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MORTALITIES OF ATLANTIC HERRING, *CLUPEA H. HARENGUS*, SMOOTH FLOUNDER, *LIOPSETTA PUTNAMI*, AND RAINBOW SMELT, *OSMERUS MORDAX*, LARVAE EXPOSED TO ACUTE THERMAL SHOCK

Entrainment of larval fishes through condenser cooling systems of electric generating stations often results in acute physical, chemical, and thermal stresses. These stresses are often lethal and the resulting mortalities could have adverse effects on populations proximal to the cooling water intake site. This is particularly true for fishes which have planktonic larvae (Schubel et al. 1978).

The rapid increase in temperature associated with passage through condenser cooling systems is seldom if ever experienced by organisms in the natural environment. Little is known of the ability of the larvae of most species of fish to withstand this kind of thermal stress. In assessing thermal stresses it is important not only to investigate the effect of different increases in temperature from some base temperature (ΔT), but also to investigate the effect of the duration of the exposure. The simplest simulation experiment, then, is one in which larvae are exposed to a rapid increase in temperature, are held at the elevated temperature for a period of time, and are then returned rapidly to the original base temperature.

Our experiments were designed to evaluate the thermal tolerances of three species of larval fish occurring in the Gulf of Maine and its estuaries: Atlantic herring, *Clupea h. harengus*, smooth flounder, *Liopsetta putnami*, and rainbow smelt, *Osmerus mordax*. These fish, although differing somewhat in their life histories, are all common in inshore areas during some part of their larval life, and are therefore subject to power plant entrainment. This paper presents the results of thermal tolerance experiments which encompassed the range of temperatures planktonic organisms encounter in condenser cooling systems.

Methods

All larvae used in the experiments were reared in the laboratory. Atlantic herring eggs and milt were stripped from ripe adults captured off Gloucester, Mass. The eggs were fertilized and held in 2 l shallow glass bowls of filtered seawater (31.8‰) at approximately the ambient temperature where the adults were collected (8°±1° C). Most of the larvae hatched after 13 d. Ripe adult smooth flounder were collected from Montsweag Bay, part of the Sheepscot River estuary, Maine. Eggs and milt were stripped from the adults, the eggs fertilized, and also kept in 2 l shallow glass bowls of filtered seawater (25.5‰) at the ambient temperature (4°±1° C). The larvae began to hatch after 21 d but the majority hatched after 27 and 28 d. Fertilized rainbow smelt eggs were collected directly from a spawning site in Wiley Brook, a tributary of the Damariscotta River estuary, Maine. The eggs were kept in 40 l aquaria with filtered brook water at the ambient temperature (13°±1° C). The brook water was treated with streptomycin and penicillin according to methods described in Shelbourne (1964) and malachite green hydrochloride was added to control fungal growth. Some of the rainbow smelt larvae began to hatch immediately upon collection but most hatched 2 and 3 d later.

Thermal tolerance experiments were performed using a thermal gradient apparatus. Details of the design and the operating characteristics are given in Barker and Stewart (1978). In each experiment groups of 10-15 larvae were transferred from the ambient temperature water to test tubes containing 25 ml of water at the test temperatures in the thermal gradient apparatus and were exposed for 5-60 min. After exposure the larvae were returned to the ambient water. The addition of the larvae to the apparatus also involved the addition of about 5 ml of ambient temperature water which resulted in a slight lowering of the test temperatures. About 10-15 min were needed for the test temperatures to be reached again, so the temperatures given in the results section for the 5 min exposures were those reached after 5 min.

A control was maintained outside of the thermal gradient apparatus for all experiments. These larvae were held at ambient temperatures and were subjected to the same handling procedures as those larvae which received the exposures to elevated temperatures.

All larvae were observed for mortality 2 h after testing, at which time any dead larvae were removed. The remaining larvae were observed again after 24 h. Dead larvae could usually be recognized by their opaque appearance and any larvae that showed no movement when prodded were also considered dead.

Each experiment was replicated once for the smooth flounder larvae and the Atlantic herring larvae. The replicate experiments were performed for the rainbow smelt larvae in brook water and also in seawater (28.8‰, after acclimation for 1 d at 13°±1° C). All larvae tested were <5 d old and had yolk sacs.

Results

The results of all experiments are presented in Table 1. The Atlantic herring larvae were exposed to ΔT's ranging from 16° to 25° C for exposures of 5, 15, 30, and 60 min. It appears that the larvae acclimated to 8° C survived ΔT's up to 17° C for up to 60 min. The larvae survived higher temperatures at shorter exposure times. In all cases, except the 5 min exposures, the mortalities increased from approximately 0 to 100% over a range of 2° C.

The smooth flounder larvae were exposed to

TABLE 1.—Percentage mortalities of larvae of Atlantic herring, *Clupea h. harengus*, smooth flounder, *Liopsetta putnami*, and rainbow smelt, *Osmerus mordax*, in fresh and saltwater, under different time-temperature combinations. Values for each of the replicate experiments are listed. The temperature values in parentheses indicate the adjusted temperatures for the 5 min exposures as explained in the text.

Species	Time (min)	Temperature (° C)					
		[1]8.0	25.0 (24.0)	27.0 (26.0)	29.1 (27.9)	31.0 (29.8)	33.0 (32.7)
Clupea h. harengus	5	0	0	0	0	76.5	100
		0	0	0	6.7	18.8	100
N = 704	15	—	0	0	6.7	100	100
		0	0	0	12.5	100	100
	30	6.7	0	0	100	100	100
		0	0	0	100	100	100
	60	7.1	6.7	81.2	100	100	100
		0	0	100	100	100	100
		[1]4.0	25.4 (24.0)	27.6 (25.2)	29.8 (28.4)	32.0 (30.5)	34.2 (33.9)
Liopsetta putnami	5	0	0	6.7	26.7	46.7	100
		0	0	6.7	20.0	100	100
N = 525	30	6.7	20.0	0	90.9	100	100
		6.7	6.7	18.8	68.8	100	100
	60	0	0	80.0	100	100	100
		6.2	7.7	26.7	100	100	100
		[1]13.2	24.9 (24.5)	26.8 (26.6)	28.8 (28.6)	30.8 (30.6)	32.6 (32.4)
Osmerus mordax	5	6.7	0	0	7.1	0	100
		0	6.7	0	7.1	7.1	100
(fresh-water)	30	0	0	0	0	100	100
		0	0	0	40.0	100	100
N = 525	60	6.7	0	0	57.1	100	100
		0	0	0	62.5	100	100
		[1]13.0	24.9 (24.5)	26.9 (26.7)	28.8 (28.6)	30.8 (30.6)	32.6 (32.4)
Osmerus mordax	5	0	14.3	0	11.1	11.1	100
		20.0	0	22.2	27.3	40.0	100
(salt-water)	30	10.0	60.0	50.0	100	100	100
		10.0	40.0	50.0	100	100	100
N = 346	60	20.0	50.0	90.9	100	100	100
		50.0	40.0	88.9	100	100	100

[1]Control (ambient temperatures).

ΔT's ranging from 20.0° C to 30.2° C for exposures of 5, 30, and 60 min. The larvae acclimated to 4° C survived ΔT's up to 21.4° C for 60 min with negligible mortality. The mortalities increased from approximately 0 to 100% over a range of about 5° C in the 30-60 min exposures. At the 5 min exposure mortality increased from 6.7% (considered background mortality) to 100% over a 8.7° C range (25.2°-33.9° C).

The rainbow smelt larvae held in freshwater were exposed to ΔT's ranging from 11.3° to 19.4° C for exposure times of 5, 30, and 60 min. The larvae survived a ΔT of 13.6° C for up to 60 min, and at exposures of shorter duration the larvae survived higher exposure temperatures. For exposures of 30-60 min the mortalities increased from 0 to 100% over a range of 4.0° C (26.8°-30.8° C). This range was 1.8° C for the 5 min duration exposure.

The rainbow smelt larvae which had been acclimated in seawater at 13°±1° C, after hatching in freshwater, were exposed to ΔT's ranging from

11.9° to 20.9° C for exposure times of 5, 30, and 60 min. The lowest ΔT at which 100% mortality was observed was 15.8° C. This occurred in larvae exposed 30 and 60 min. In the case of the 5 min exposure, some larvae survived up to a 19.4° C ΔT before experiencing 100% mortality. There was a high background mortality in these experiments which was probably due to stress resulting from the immediate transfer of larvae to seawater 1 d prior to treatment. This was not an unnatural stress, however, since in nature the larvae are immediately washed from the brook into the estuary, <50 m away, once they hatch from the adhesive eggs.

Discussion

The larvae of all three species appear to be able to survive ΔT's of short duration which are near the upper limits of cooling systems in most normally operating nuclear power plants (18.6° C, Schubel et al. 1978). Our results show that the Atlantic herring larvae are much more tolerant to brief (<60 min) increased temperature exposures than to the longer term exposure (24 h) reported by Blaxter (1960). It should be noted that Atlantic herring larvae are usually older and developed beyond the yolk-sac stage when they arrive at the inshore nursery areas from the spawning grounds and the results of these experiments should be considered in light of that fact. Smooth flounders, on the other hand, spawn in the estuaries and inshore areas of the Gulf of Maine and the larvae are susceptible to entrainment by power plants at an early age.[1] These larvae have a greater thermal tolerance than Atlantic herring and appear to be able to survive ΔT's in excess of those normally encountered during entrainment. Rainbow smelt larvae differ from both the Atlantic herring and smooth flounder. Rainbow smelt normally spawn in freshwater brooks during April and May in coastal Maine and almost immediately upon hatching the larvae are swept downstream into saltwater where they experience a sudden increase in salinity. The rainbow smelt larvae which we tested in brook water showed thermal tolerances very similar to smooth flounder larvae but those tested in seawater showed the lowest temperature tolerance of all the experiments. It appears, then, that if rainbow smelt larvae are entrained at this time the effects of increased salinity might act synergistically with the temperature increase to produce a lethal stress.

[1]Lindsay, P., S. L. Barker, and J. R. Stewart. 1978. Section 4. Monitoring of the effects of the condenser cooling water system on plankton and larval organisms. *In* Final report, environmental surveillance and studies at the Maine Yankee Nuclear Generating Station, 1969-1977, p. 4.1-4.1.135. Maine Yankee Atomic Power Company, Augusta, Maine.

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FOOD OF 10 SPECIES OF NORTHWEST ATLANTIC JUVENILE GROUNDFISH

The food of fishes in the northwest Atlantic has been studied over many years. Verrill (1871) was one of the first investigators to document the food of marine fish. Recent investigations have identified the food of commercially important fish or fish currently composing a large portion of the fish biomass in the northwest Atlantic (Edwards and Bowman 1979; Langton and Bowman 1980), but still little is known about the diet of juvenile groundfish.

Most groundfish larvae are wholly planktonic until they either become demersal or grow large