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Fish survival on fine mesh traveling screens

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Abstract

The survival of fish impinged on 1-mm mesh Ristroph-type traveling screens was evaluated at Somerset Station, a 625-MW coal-fired electric generating station located on the south shore of Lake Ontario. Somerset Station was designed and built with an offshore intake, discharge and fish return system. Survival testing was conducted over a 4-year period that included all four seasons. Test fish were diverted from the fish return and held for 96 h for observation. Following observation, a specially constructed screening table was used to differentiate test fish that typically would have been impinged on a standard 9.5-mm mesh screen from smaller individuals that typically would be entrained. Twenty-eight species were tested, and collections were dominated by five species: alewife, emerald shiner, gizzard shad, rainbow smelt, and spottail shiner. Survival rates commonly approached or exceeded 80%, and were influenced by species, fish size or life stage, season and fish condition. Results are interpreted in terms of survival rates demonstrated elsewhere for entrained fish and fish impinged on alternative traveling screen technologies. © 2000 Elsevier Science Ltd. All rights reserved.

Keywords: Fine mesh traveling screen; Impingement survival; Ristroph screens; Mitigation; Fish return system; Lake Ontario

1. Introduction

New York State Electric and Gas Corporation began commercial operation of its 625-MW coal-fired Somerset Station in August 1984. For a period from 1991 until 1999, Somerset Station was known as the Allen E. Kintigh Station. Somerset Station was designed to reflect state-of-the-art technology for all environmental concerns at the time. Although it retains a once-through cooling system, cooling water flow rates are much reduced. The station withdraws 195,000 gpm or 281 mgd for cooling water needs. Under its 402 Discharge Permit, Somerset Station is allowed to raise the temperature of the circulating system water a daily average not to exceed 18°C (33.7°F) or a maximum of 21.7°C (39.0°F) during non-winter months. During winter months (mid-November to mid-April), the maximum ΔT is set at 22.2°C (40.0°F).

Several features were designed into the once-through cooling system for the protection of fish and other aquatic animals. Although relatively untested, fine (1-mm) mesh traveling screens were installed as part of a system that would return fish to the source water body, Lake Ontario. The rationale for fine mesh screening was to prevent as many organisms as possible, including fish eggs and larvae, from being entrained through the cooling water system, where the relatively high ΔTs would be assumed to cause 100% mortality. Therefore, any survival of typically entrainable organisms screened by the fine mesh would be a benefit gained. In essence, the overall strategy for fish protection was to reduce the number of organisms withdrawn from the lake by reducing the volume of water withdrawal, while maximizing the screen recovery and survival of screened organisms for return to the lake.

An extensive aquatic monitoring program was conducted at Somerset Station during 1982 through 1986, and included both lake sampling and pumphouse

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sampling. The pumphouse sampling component was continued during 1987–1992. In addition to monitoring impingement rates, the pumphouse studies had the following objectives:

1. to determine the overall effectiveness of the fish screen removal/return system;
2. to optimize fish removal from the traveling screens by means of system adjustments;
3. to assess fish survival following impingement and transport in the fish trough;
4. to assess the survival of fish transported to the lake through the fish return pipe; and
5. to compare survival of early life stages afforded by the fine mesh screening to that of juvenile and adult fish.

2. Station description

Somerset Station is located in the Town of Somerset in Niagara County, New York, approximately 40 km east of the mouth of the Niagara River. To reduce the effects of water withdrawal and thermal discharge on the near-shore zone of Lake Ontario, Somerset Station has offshore intake and discharge structures. The intake tunnel runs nearly perpendicularly offshore for a distance of 625 m, and the 670-m long discharge tunnel is at a 30° angle to the intake tunnel. The intake is a capped octagonal structure with eight ports at an average depth of 7 m below the lake surface and a minimum distance of 1.8 m above the lake bottom. Three circulating pumps withdraw water through four separated forebays and four conventional traveling screens fitted with 1-mm smooth nylon mesh. Mean approach velocities in front of the screens typically will range from 0.88 to 1.08 fps, but maximum velocities of 2.5–3.1 fps have been observed during low water level. Screens continuously rotate at either 10 or 20 fpm. Fish lifting buckets incorporated into each screen basket hold 5 cm of water.

Impinged fish are washed from the screens by a low-pressure spray wash, located on the interior descending side of the screens, into a 51-cm wide fiberglass fish trough with a semi-circular cross-section. A 60-psi spray wash is mounted beneath the fish trough on the interior of the screen to wash debris into a concrete trough, sloped in the opposite direction to the fish trough and terminating in a debris collection basket. A supplemental flow of 400 gpm is provided to the fish trough to maintain a water depth of 15.2 cm. The fish trough connects to a fiberglass return pipe that is imbedded in the intake tunnel and terminates 305 m offshore at a water depth of approximately 4.6 m at low water level. The internal diameter of the return pipe transitions from 38.1 cm, branching to two 25.4-cm pipes, and finally to a single 35.6-cm pipe. This fish return pipe receives a make-up flow of approximately 2800 gpm to maintain a velocity of 5–7 fps for returning fish to the lake.

3. Collection efficiency testing procedures

Optimization of the fish screen removal/return system required assessment of the efficiency of fish removal from the traveling screens (collection efficiency) and post-impingement survival. Collection efficiency testing was initiated in November 1984 to determine the appropriate operating modes of the screening system for subsequent testing, particularly the operating pressure (14 psi) for the fish spray header. Testing continued throughout 1985 to investigate alternative spraywash designs that would increase removal of the smallest impinged fish. Alternative configurations tested included: (1) replacement of the five original deflector-type spray nozzles with eight 60° cone-type spray nozzles, and (2) addition of a separate inside spray header fabricated with a longitudinally-slotted spray outlet. Following this testing, screen-washing system upgrades were installed during 1987 and 1988, and were tested in 1989. The upgrades (Fig. 1) consisted of: (1) the addition of five spray nozzles directed at the inside of the screen loop to remove small fish from the articulation between the adjoining screen panels; (2) the addition of external low pressure sprays on the descending side to wash fish down the screen panel into the fish trough; and (3) the installation of articulating fiberglass deflectors to prevent fish from dropping between the fish trough and the screen. These modifications required further testing for optimal spraywash pressures.

Collection efficiency tests were conducted by releasing marked dead or live fish into the ascending screen buckets and recovering the fish in collection devices at the end of the fish trough just prior to entry into the fish return pipe. A gate was installed at the end of the fish trough which would divert fish to either a concrete pool built into the floor of the pumphouse deck, or into a collection, or "larval," table (Fig. 2) constructed in 1986 and used for subsequent testing of small fish. Fish used for testing generally were of sizes and species available from impingement collections, and were marked with rose bengal stain, clothing dye or fin clips.

To evaluate the effectiveness of the fine mesh screening relative to standard mesh screening, a device was constructed to separate the fish that would have been impinged on a standard 9.5-mm square mesh from those that had been retained by the 1-mm mesh. This device was a "screening table" consisting of a hinged,

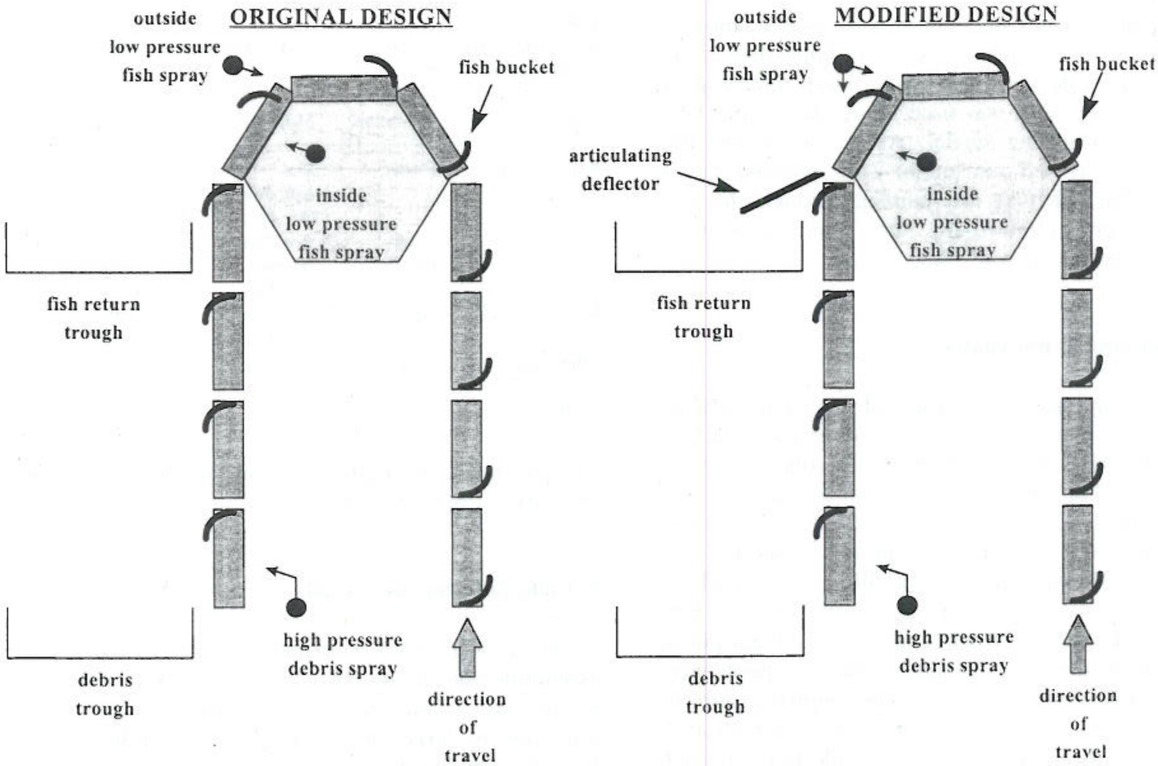

Fig. 1. Schematic cross-section of the traveling screen systems installed at Somerset Station, showing the original (left) and modified (right) designs.

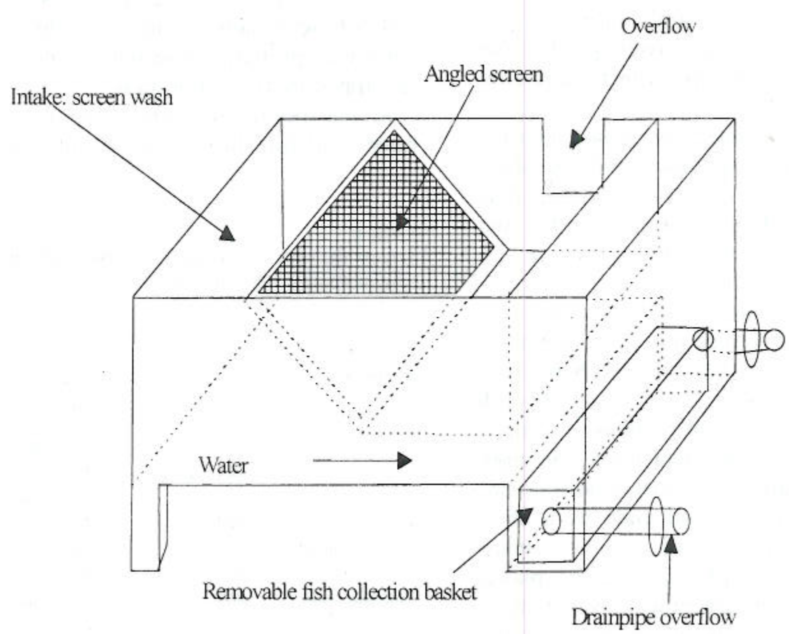

Fig. 2. Fish survival collection table.

flat horizontal screen of 9.5-mm mesh placed above a table surface that concentrates and holds fish small enough to pass through the 9.5-mm mesh screening. A hand-held spray wash was used to simulate water flow through the traveling screen. As a convention, fish retained by the 9.5-mm mesh were referred to as impinged fish, whereas fish passing through the 9.5-mm mesh and retained by the 1-mm mesh were referred to as "entrapped" fish.

4. Survival testing procedures

In 1985, impinged and entrapped fish were collected from the fish trough by use of a screened collection basket immersed in the concrete fish collection pool. Beginning in 1986, all fish for survival studies were collected using the collection table. Individual collections were made over a 15-min–2-h period. Collected fish were removed with minimal handling, separated by condition (live, stunned or dead), and placed into holding tanks (10 or 24 gal capacity) or 100-gal pools, depending on their size. Holding tanks and pools were equipped with flow-through systems supplying ambient lake water. Fish were held for 96 h and observed at 2, 4, 6, 8, 12, 24, 48, and 96 h after collection. At each observation interval, dead fish were removed, identified to species, and logged for use in final test counts. Water temperature, dissolved oxygen concentration, turbidity, and conductivity in the holding tanks and pools were recorded every 8 h. At the conclusion of the holding period, test fish were identified to species, counted according to condition, and sorted by size (entrapped vs impinged) using the screening table. No control tests for handling or holding effects were conducted.

Survival testing was conducted by season (spring: March–May, summer: June–September, fall: October–December, winter: January–February) in 1985, 1986 and 1989. Only limited testing occurred in 1987, and no testing was conducted in 1988 while screening systems upgrades were being installed.

Objective 4, assessing the survival of fish transported to the lake through the fish return pipe, was addressed by tests conducted from mid-May to mid-September 1986. For these tests, fish were collected at the fish return line discharge port in Lake Ontario using a modified hoop net equipped with detachable cod ends, which also served as containers for post-collection survival observations. Initially the cod ends were 86 × 135-cm perforated plastic bags fitted over a stainless steel frame, but were later replaced by 227-l plastic drums with three 33 × 51-cm openings covered by 3-mm plastic screening. Collections lasted up to 2 h and were performed by SCUBA divers. Following collections, the cod-end containers were detached, sealed and attached to a weighted ground line for subsequent fish survival observations.

Table 1
Percent recovery of impingeable marked fish released onto Somerset Station screens, 1985

Species	Condition	Months	N_{tot}	% Recovery[a]
Rainbow smelt	Dead	Mar	100	95
		Apr–Jun	400	97–100
		Oct–Dec	200	71–82
	Live	Apr–Jun	550	92–100
Alewife	Dead	Jul–Sep	1324	78–95
		Oct–Dec	199	84–96
Spottail shiner	Dead	Apr–Jun	100	90–100
	Live	Oct–Dec	314	87–93
White bass	Live	Oct–Dec	187	74–87

[a] Per screen.

5. Collection efficiency results

The recovery rates of marked fish released onto the ascending side of the traveling screens were governed by the species and size of the fish. As expected, recovery rates of larger individuals tended to be greater than for smaller individuals. Screen-specific recovery rates for fish large enough to be impinged on 9.5-mm mesh screens were high, frequently exceeding 90% (Table 1). Recovery rate appeared to be unrelated to the condition of the fish (live vs dead). The data presented for impingement-sized fish only include tests in 1985, for which total sample sizes were greater than 100 fish seasonally. Collection efficiency testing after 1985 was primarily directed at smaller fish, i.e., fish entrapped by the 1-mm mesh.

Screen-specific recovery rates for smaller, entrapment-sized fish during 1985 testing were relatively low

Table 2
Percent recovery of entrappable marked fish released onto Somerset Station screens, 1985 and 1989

Species	Year	Condition	Months	N_{tot}	% Recovery[a]
Rainbow smelt	1985	Dead	Mar	124	4–24
			Apr–Jun	75	0–52
			Jul–Sep	75	28–40
			Oct–Dec	457	24–40
	1985	Live	Mar	177	47–64
			Apr–Jun	125	18–38
	1989	Live	Mar	175	79
Spottail shiner	1985	Live	Oct–Dec	43	69
	1989	Live	Mar	75	99
Emerald shiner	1989	Live	Apr–Jun	825	83–90
			Jul–Sep	50	96
Fathead minnow	1989	Live	Jul–Sep	25	64

[a] Per screen.

(usually less than 50%), as shown by the data for rainbow smelt and spottail shiner (Table 2). This low recovery rate prompted the screening system modifications that were made between 1985 and 1989. With the modifications completed, the 1989 data showed a marked increase in the recovery rates; e.g., from <65% in 1985 to 79% in 1989 for live rainbow smelt, and from 69% in 1985 to 99% in 1989 for live spottail shiner (Table 2). Based on the 1989 results, the screening system modifications made in 1987–1988 were considered to have been successful in optimizing the effectiveness of fish removal from the traveling screens and conveyance to the fish return pipe.

6. Survival results

The seasonal availability of impinged or entrapped fish for survival testing dictated the species, life stages, and years for which data could be analyzed with sufficient sample sizes (e.g., 50 or more fish). For the most frequently impinged species, the observed 96-h survival rates appeared to be highly variable (Table 3). Alewife had the lowest 96-h survival rates, being nearly 0% in the spring but increasing to 44.5% in the summer of 1989, following the screening system modifications (Table 3). Impinged rainbow smelt also demonstrated a highly variable seasonal survival, with 96-h rates in 1985 ranging from a high of 94.9% in the spring to 1.5% in the summer and 21.8% in the fall (Table 3). The 1985 tests were made prior to system modifications, and insufficient data were available from 1989 testing to determine whether system modifications might have altered survival rates for impinged rainbow smelt. With the exception of gizzard shad (53.7–65.3%), the 96-h survival rates for other species exceeded 70–80% (Table 3).

The degree to which handling and holding stress contributed to the mortality of impinged alewife and rainbow smelt could not be determined because of the absence of control tests. To be valid, control testing for impingement mortality requires a supply of fish, usually from a hatchery source, that is representative of the size, species, and condition of fish that are being impinged. Control testing was not conducted for this reason. The estimated 96-h survival rates therefore may be conservative and underestimate the true survival rates.

The estimated 96-h survival rates for entrapment-sized fish (principally juveniles and some adults of small species) were similar to the rates for impingement-sized fish. The lowest survival rates (Table 4) were recorded for alewife (0–0.9%) and rainbow smelt (6.8–49.4%), whereas darters, sculpins and emerald shiners had 96-hr survival rates of approximately 70% or greater. The only data available for pre-juveniles was collected for post-yolk-sac rainbow smelt in the summer of 1986, for which the 96-h survival rate was estimated to be 26.9% (Table 4). The only tests of sufficient sample size and conducted after the 1987–1988 screening system modifications yielded a 96-h survival rate of 40.8% for juvenile and adult rainbow smelt in the fall of 1989, similar to the 49.4% survival recorded in the summer of 1986 prior to these system modifications (Table 4).

Fish species that were not frequently impinged or

Table 3
Initial and 96-h seasonal survival rates of impinged fish at Somerset Station for frequently impinged species

Species	Season	Year	N	Initial survival %	96-h survival %
Alewife	Spring	1985	184	100	0.0
		1986	202	99	1.0
	Summer	1985	1144	98.1	15.4
		1986	905	97.7	19.0
		1989	1068	99.5	44.5
Gizzard shad	Summer	1986	695	99.6	65.3
	Fall	1986	108	100	53.7
Rainbow smelt	Spring	1985	1459	99.4	94.9
	Summer	1985	65	63.1	1.5
	Fall	1985	248	98.4	21.8
Rock bass	Summer	1985	56	100	94.6
Spottail shiner	Winter	1985	107	100	100.0
	Spring	1985	72	100	100.0
	Summer	1985	62	100	95.2
		1986	56	100	83.9
	Fall	1985	408	100	100.0
		1986	113	100	100.0
White bass	Fall	1985	461	100	95.9
White perch	Winter	1985	78	100	72.0
Yellow perch	Winter	1985	47	100	80.9

Table 4
Initial and 96-h seasonal survival rates of entrapped juvenile and adult fish (except as noted) at Somerset Station for frequently entrapped species

Species	Season	Year	N	Initial survival %	96-h survival %
Alewife	Summer	1985	171	43.9	2.9
		1986	339	63.1	0.9
Darters	Summer	1986	434	97.5	89.6
Emerald shiner	Summer	1986	3445	99.2	78.9
Gizzard shad	Summer	1986	55	83.6	49.1
Rainbow smelt	Winter	1985	109	89.9	14.7
	Spring	1985	978	97.8	35.5
	Summer	1985	1491	83.6	6.8
		1986	5496	80.2	26.6
		1986[a]	1972	68.9	26.9
	Fall	1985	248	98.4	21.8
		1986	3461	92.9	49.4
		1989	174	100	40.8
Spottail shiner	Summer	1986	337	99.4	83.1
	Fall	1985	74	100	100
		1986	90	100	95.6
Sculpins	Summer	1986	196	85.2	67.9

[a] Post-yolk-sac larvae.

entrapped had high survival rates, approaching 100% with the exception of trout and salmon (Table 5). Due to small sample sizes, seasonal survival rates could not be estimated reliably for these species. Most trout and salmon were large fish that probably resided in the intake forebay for a long period of time, as indicated by their frequently being observed swimming in the forebay in front of the screens, and their weakened and emaciated condition when impinged.

Survival testing in 1986 for fish captured in the lake at the fish return pipe (Objective 4) had only limited success. Problems were encountered with water circulation in the detachable cod ends, and were eventually solved by using the plastic drums. Many fish were subjected to lethal temperature changes caused by a thermal upwelling during the holding period, and normally would have been free to avoid these temperature changes. Therefore, the results of this testing were not considered to be representative of the survival of fish returned to the lake. This testing was not repeated.

7. Advantages and disadvantages of fine mesh screening

In its application at Somerset Station, a measure of success for fine mesh screening would be the relative numbers of organisms that are entrapped, and thus saved from an assumed 100% entrainment mortality.

Table 5
Initial and 96-h seasonal survival rates of infrequently impinged (I) or entrapped (E) species at Somerset Station, 1985–1986

Species	I/E	Sample size	Initial survival	96-h survival
American eel	I	2	100	100
Centrarchids[a]	E	2	100	100
	I	143	99.3	93.7
Brown bullhead	I	3	100	100
Trout/salmon[b]	I	33	93.9	42.4
Emerald shiner	I	6	100	100
Freshwater drum	I	7	100	71.4
Lake chub	E	9	100	100
	I	25	96	96
Mottled sculpin	I	34	100	100
Threespine stickleback	E	2	100	100
	I	2	100	100
Trout-perch	I	22	100	100
Percids[c]	I	94	100	84

[a] Includes bluegill and smallmouth bass.
[b] Includes brown trout, rainbow trout, lake trout, coho salmon, and chinook salmon.
[c] Includes walleye and yellow perch.

Table 6
Percent contribution of entrapment to the combined annual total impingement (I_{tot}) and entrapment (E_{tot}) at Somerset Station, 1985–1989

Year	E_{tot}	I_{tot}	$E_{tot}+I_{tot}$	%E
1985	780,361	147,667	928,028	84.1
1986	131,491	304,087	435,578	30.2
1987	123,391	63,069	186,460	66.2
1988	352,335	10,128	362,463	97.2
1989	338,449	46,472	384,921	87.9

These numbers can also be compared to the number that would be impinged on standard (e.g., 9.5-mm) screens. Estimates of total annual entrapment and total annual impingement were made using mean daily entrapment and impingement densities (or representative daily subsamples), and the total daily water withdrawal volumes. From 1985 through 1989, the estimated total number of fish entrapped by 1-mm mesh screening ranged annually from 123,391 fish to 780,361 fish (Table 6). Except for 1986, this number exceeded the number that would have been impinged on 9.5-mm screening by a factor of 2:35.

For a different perspective, the maximum number of fish of a particular species and life stage entrapped annually was estimated for the same 5-year interval. Considering the six most frequently entrapped species (Table 7), it was apparent that entrapment could be relatively important for some species and life stages, but there was great annual variability.

For example, in 1985 approximately two-thirds of all alewives entrapped or impinged were entrapped larvae (Table 7). Likewise, over 96% of rainbow smelt either entrapped or impinged were entrapped juveniles. Annual variations likely were related to population size or spatial distribution in Lake Ontario. In almost all cases, however, the estimated total number of fish entrapped or impinged at Somerset Station was relatively low compared to impingement and entrainment rates observed at other steam electric generating stations. The low numbers at Somerset Station undoubtedly reflect the intake design, station siting and reduced water withdrawal rates.

Table 7
Maximum estimated annual entrapment (E) at Somerset Station for the six most commonly entrapped species, 1985–1989

Species	Lifestage	Year	Maximum E	% of total[a]
Alewife	Egg	1985	79,262	24.4
	Larva	1985	216,684	66.7
	Juvenile	1987	2761	7.1
Emerald shiner	Larva	1986	5332	22.8
	Juvenile	1986	15,895	67.8
	Adult	1986	1553	6.6
Mottled sculpin	Larva	1988	7882	71.7
	Juvenile	1985	3257	35.1
	Adult	1985	4561	49.1
Rainbow smelt	Egg	1985	96,136	21.8
	Larva	1985	9251	2.1
	Juvenile	1986	991,774	96.5
	Adult	1986	1818	0.2
Spottail shiner	Juvenile	1988	20,466	95.1
	Adult	1989	2545	13.1
Tesselated darter	Larva	1989	3189	38.6
	Juvenile	1986	7161	81.7
	Adult	1987	1618	73.5

[a] Percentage of the combined estimated totals of entrapment and impingement of the species (all life stages) in that year.

Alewife and rainbow smelt were the only species having 96-h survival rates considerably less than 50% at Somerset Station. Low survival rates have been observed for these two species at other steam electric generating stations using standard mesh screens or alternative screen designs. Direct comparison of survival data from these other facilities to the Somerset Station data is difficult because of varying holding times, seasons, sampling and fish handling methods, and analytical methods. Nevertheless, qualitative comparisons can be made.

For rainbow smelt, 96-h survival observed for impingement on conventional traveling screens at Bowline Point Generating Station ranged from 2% for young-of-the-year to 17% for adults (EA, 1982). Rainbow smelt impinged on conventional traveling screens at the Thunder Bay Generating Station and held for 165–181 h had a 41.1–60.5% survival rate (Beak, 1980). For unmodified Ristroph-type traveling screens at Unit 2 of Indian Point Generating Station, the 96-h impingement survival rate based on a small sample size was estimated to be 44% (Con Edison, 1986). Seasonal 24-h survival rates from Beaudrey-type dual-flow screens at Dunkirk Steam Station during testing in 1987 varied from 91.2% in winter to 53.6–90.3% in the spring and 12.2–58.6% in the fall (Beak, 1988). The 96-h entrapment and impingement survival rates at Somerset Station are similar or superior to these survival rates for other facilities. Survival appears to be the greatest for rainbow smelt adults during the spring.

For alewife, survival rates after extended holding periods (up to 96 h) following impingement also have been consistently low at facilities other than Somerset Station. The 24-h survival rate for young-of-the-year alewife at Dunkirk Steam Station in the fall of 1987 was 4.1% (Beak, 1988). The 48-h survival rate from conventional screens at the Albany Steam Generating Station ranged from 0% in the summer and fall to a maximum of 15% in the spring (LMS, 1985). The 96-h survival rates recorded from Bowline Point (EA, 1982) and from unmodified Ristroph-type screens at Indian Point (Con Edison, 1986) were 3–9% and 8%, respectively. When the Ristroph screens at Indian Point were modified using redesigned fish buckets and spraywash systems, 8-h survival rates for alewife increased from 2 to 38% (Fletcher, 1990).

Fine mesh screens have been tested at facilities other than Somerset Station, such as Big Bend Station in Tampa (Brueggemeyer et al., 1988), Prairie Island Nuclear Generating Plant in Minnesota (NSP, 1988), and Brunswick Steam Electric Station in North Carolina (CP&L, 1985). The species tested included both freshwater and saltwater species. The results were promising for all but the most fragile species, but the survival rates may not have exceeded the expected survival if these organisms had been entrained through the circulating water system.

For many species, the survival of juvenile and small adult fish on the 1-mm mesh screens at Somerset Station rivaled that of larger fish that would be impinged on 9.5-mm mesh screens, i.e., 70% or greater survival over 96 h. Species with lower survival, such as alewife and rainbow smelt, had entrapment survival rates that were similar to their impingement survival rates. Thus it appears that the 1-mm mesh screens provide protection for small fish that otherwise would have been entrained and killed.

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