THERMAL EFFECTS OF A MODEL POWER PLANT ON THE HATCHING SUCCESS OF AMERICAN SHAD, *ALOSA SAPIDISSIMA*, EGGS

J. R. Schubel
A. H. Auld
Chesapeake Bay Institute
The Johns Hopkins University
Baltimore, Maryland 21218

ABSTRACT

A model power plant, constructed to simulate the time-temperature exposure histories experienced by organisms entrained in the intake of an actual plant, was used to study the thermal effects of an operating power plant on the hatching success of American shad, *Alosa sapidissima*, eggs. Eggs from a single female were divided into 5 sub-samples; two controls, and three experimental batches. One control was stocked immediately in a constant temperature bath. The second control was passed through the unheated plant to assess the mechanical effects of passage through the model plant on hatching success. The experimental batches of eggs were passed through the operating plant set to produce a Δ T of about 6°C, and were cooled at different rates to the intake temperature of 18.5°C. Exposure times to a Δ T of at least 6°C ranged from 5 to approximately 15 minutes, and the cooling period from 1 hour to nearly 3 hours. The hatching success of each of the controls was 88%, and it ranged from 82% to 84% for the experimental batches, being highest for the sub-sample with the shortest exposure to elevated temperature. The differences in the hatching success of the controls, and the experimental batches were however, not statistically significant.

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INTRODUCTION

Although there has been a considerable amount of research on the effects of temperature on fish and other aquatic organisms (see, for example, the bibliographies by Coutant, 1968, 1969, 1970, 1971; Kennedy and Mihursky, 1967), there has been relatively little work on the effects of temperature on the hatching success of fish eggs, and very little of this research is of any significant value in making predictions of the thermal effects of power plants on the hatching success of any species of fish eggs. In nearly all of the fish egg experiments described in the published literature the eggs were subjected to elevated temperatures for almost the entire incubation period (e.g. Kelley, 1968; Bradford, *et al.* 1968). Until recently little effort has been made to subject fish eggs, or any other organisms, to time-temperature histories similar to those experienced in connection with operating power plants. Hoss, *et al.* (1971) studied the effects of thermal increases encountered by post-larval and juvenile estuarine fishes entrained in power plant cooling systems, and Mihursky (personal communication, 1972) and his co-workers are conducting experiments with shellfish eggs and larvae.

Planktonic organisms, including fish eggs, may be drawn into the cooling water intake of a plant, passed through the condensers, and discharged back into the environment; or they may be entrained into the thermal plume along with the diluting water without having passed through the plant. The organisms that pass through the plant are initially subjected to a very rapid rise in temperature approximately equivalent to the temperature rise across the condensers. They are exposed to this excess temperature during passage through the plant and to the point of discharge, and then to decreasing temperatures as they are carried down the plume. In the near field the rate of cooling along the plume is determined almost entirely by the intensity of the lateral and vertical mixing. Planktonic organisms that are entrained in the thermal plume without having passed through the plant are subjected to a less rapid rise in temperature and to somewhat lower excess temperatures. The actual time-excess temperature exposure histories experienced by planktonic organisms will vary from plant to plant, and to a much smaller extent with time at any given plant. The time-temperature exposure histories depend upon the design of a plant's intake-discharge system which is, of course, influenced by state temperature regulations, upon the circulation of the receiving waters, and upon the plant's operating load.

We have studied the effects of some "typical" time-excess temperature exposure histories — typical at least in the Chesapeake Bay region[1] — on the hatching success of *Alosa sapidissima* eggs.

METHODS

A model power plant, Fig. 1, was constructed to simulate the time-temperature exposure histories experienced by planktonic organisms that are either passed through the once-through cooling system of an actual plant, or are entrained in the thermal plume without having passed through the plant. The model plant was not designed to simulate the mechanical effects of passage through an actual plant, and the effects of chlorine were not investigated.

The plumbing system of the model plant was fabricated from 2.54 cm (1.0 in.) diameter copper tubing. Electric immersion heaters were used to simulate the condensers of an actual plant. The plant's power line was connected to a heavy duty rheostat, and the desired ΔT between the intake and the discharge was achieved by adjustment of the rheostat. This setting would obviously change with flow rate, but a uniform flow rate of about 63 cm^3/sec (1 gal min^{-1}) was maintained with a simple constant head device. This flow rate resulted in a travel time through the plant of about 30 seconds. The intake and discharge temperatures were monitored with in-line thermistors, Fig. 1.

Eggs were stripped in the field from a single female and artificially fertilized in a finger bowl with the milt from several males. After several minutes the eggs were thoroughly rinsed, transferred to a plastic bucket, and put in an insulated chest for transportation to the laboratory. The average temperature in the spawning grounds was about 16.5°C. The bucket temperature had risen to 18.5°C by the time the laboratory was reached. At the laboratory the eggs were placed in a constant temperature bath set at this temperature, 18.5°C. Eleven hours after fertilization five sub-samples, each of approximately 200 viable eggs, were withdrawn. Most of the eggs were in the early blastula stage of development; a few were in late morula. One sub-sample was placed in a modified hatching box with a nylon mesh bottom and immediately returned to

[1] H. H. Carter, personal communication, 1972.

the constant temperature bath to serve as a control, Control 1. A second sub-sample, Control P, was passed through the *unheated* plant before incubation to assess the *physical* effects of passage through the plant on the hatching success. The remaining three sub-samples of eggs were passed through the *heated* plant, cooled to the intake temperature at different rates, and incubated in the constant temperature bath until hatching.

At the beginning of the experiment water was passed through the plant until the desired Δ T between the intake and discharge was attained. This flow was continued and a sub-sample of eggs was added to the cooling water. After passage through the plant the eggs were collected by passing the discharge water through a hatching box with a nylon mesh bottom that was held in a plastic bucket. The water level in the bucket was maintained with a siphon and the flow through the plant was continued for approximately 2 minutes after all eggs had been collected. The bucket of water containing the hatching box and eggs was then placed in a large water bath and cooled to the intake temperature, 18.5°C, by adding ice to the holding bath. During cooling the sample was aerated and stirred gently. After reaching the intake temperature the hatching box was transferred to a 57 liter (15 gallon) aquarium held in a constant temperature bath set at the intake temperature. The water in the aquarium was continuously aerated and gently agitated, and was completely replaced every 48 hours by small additions every 30 minutes throughout the incubation period. All of the water used in the experiment was collected from the spawning grounds.

The time-temperature curves for the three test runs are depicted in Fig. 2. The temperatures were measured with a thermistor at least every minute during the first 10 minutes of each run, and every 2-5 minutes for the remainder of the run.

During incubation dead eggs were periodically removed from each of the hatching boxes, counted, and preserved. At approximately 130 hours after fertilization, 119 hours after passage through the model plant, the experiment was terminated. At this time less than 14% of the total number of eggs at the start of the experiment remained unhatched and still viable. There was no evidenc of abnormal development in any of these eggs, and it was assumed in the calculations of hatching success that they had hatched.

RESULTS AND CONCLUSIONS

The absolute hatching success was calculated for each sub-sample, and the results are summarized in Table 1. The hatching success was the same, 88%, for each of the controls. The hatching successes of the three experimental sub-samples were slightly lower, 84%, 82%, and 82% with the highest of these being for Sub-sample A which had the shortest exposure time to elevated temperatures. A Chi-squared test of the results however, showed that the differences in hatching success were not significant. There was no evidence of abnormal egg or larval development, or of increased larval mortality following exposure of the eggs to the time-temperature histories depicted in Figure 2.

These results suggest that exposure of *Alosa sapidissima* eggs at the early blastula stage to similar time-temperature histories at an actual power plant would probably have little affect on hatching success or on egg development. Mechanical damage during passage through the condenser system of an operating plant and exposure to free chlorine and its derivatives in the plant, and in the receiving waters, probably have a much greater impact on the hatching success and development of eggs than the excess temperatures. The synergistic effects of elevated temperature and these other factors may also be important.

Table 1. Summary statistics of the effects of the time-excess temperature histories depicted in Figure 1 on the hatching success of *Alosa sapidissima* eggs.

Sub-Sample	Sample Size (No. of eggs)	Absolute Hatching Success (%)
Control 1[1]	201	88
Control P[2]	200	88
Sub-Sample A	203	84
Sub-Sample B	200	82
Sub-Sample C	203	82

[1]Eggs were not passed through model plant.
[2]Eggs were passed through *unheated* plant.

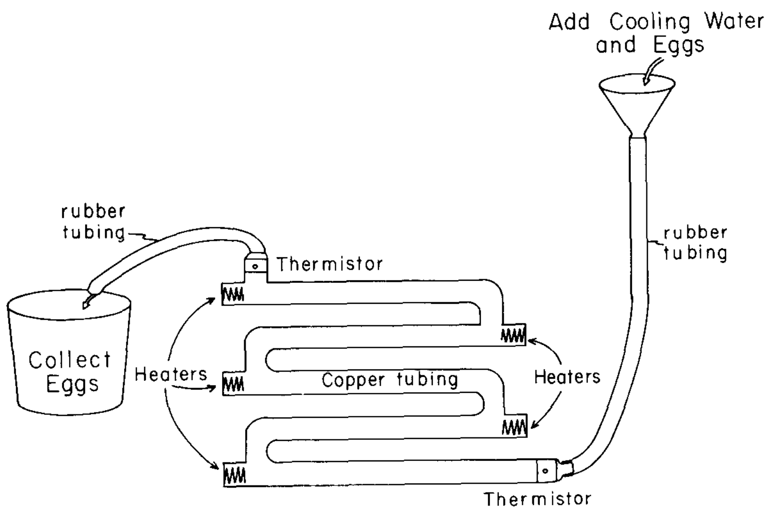

Figure 1. Sketch of model power plant used in experiment.

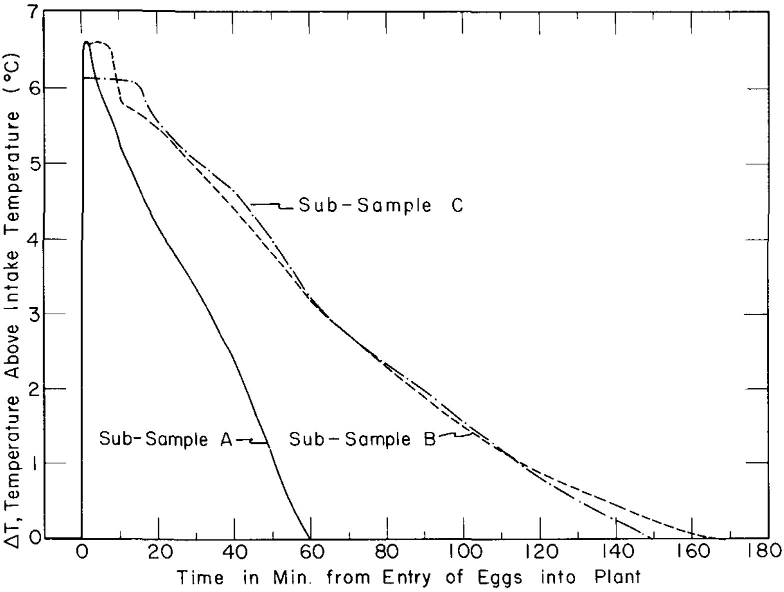

Figure 2. Time-excess temperature exposure histories of the three sub-samples of eggs. The temperature above the intake temperature, 18.5° C, is plotted against the time in minutes from the time of entry of the eggs into the plant.

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