Mortality of Adult American Shad Passing Through a 17-Megawatt Kaplan Turbine at a Low-Head Hydroelectric Dam

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B. Kynard
University of Massachusetts Amherst

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Mortality of Adult American Shad Passing Through a 17-Megawatt Kaplan Turbine at a Low-Head Hydroelectric Dam[1]

CHARLES E. BELL AND BOYD KYNARD

Massachusetts Cooperative Fishery Research Unit
Holdsworth Hall, University of Massachusetts
Amherst, Massachusetts 01003

ABSTRACT

In May 1982, we investigated the mortality of pre-spawning American shad (*Alosa sapidissima*) over a 5-hour period after passage through the 17-megawatt Kaplan turbine at Holyoke Dam, Connecticut River, Massachusetts. Radio telemetry was used to determine the survival of 36 test fish during 7 experiments by comparing their movement patterns with those of 21 sacrificed fish that were also passed through the turbine. Sixty-nine control fish fitted with dummy tags were released and held in an instream net for direct observation of mortality due to handling, tagging, and introduction procedures. The mean turbine mortality ($\bar{N}_T$) was 21.5% (95% confidence limits of 3.3–36.2%). Similar preliminary experiments with post-spawned American shad indicated that mortalities during their normal outmigration should be higher than the mortality estimate for pre-spawned fish.

Recent interest in hydroelectric dam development on the east coast, particularly for small-scale facilities less than 15 megawatts (MW) (Watson 1979), has fostered renewed research on turbine-induced mortality of anadromous fish. Most fishery work associated with hydroelectric dams concentrated on providing upstream fish passage facilities that ensured access to spawning and rearing areas for anadromous and catadromous fishes. Consequently, information on the effects of hydroelectric dams on most species during outmigration is limited. Bell (1982) and Turback et al. (1981) provided comprehensive reviews of research on turbine-induced fish mortality. Most of these investigations dealt with juvenile salmonids (*Oncorhynchus* spp.) on the west coast, where mortality at hydroelectric turbines represents a reduction in the population at a life-history stage that does not allow for any biological compensation against such losses (Ricker 1954). Few studies have utilized adult fish because it was assumed they would be prevented from entering turbine intakes by screens or trash racks or, in the case of *Oncorhynchus* spp., die after spawning (semelparous).

Except for the sea lamprey (*Petromyzon marinus*), all anadromous fish on the east coast are repeat spawners (iteroparous). Repeat spawning is an important component of the total reproductive adaptation of American shad (*Alosa sapidissima*) and contributes to the maintenance of long-term stability of a population in unpredictable environments of spawning streams (Leggett 1967; Glebe and Leggett 1981). The degree of iteroparity increases with latitude of east coast rivers such that spawning populations of American shad entering the St. John (New Brunswick) and Miramichi rivers are composed of 60–80% repeat spawners (Leggett and Carscadden 1978). Estimates of the percentage of repeat spawners entering the Connecticut River range from 20 to 55%, depending on previous year-class strength (Fredin 1954; Leggett and Carscadden 1978; Crecco et al. 1981). Repeat spawners also represent a significant portion of the commercial catch in the Connecticut River due to selectivity of fishing gear for larger fish (Leggett 1976; Crecco et al. 1981). To maintain American shad runs in the Connecticut River with normal frequencies of repeat spawners during a restoration program where increasing numbers of adults are being passed upstream at Holyoke Dam (Moffitt et al. 1982), fishery managers need information on survival of adults during their outmigration past the dam. Post-spawned American shad begin appearing at Holyoke in early June when

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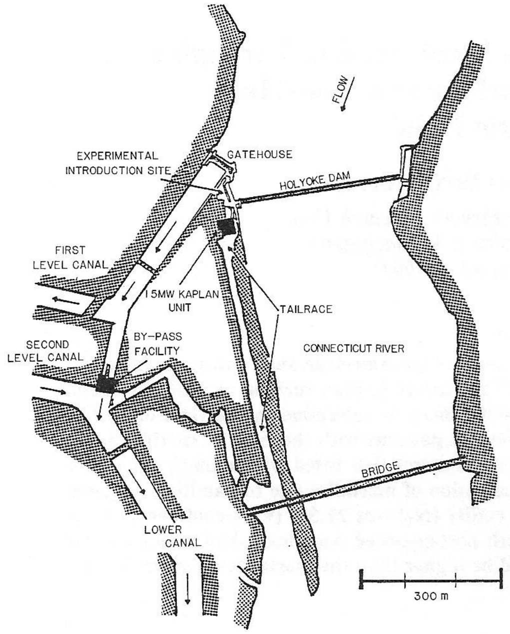

Figure 1. Location of dam and canal system at the Hadley Falls Station powerhouse on the Connecticut River at Holyoke, Massachusetts.

spillage over the dam is minimal or non-existent. As a result, all fish either pass through a Kaplan hydroelectric turbine and its associated structures, or enter an adjacent canal system (Fig. 1). Once into the canal system, they either enter a downstream fish passage facility and return directly to the river (O'Leary and Kynard 1981; Taylor and Kynard 1983), or pass through two other turbines before reaching the river.

The objective of this study was to use radio telemetry to determine the immediate turbine-related mortality of adult American shad passed through the conventional 17-MW Kaplan turbine at Holyoke Dam in the Connecticut River, Massachusetts. Immediate mortality was defined as mortality that occurred within 5 hours after turbine passage. Studies of adult American shad survival after passing through hydroelectric turbines were done on the Susquehanna River in 1958–1960. Whitney (1961) used mark-recapture techniques and estimated less than 50% survival of fish to time of recapture. Procedural difficulties of the study make the estimate questionable. Mark-recapture techniques were not used in the present study because recapture nets could not be set below Holyoke Dam without possibly impinging and killing other important anadromous species, particularly Atlantic salmon (*Salmo salar*). Radio telemetry was selected as a more economical and practical approach.

Methods

Holyoke Dam is located at river kilometer 139 on the Connecticut River. It was built in 1849 to provide water for an extensive canal system. The Holyoke Water Power Company was formed in 1859 and, as early as 1885, electrical generators were installed in mills owned by the company. The 17-MW Kaplan turbine built by Allis-Chalmers Corporation, York, Pennsylvania was installed in a powerhouse at Holyoke Dam in 1951 and designated Hadley Falls Station No. 1 Unit. Additional information on Holyoke Dam and associate canal systems is provided in Moffitt et al. (1982).

Experiments were conducted from May 10 to 19, 1982 during the period of natural upstream migration of American shad. The results of experiments in which spent American shad were passed through the turbine in 1981 suggested that pre-spawning rather than spent fish should be used to eliminate problems of fish availability and mortality associated with handling and temperature-induced stress (Knapp et al. 1982). Fish used in the experiments were divided into test, sacrificed, and control fish groups. Test fish and sacrificed fish were released simultaneously into the turbine penstock via an introduction apparatus and observed remotely by radio telemetry (Fig. 2). The drift or downstream movement of sacrificed fish established a distribution for dead fish that could be compared with the movements and distribution of individual test fish. In this way, test fish that were killed were identified. Control fish were tagged with dummy radio tags and released through an identical introduction system that emptied into a circular net (2.45 m in diameter and 0.9 m deep; Fig. 3). Control fish were observed directly for a minimum of 5 hours. The introduction site for test and sacrificed fish was located over the gatewell opening of the penstock. Fish were released into the top 2 m of the water column parallel to the flow. The control fish introduction site was adjacent to the test fish site where fish were released into a holding pen located in the forebay in front of the trash racks (Fig. 2).

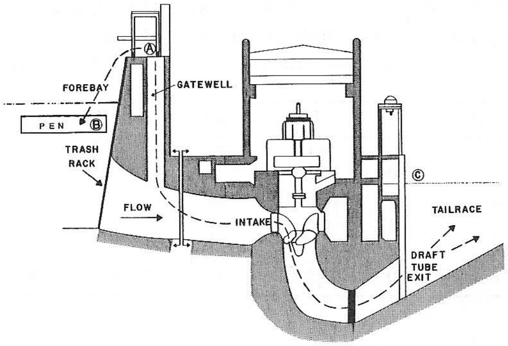

Figure 2. Kaplan turbine at Holyoke Dam showing introduction site (A) for test, control, and sacrificed fish and location of control fish holding pen (B). Dotted lines indicate pathways traveled by American shad.

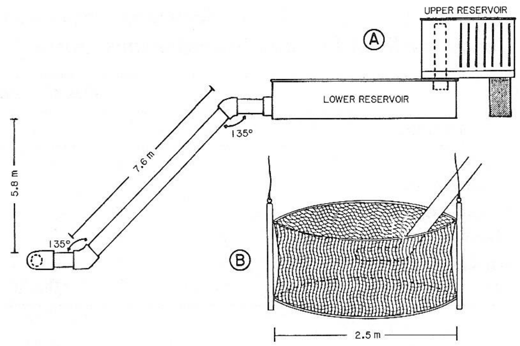

Figure 3. Introduction area consisting of (A) a 189-liter upper reservoir and 378-liter lower reservoir, and (B) holding pen for control fish.

Pre-spawned American shad were collected by dipnet from the fish-trapping facility of the Holyoke fishlift and transferred in 94-liter barrels to the 378-liter lower reservoir of each introduction system. Females, which composed 16% of the fish collected, ranged from 52–60 cm in total length (mean 56 cm); lengths of males ranged from 43–56.5 cm and averaged 50.3 cm. All measurements and sex determinations were made on the group of 69 control fish after the experiments were completed.

Radio transmitter construction was based on the design of Knight (1975). Each unit weighed 5.3–5.6 g in air, measured 3.3–3.6 cm long, and were 1.4–1.6 cm in diameter. Transmitters operated on a frequency from 30.05–30.25 megahertz (mHz) and lasted for approximately 3 days at an output of 0.8–1.0 millivolts. They were inserted into the esophagus of test and sacrificed fish while held under water in the lower reservoir of the introduction device. Fish in the sacrificed group were killed just before release by manually serving the spinal cord behind the head. Dummy tags of the same size and weight as the radio transmitters were inserted into the control fish. These tags enabled us to detect transmitter rejection and mortality associated with transmitter insertion.

After release, the survival of control fish was determined by visual observation. Test and sacrificed fish were located by radio telemetry as they exited the draft tube and their movements monitored continuously for a minimum of 5 hours. Quantitative measurements of movement distance and elapsed time from the draft tube exit were recorded periodically to evaluate differences in the rate of movement of test and sacrificed fish. Qualitative evaluation of fish movement relative to speed and direction of river current, river channel location, and instream barriers (as well as directional changes in radio transmitter signal) were recorded. This information was used to classify each test fish as alive or dead.

The instaneous mortality rate (M_T) for each experiment was computed by:

$$M_T = -\log_e(S_{TOT}/S_H)$$

where S_{TOT} is the percent survival of test fish and S_H is the percent survival of control fish. The mean instanteous mortality ($\bar{M}_T$) was transformed to mean percent survival (S_T) with:

$$S_T = e^{-\bar{M}_T}$$

The corresponding mean percent turbine mortality ($\bar{N}_T$) was calculated by:

$$\bar{N}_T = 1 - \bar{S}_T$$

Results

A total of 126 American shad were used in 7 days of experiments (Table 1). We introduced 36 test fish into the turbine at a power generation of 16.5–16.9 MW. Radio tracking revealed that all fish passed through the turbine within 1 minute after introduction. One transmitter in a test fish failed immediately and it was not included in the analysis. Of the remaining 35 American shad, 28 survived and moved upstream, down-

Table 1. Summary of American shad experiments showing the number introduced of test, control, and sacrificed fish and instantaneous mortality rate (M_T) for test fish during May 1982.

Fish group	Day of month							Totals	Mean ($\bar{M}_T \pm$ SD)
	10	12	13	14	16	18	19		
Test fish	5	5	5	5	5	5	5	35	
Number dead	2	2	0	1	1	0	1	7	
Control fish	9	10	11	10	9	10	10	69	
Number dead	0	0	0	0	0	1	0	1	
Sacrificed fish	2	1	3	2	2	3	3	16	
M_T	0.511	0.511	0	0.223	0.223	0	0.223		0.242 ± 0.208

stream, and/or laterally relative to flow. Seven fish died within 2 hours after introduction, resulting in a mean instantaneous mortality estimate ($\bar{M}_T$) of 0.242 for test fish. Although the test fish were followed for a minimum of 5 hours, no additional mortality was noted after 2 hours. The 69 control fish were introduced into the holding net during the same period: 1 fish died immediately and 68 survived at least 5 hours. $\bar{M}_T$, transformed to mean percent turbine mortality ($\bar{N}_T$), yielded an estimate of 21.5% with confidence limits of 3.3–36.2%, (df = 6, $P < 0.05$) for test fish.

Among the 21 sacrificed fish that were released into the turbine penstock with test fish, 1 transmitter failed immediately and 4 failed within 3 hours. Elapsed time and corresponding drift distances of the remaining 16 fish were monitored for at least 24 hours. Sacrificed fish settled to the river bottom in an area of reduced flow between 0.6 and 1.3 km downstream from the draft tube exit. All test fish that were designated "mortalities" were located within the downstream distribution of sacrificed fish.

After an intitial downstream movement of 0.7–16.5 km within 8 hours after release, 19 of 28 live test fish moved upstream 0.4–11.8 km within 46 hours. Five fish moved up the tailrace to within 0.3 km of the draft tube exit.

Discussion

After internally tagging pre-spawned American shad with sonic tags (Leggett 1967) or with radio tags (Barry and Kynard 1982), fish swam or passively drifted downstream with the current immediately after release. Many of them resumed "normal" upstream migration after a short period of time. Pre-spawned test fish used in this study made similar initial downstream movements of 0.8–16.5 km, after which 68% moved upstream within 46 hours. The resumption of upstream movements by the fish suggested that they recovered from the experience within 2 days. The remaining 32% of the surviving test fish moved downstream at least 15 km below the draft tube exit and did not move upstream over the same period. We do not know whether or not these fish survived to spawn downstream, moved back upstream at some time after the radio transmitters had failed, or died and represent a delayed mortality component. Control fish exhibited schooling behavior and oriented themselves into the current immediately upon release into the holding net, suggesting that a minimal amount of stress or disorientation resulted from the introduction process. Further work is needed to quantitatively describe the long-term effects of turbine passage on adult American shad in terms of stress and delayed mortality, especially in those river systems where multiple turbine passage is required to complete outmigration.

These experiments were conducted in May 1982 during the early part of the upstream migration when water temperatures averaged 14.3 C. Normal downstream migration of spent American shad occurs later in June when water temperatures exceed 20 C (Leggett 1972). American shad are in a state of general physical deterioration during outmigration, their somatic weight losses ranging from 44–51% (Walburg 1960; Leggett 1972). Several investigators who have captured fish for biotelemetry, noted the difficulty of successfully handling post-spawned American shad at temperatures above 20 C (Dodson et al. 1972; Leggett 1976). Thus, estimates of turbine-related mortality of American shad also should vary with the environmental conditions (particularly water temperature) and general physical condition of the fish. Also, our experiments were conducted at power generation levels near peak turbine operating efficiency (16.5–16.9 MW) when cavitation was relatively low and wicket gate openings high (79–81.5%). A reduction in operating efficiency would result in an increase in turbine-related mortality (Turback et al. 1981). Because we used pre-spawning fish in excellent condition, worked at water temperatures below 20 C, and performed experiments during periods of efficient turbine operation, the 21.5% mean estimate of mortality represents a minimum estimate.

Another series of turbine mortality experiments provides a guide to the level of mortality that might be expected during higher water temperatures using post-spawned American shad. In June 1981, we conducted experiments similar to the ones already discussed at Hadley Falls Station Unit No. 1, using spent fish collected during their normal outmigration (Knapp et al. 1982; Bell 1982). Water temperatures averaged 20.9 C during the experiments and we found it difficult to handle fish without killing them. Seven of 18 control fish and 10 of 20 test fish died during the 7 experiments. Because of the high mortality in the control group, we were unable to calculate instantaneous mortality rates for the test fish group. These data failed to result in a mortality estimate but they emphasized the high level of mortality that can be caused by the routine capture and handling of spent fish for experiments, and suggested that less than 50% of all spent fish died after a single turbine passage. To minimize mortalities, the delay and stress of spent fish at hydroelectric dams should be minimized by operating turbines near peak efficiency during the outmigration period.

The impact of turbine passage on the spawning population of American shad above Holyoke Dam is dependent upon the number of fish that actually pass through the Kaplan unit, as opposed to entering the canal system or moving over the spillway. The trash racks in front of the Kaplan turbine should not prevent turbine passage since American shad pass through trash racks with openings 5 cm less than that of the Kaplan unit under investigation (O'Leary and Kynard 1981). The relative proportion of fish entering the Kaplan turbine probably will increase in future years. A second Kaplan turbine at Hadley Falls Station will be operational by 1984 effectively doubling the volume of water that can be passed through the two turbines. This volume of water will approximately equal that entering the adjacent canal system which presently appears to attract most of the spent fish. The increased flow entering the two Kaplan turbines will attract more spent fish and increase the proportion of fish passing through the turbines and decrease the proportion entering the canal where they may be by-passed (O'Leary and Kynard 1981, 1982), or pass through two turbines before re-entering the river. Also, during 3 of the last 5 years there has been spillage over the dam during at least the early period of downstream migration. This water now can be used to run the new turbine unit and, if this is done, it will effectively eliminate spillage in most years as a route for downstream migrants. Future concerns for the survival of spent adult American shad should include preventing fish from entering the two turbines at Holyoke Dam and those on the canal and increasing the effectiveness of the by-pass system in the canal.

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References

Barry, T., and B. Kynard. 1982. Movements of adult American shad (*Alosa sapidissima*) in the Holyoke Dam tailrace during spawning migration. Final Report to Northeast Utilities Service Company, Berlin, Connecticut, USA.

Bell, C. E. 1982. Immediate mortality of adult American shad (*Alosa sapidissima*) resulting from passage through a Kaplan turbine at Holyoke Dam, Massachusetts. Master's thesis, University of Massachusetts, Amherst, Massachusetts, USA.

Crecco, V., L. Gunn, and T. Savoy. 1981. Connecticut River American shad study, 1980. Final Report AFC-12 (Connecticut) submitted to National Marine Fisheries Service, Woods Hole, Massachusetts, USA.

DODSON, J. J., W. C. LEGGETT, AND R. A. JONES. 1972. The behavior of adult American shad (*Alosa sapidissima*) during migration from salt to fresh water as observed by ultrasonic tracking techniques. Journal of the Fisheries Research Board of Canada 29:1445–1449.

FREDIN, R. A. 1954. Causes of fluctuations in abundance of Connecticut River American shad. U.S. Fish and Wildlife Service, Fishery Bulletin 54:247–259.

GLEBE, B. D., AND W. C. LEGGETT. 1981. Temporal, intra-population differences in energy allocation and use by American shad (*Alosa sapidissima*) during the spawning migration. Canadian Journal of Fisheries and Aquatic Sciences 38:795–805.

KNIGHT, A. E. 1975. A tuned-antenna radio-telemetry tag for fish. January Underwater Telemetry Newsletter, Electrical Engineering Department, University of New Brunswick, Fredericton, New Brunswick, Canada.

KNAPP, W. E., B. KYNARD, AND S. P. GLOSS. 1982. Potential effects of Kaplan, Ossberger, and Bulb turbines on anadromous fishes of the northeast United States. FWS/OBS-82/62. U.S. Fish and Wildlife Service, Newton Corner, Massachusetts, USA.

LEGGETT, W. C. 1967. A study of the rate and pattern of American shad migration in the Connecticut River—utilizing sonic tracking apparatus. Progress Report, Contract AFC-1, Bureau of Commercial Fisheries, Woods Hole, Massachusetts, USA.

LEGGETT, W. C. 1972. Weight loss in American shad (*Alosa sapidissima*) during the freshwater migration. Transactions of the American Fisheries Society 101:549–552.

LEGGETT, W. C. 1976. The American shad (*Alosa sapidissima*) with special reference to its migration and population dynamics in the Connecticut River. Pages 169–225 *in* D. Merriman and L. M. Thorpe, editors. The Connecticut River ecological study. Monograph No. 1, American Fisheries Society, Bethesda, Maryland, USA.

LEGGETT, W. C., AND J. E. CARSCADDEN. 1978. Latitudinal variation in reproductive characteristics of American shad (*Alosa sapidissima*); evidence for population-specific life history strategies in fish. Journal of the Fisheries Research Board of Canada 35:1469–1478.

MOFFITT, C. M., B. KYNARD, AND S. G. RIDEOUT. 1982. Fish passage facilities and anadromous fish restoration in the Connecticut River basin. Fisheries (Bethesda, Maryland) 7(6):1–10.

O'LEARY, J., AND B. KYNARD. 1981. Holyoke Dam fishery studies—1980. Report to Northeast Utilities Service Company, Berlin, Connecticut, USA.

O'LEARY, J., AND B. KYNARD. 1982. Holyoke Dam fishery studies—1981. Report to Northeast Utilities Service Company, Berlin, Connecticut, USA.

RICKER, W. E. 1954. Stock and recruitment. Journal of the Fisheries Research Board of Canada 11: 559–623.

TAYLOR, R., AND B. KYNARD. 1983. Holyoke Dam fishery studies—1983. Report to Northeast Utilities Service Company, Berlin, Connecticut, USA.

TURBACK, S. C., D. R. REICHLE, AND C. R. SHRINER. 1981. Analysis of environmental issues related to small-scale hydroelectric development: IV. Fish mortality resulting from turbine passage. Environmental Sciences Division Report ORNL/TM 7861. Oak Ridge National Laboratory, Oak Ridge, Tennessee, USA.

WALBURG, C. H. 1960. Abundance and life history of American shad, St. Johns River, Florida. U.S. Fish and Wildlife Service, Fishery Bulletin 60:487–501.

WATSON, J. H. 1979. The role of small-scale hydropower in emerging energy policy. Pages 1–7 *in* Waterpower '79: Proceedings of the first international conference on small-scale hydropower, October 1–2, 1979, Washington, D.C., Superintendent of Documents, U.S. Government Printing Office, Washington, D.C., USA.

WHITNEY, R. R. 1961. The Susquehanna fishery study, 1957–1960. A report of a study on the desirability and feasibility of passing fish at Conowingo Dam. Contribution 169. Maryland Department of Resource Education, Solomonds, Maryland, USA.