetime fecundity (Table 6), the assumption of approximately constant yearly population sizes and the two recruits per female maintenance

requirement implies that survival from egg to recruit differs between tributary populations (Carscadden and Leggett 1973). Under these conditions, shad from Mactaquac would have the highest survival rate.

At this time, the available evidence does not indicate clearly which scenario is most realistic.

Spawning and Early Life Requirements

The relationship of dam location to spawning areas largely determines the effect of the dam on a shad population, the reduction in fish numbers probably being proportional to the amount of spawning area destroyed (Taylor 1951; Walburg and Nichols 1967). Exactly where shad once spawned in the reaches above Mactaquac Dam is uncertain, but the formation of headponds at Beechwood and Mactaquac has reduced the approximately 201 km of previously lotic conditions by 67.7%.

Shad are lotic spawners but may attempt to spawn in Saint John River headponds since the streams entering the headponds are not generally suitable. The eggs may then settle into the hypolimnion where either temperature or oxygen conditions (Ruggles and Watt 1975) would be unsuitable for development. Since the bottoms of the headponds are covered with varying amounts of wood pulp, clay and other sediments, many eggs could be lost due to siltation (Leggett, pers. comm.). Even with a suitable substrate, mortalities of one-sixth to one-third of the egg deposition are likely (Leim 1924). In Mactaquac headpond, large and expanding populations of suckers and brown bullheads *(Ictalurus nebulosus)* may be important egg predators (Meth 1973).

Development of the larval and juvenile stages of shad would undoubtedly also be affected by low dissolved oxygen and by toxic constituents in the headponds. Water temperatures in the epilimnion would not be a problem as they fluctuate gradually around 20°C between June and August (Anon. 1972). Young shad can tolerate sharp short-term temperature fluctuations between 13° and 24°C although they may seek a more stable regime (Chittenden 1969). The larger young shad of New England rivers migrate downstream throughout the summer although the majority migrate when the water temperature declines to less than about 15.5°C (Walburg and Nichols 1967; Chittenden 1969). Laboratory experiments have shown that the lower tolerance limit for shad in fresh water is approximately 2°C, and field observations in the Delaware River indicate that the last young shad leave non-tidal waters when the temperature declines to 8-9°C (Chittenden 1969, 1972).

Although data on the feeding habits of young shad in either of the Beechwood or Mactaquac headponds are unavailable, studies elsewhere indicate that larval shad in lotic environments feed actively upon copepods, other planktonic crustacea and chironomid larvae (Gill 1926; Leim 1924), while juveniles utilize mostly insects and crustaceans (Walburg 1967). Under headpond conditions, larval shad feed mainly on aquatic crustaceans and tendipedid larvae and pupae, while juveniles ingest crustaceans, tendipedid

larvae and pupae, hydropsychid larvae and adult insects (Levesque and Reed 1972). The abundant planktonic crustacea and chironomids of both Saint John River headponds are heavily consumed by *Alosa pseudoharengus* and *A. aestivalis* (Watt and Duerden 1973), which suggests that the feeding of young shad may also be unimpeded.

Potential predators of young shad in the headponds include American eels *(Anguilla rostrata)*, chain pickerel *(Esox niger)*, yellow perch *(Perca flavescens)* and smallmouth bass *(Micropterus dolomieui)*. Leim (1924) could not demonstrate predation of shad by eels but Walburg and Nichols (1967) mention its occurrence in hatchery ponds. Smallmouth bass and chain pickerel are the most abundant of the potential predators (Meth 1973) but their importance as predators of young shad is unknown.

Commercial Exploitation

Overfishing has been blamed as a major cause in the decline of Atlantic Coast shad stocks since before 1850 (Stevenson 1899). Certainly before the advent of hydroelectric dams and heavy industrial pollution, overfishing likely was a primary factor in the fluctuations in commercial shad catches on the Saint John River. Studies on the Connecticut and Hudson rivers indicated that over 80% of the annual variation in population size (and catch) resulted from changes in spawning escapement caused by excessive fishing pressure (Fredin 1954; Talbot 1954). In both cases, decreased fishing pressure led to increased shad abundance. While the catch has declined irregularly since 1950 in the Saint John River, a spawning population consisting of 76.8% repeat spawners averaging 2.8 spawnings per fish with up to 5 spawnings (Carscadden and Leggett 1973) suggests that the decline is due to factors other than over-fishing. Since the relationship of catch to effort and to total population size is unknown, the full extent of the general population decline cannot be defined.

SUMMARY OF POSSIBLE CAUSES OF POPULATION DECLINE AT MACTAQUAC DAM

The decline in the numbers of shad returning to Mactaquac Dam was likely accentuated by fishing pressure. However, the major causes appear to involve the biology of the population, the difficulties of fish passage at hydroelectric dams and the impact of adverse environmental conditions on the success of reproduction.

Evidence has been given for substantial adult shad mortality during upstream passage at the Mactaquac Dam, for poor attraction conditions at Beechwood Dam, and for possible headpond mortality and for possible mortality during downstream passage at both dams. These mortalities have not been quantified at present, nor has the exploitation by fisheries below the dam of shad returning to Mactaquac.

Typically, the greatest mortalities in fishes occur during the earliest life stages - egg, larva and juvenile - the fresh-water stages for shad. Assuming comparable marine mortalities for the tributary populations, the sharp decline in returns to

Mactaquac probably reflects heavy freshwater mortality. Of the previously mentioned factors which might cause such mortality, i.e., reduction in spawning area, adverse environmental conditions, predation and mortality during downstream migration, only the effect of a reduction in spawning area is quantifiable at this time. Assuming an average pre-Mactaquac Dam population of 37,600 shad, and a reduction in expected return proportional to the reduction of lotic conditions above Mactaquac and Beechwood (67.7%), then the present expected return to Mactaquac should be about 12,100 shad. Records of past fishing effort for shad on the Saint John River are incomplete but the catch records (Table 5) probably reflect some decrease. Present returns fall short of this level and it is apparent that other sources of freshwater mortality are also important.

NEEDS FOR REHABILITATION AND MANAGEMENT

Increases in the return of shad to Mactaquac Dam are contingent upon reducing stress during upriver passage and improving the headpond environment. At best, the effort to be expended in rehabilitating the shad run should probably be related to the magnitude of the historical run above the dam. There are no acceptable estimates of this magnitude, but apparently it was not very great. Presently, the reduction of suitable spawning area by headpond formation sets an upper limit on potential shad production, and rehabilitation effort should attempt to optimize the yield presently achievable.

Fish culture techniques have often been used to maintain and improve stock abundance. In view of this, some comments on the success of shad hatcheries and fry release are pertinent. United States experience confirms that large numbers of young shad can be reared for release, but 60 years of such work did not justify its continuation (Walburg and Nichols 1967). The hatcheries did not maintain the shad runs and, for all the effort involved, the number of eggs obtainable for hatchery use is only a minute part of the amount naturally spawned (Talbot 1954). Efforts would have been better spent reducing the exploitation rate and improving the river environment (Fredin 1954; Talbot 1954). Prior to determining the form of management or rehabilitation programs for the Mactaquac shad population, a decision based on social and biological grounds must be made as to whether the population warrants such programs and to what degree. Assuming a decision is made for management and rehabilitation, then the immediate measures to be taken might include:

1. A continuous program to monitor not only the numbers of returning fish but also the age structure, sex ratios, growth patterns, etc., of the population, so that the success of rehabilitation measures can be assessed.

2. Annual transportation to the headpond of approximately the number of shad desired in the population, if available (based on the egg-recruit projections of Carscadden and Leggett 1973).

3. Consideration of the reduction or elimination of the marginal shad fisheries in Districts 57 and 58.

4. A study of the practicability of separating shad from alewives at the fish-lift.

5. Improvement of the hoist mechanism of the fish-lift to reduce vibration.

It is doubtful that the Mactaquac shad population will ever regain its pre-dam abundance, and continuing efforts will be required to maintain its existence. Longer term rehabilitation projects might include:

1. Determination of whether all (or what percentage of) shad approaching Mactaquac Dam actually use the collection facility, and whether there is significant delay in passing them above the dam.

2. Investigation of methods to reduce handling and trucking mortality, such as determining the optimum number of fish per truck, and the possible use of a saline transporting medium.

3. Assessment of adult and juvenile shad mortalities resulting from passage through turbines.

4. Investigation of the feasibility of using turbine gatewells at Mactaquac for collecting juvenile shad and avoiding turbine passage.

5. Investigation of the location of spawning areas and subsequent spawning success.

6. Assessment of the impact of the commercial shad fishery at the mouth of the river on the numbers returning to Mactaquac Dam.

7. Development of a management program specifically designed for those shad populations resident below the Mactaquac Dam.

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