HEAT TOLERANCE OF FREE-LIVING ESTUARINE ANIMALS TO PREDICT THEIR SURVIVAL IN HEATED EFFLUENTS

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Abstract: Individual heat resistance times were determined in 180 min experiments during June 1974 through September 1975 for 8 species of crustaceans and 47 fishes taken directly from the intake canal of the P. H. Robinson Generating Station, Bacliff, Texas. Individual resistance times increased with an increase in capture temperature and with a decrease in test temperature. June-September is the most thermally critical period of the year for animals transported by the power plant from intake water and exposed to hot discharge effluent. During the rest of the year, nearly all organisms survived 3 h at temperatures higher than average discharge canal temperature.

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Previous reports (McCullough 1971, Reimer and Strawn 1973, French 1973, Landry and Strawn 1974) indicated that numerous entrained and impinged organisms were killed during the summer by heat in the discharge canal at the P. H. Robinson Generating Station, Bacliff, Texas. Living crustaceans (Reimer and Strawn 1973) and fishes (Landry 1971) were abundant in the discharge canal during cool weather indicating high survival, so our heat resistance experiments were performed 5 days per week during June-September and once a month during the rest of the year.

Our desire was to produce data that engineers can use to design power plants with either no kill in the discharge canal or known kill rates. For power plant design, data on resistance times of wild animals are needed to estimate population survival at temperatures predicted for the heated effluent.

There is a scarcity of published reports on resistance times of wild organisms and a void for most of the organisms covered in this paper. Most published studies report on thermal tolerance of aquatic organisms acclimated to temperature or combinations of temperature and salinity in the laboratory. This study was designed to determine the heat resistance times of crustaceans and fishes taken directly from the intake canal of the P. H. Robinson Generating Station, Bacliff, Texas, and to determine the thermally critical period of the year for animals exposed to heated discharges.

Previous thermal history or acclimation temperature influences, heat or cold resistance (Fry 1957). Animals acclimated at lower temperatures generaly have shorter resistance times at a given high lethal temperature than others acclimated to higher temperatures (Gibson 1954, Neill et al. 1966, Allen and Strawn 1967). Brett (1944) showed that acclimation level of wild fishes follows ambient lake temperatures. We sought to determine if marine organisms have a similar pattern.

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MATERIALS AND METHODS

Study Area

This study was performed at the Houston Lighting & Power Company's P. H. Robinson Generating Station located on State Highway 146 approximately 1 mile south of Bacliff, Texas. Two 450,000 kw generating units (Unit 1 and 2), one 565,000 kw generating unit (Unit 3) and a 750,000 kw unit (Unit 4) are capable of pumping a total of 265,056 m^3/h of cooling water through the condensers. The plant uses the Galveston

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Bay estuarine system as a cooling water source. Cooling water is drawn from Dickinson Bay, a subsystem of Galveston Bay, via a 3.7 km intake canal. The water is heated upon passing through the plant's condenser-tube network and returns to Galveston Bay between Bacliff and San Leon, Texas, via a 3.2 km discharge canal.

The cooling towers operate during June through September and are located on the discharge canal between the plant and Galveston Bay. Cooled water from the towers is mixed with about 40 C discharge-canal water, reducing canal temperatures to a maximum of 35 C downstream of the cooling towers.

There are 2 ways for an organism to arrive in the discharge canal of the P. H. Robinson Generating Station. Both ways result in a sudden exposure to high temperature. Entrained organisms pass through the meshes of the revolving screens and the condenser tubes. Entrapped organisms are those impinged on the revolving screens, washed off and sluiced to the discharge canal. A drop structure at the downstream end of the discharge canal prevents entry of animals from Galveston Bay except during storm tides.

Equipment and Procedure

Ten 37.85 l all-glass aquaria were used as experimental tanks. A contact thermometer and an aquarium heater were used to regulate the water temperature to ± 0.1 C in each tank. A standardized thermometer graduated in 0.1 C increments was placed in each tank to monitor water temperature. Air stones were used to provide circulation and aeration. A General Electric P.N. 227873 timer reading to 0.1 min was used to time each experiment.

Each tank was filled with water from the intake canal and heated during June-September to 1 of 10 temperatures between 32 and 41 C in 1 C increments. The test temperatures above 35 C were representative of those found in the discharge canal between the plant and the cooling towers; 35 C and lower temperatures were representative of temperatures between the cooling towers and Galveston Bay. Lower experimental-tank temperatures were used when discharge-canal temperatures were lower during October-May. A screen, 1.5 mm mesh, was used to confine small animals to the front of the tank for easier observation. Drift-bottle studies indicated that surface water passed from the plant discharge to the first cooling-tower intake in approximately 30 min. Most aquatic animals tend to swim counter to waterflow. Thus, 180 min (6 times 30 min) was arbitrarily chosen as the length of time for each experiment. Surface temperature (hand thermometer) and salinity (American Optical Instrument Company refractometer) were measured in the intake and discharge canals on the day of each experiment.

Experiments were conducted over a period of 16 mo, June 1974 through September 1975. Number of animals used in each experiment, capture and survival data, and days in cage before an experiment are given by Chung (1977). All organisms tested were captured from the intake canal. Dip net, cast net, lift net, hoop net, and various fish traps were used to capture organisms on a daily basis during June-September and once a month during October-May. Twenty-two crustaceans and about 50 fish were revolving-screen and otter-trawl captures, respectively. Many individuals of the harder-to-capture species were taken from cavities in the log (trash) screens when these screens were raised for cleaning. Hook and line and seine were used once a week during June-September and once a month during the rest of the year.

After capture, most animals were placed in a 45.5 l Igloo ice chest with aeration and transported from the intake canal to the laboratory in less than 5 min to minimize temperature changes, drained of water, and dropped into tanks at experimental temperatures. Some animals were placed in cages (61 cm in diameter and 63.5 cm in depth) in the intake canal for later experimentation.

Individuals were divided among experimental-tanks according to species and previous results at various temperatures. Number of animals in a tank belonging to one species never exceeded 30, rarely exceeded 10 except for small common species, and because of availability was usually limited to 1 or 2 for most species. Species were mixed in the test tanks, except highly predaceous species such as the blue crab (*Callinectes sapidus*) were tested separately from other species. Care was taken only to use animals that appeared to be in good health. For a given capture temperature, 100 percent of a sample frequently survived at reduced test temperatures and thus served as controls. This was true even during hot weather for the easily injured Gulf menhaden (*Brevoortia patronus*).

Cessation of opercular motion was the criterion for death in fishes. Crustaceans were considered dead when appendages no longer moved. When animals died, the survival time was recorded to the nearest 0.1 min and organisms were measured to the nearest 1.0 mm. Fishes were measured for total length; shrimp were measured from the tip of rostrum to the distal end of the telson; and crabs were measured across the width of the carapace. Individuals were used only in 1 experiment.

RESULTS AND DISCUSSION

Temperature ranged from 7.2 to 30.5 C in the intake canal, from 19.4 to 41.6 C in the discharge canal upstream of cooling towers, and from 14.4 to 37.8 C in the canal downstream of the cooling towers. Average temperature in the discharge canal afferent to the cooling towers was about 27 C in November-April, 32 C in May and October, and around 40 C during June-September (Fig. 1). Since effluent temperatures were under 35 C in non-summer months, the cooling towers were not operated before June and after September. The difference between average water temperatures in the intake canal and afferent part of the discharge canal was about 10 C during all seasons. Average water temperature changes from the upper part of the discharge canal to below the cooling towers were approximately 4.5 and 5.5 C in summers of 1974 and 1975, respectively. Difference between average water temperatures in the summer of 1974 and 1975 was because 4 cooling towers were in operation in 1974 and 5 cooling towers were functional in 1975.

Salinity values from the intake and discharge canals were similar; thus, only intake-canal salinities are presented in this paper. Capture salinities ranged from 1 to 20 ppt. There was a striking difference in salinity between the 2 yr, with salinities ranging from 6.8 to 24.8 ppt in 1974 and from 1 to 12.4 ppt in 1975. This was especially true in early June and early July with 1975 salinities 5.3 ppt or less and 1974 salinities 10.3 ppt or more. This was because of heavy rains in early June and early July 1975. Daily salinities taken by power-plant personnel are given in Fig. 1.

Heat-tolerance experiments were performed during June 1974 through September 1975 on 10 species of crustaceans and 65 fishes. For several test temperatures, both percentage of each sample surviving at 180 min and individual resistance times were plotted by intake-canal temperature for 8 species of crustaceans and 47 fishes (Chung 1977).

Multiple regression analyses indicated that capture temperature and, to a lesser degree, salinity were the main factors affecting resistance times of a species at a given test temperature. Capture method and days test animals were held in a cage in the intake canal before an experiment rarely were significant ($a = 0.05$).

Almost all crustaceans tested during the summer survived more than 180 min at test temperatures of 37 C and below. Nearly all individuals of all fishes except bay anchovy (*Anchoa mitchilli*) and Atlantic cutlassfish (*Trichiurus lepturus*) survived more than 180 min at 35 C and lower during the summer. In general, both crustaceans and fishes reached their maximum heat resistance between mid-June to mid-July as intake-canal temperatures increased to around 28-30 C and maintained this level through August. Survival times decreased during September as intake-canal temperatures dropped to around 22 C. During November-April when average daily temperatures in the intake canal ranged from 8.3 to 25.5 C (Fig. 1), the number of individuals surviving 180 min at 34 and 35 C was greatly reduced for all but the most resistant species. Survival rates were lowest in mid-winter and were higher early and late in this period. All species would survive at 27 C, the average November-April discharge temperature. However, temperature ranged from 21.6 to 35.5 C in the discharge canal and heat deaths would be expected at peak temperatures. For example, all 30 of the heat-sensitive bay anchovy tested at 27 to 29 C during January-April survived past 180 min, but all 59 of those tested during mid-November through mid-April at 32 C died within 22.2 min. Most organisms tested in May and October would survive past 180 min at the average discharge-canal temperature of about 32 C. Therefore, the thermally critical period of the year for aquatic animals entrained and entrapped from intake water and exposed in the discharge canal system is the summer (June-September), especially June-August.

Capture temperatures (intake-canal temperatures) are assumed to approximate acclimation temperatues. Generally, resistance times of organisms increased with an increase in intake temperature and with a decrease in test temperature (figures in Chung 1977). Similar results have been reported for laboratory-acclimated channel catfish (*Ictalurus punctatus*) (Allen and Strawn 1967), freshwater fishes (Brett 1944), blue crab (Holland et al. 1971), marine and brackish-water animals (Kinney 1963), sheepshead minnow (*Cyprinodon variegatus*) (Simmons 1971), salt and freshwater marsh fishes (Strawn and Dunn 1967), and brown (*Penaeus aztecus*) and white shrimp (*P. setiferus*) (Wiesepape 1975).

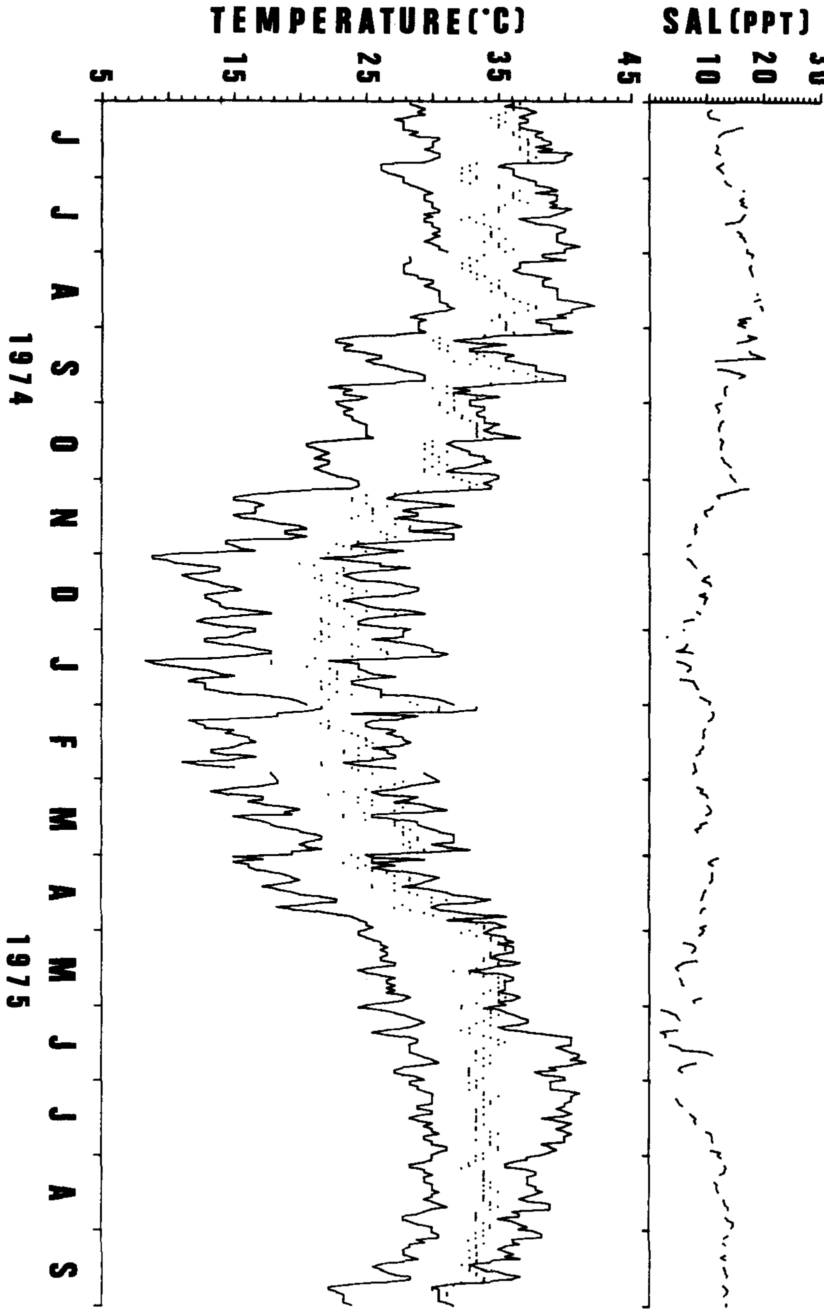

Fig. 1 Daily salinity in the intake canal; average temperature in the discharge canal afferent (upper solid line) and efferent to the cooling towers (dotted line) and in the intake canal (lower solid line) during June 1974 through September 1975 at the P. H. Robinson Generating Station, Bacliff, Texas.

Shrimp (Wiesepape 1975) and fishes (Doudoroff 1942, Allen and Strawn 1971) are known to gain resistance to heat death with increasing acclimation temperature faster than they lose it with decreasing acclimation temperature. However, it takes 3 or more days at an increased temperature for organisms to fully reach a higher level of resistance to heat death (Simmons 1971, Wiesepape 1975). Gain in acclimation level lagged behind ambient temperature when intake-canal temperatures were rising in the spring. Acclimation levels remained rather constant during mid-June through mid-August when intake-canal temperatures were fairly high and constant. In September, as water temperature fell, loss of acclimation lagged behind ambient temperature and acclimation levels were higher than expected based on temperatures at which experimental organisms were captured. For example, Gulf menhaden survival was as follows:

Date		19 April 1975	late September (1974 & 1975)
Intake temperature, C:		22.2	20.0-20.8
		Resistance time (min)	
Test temperature, C:	34	24.7-34.0	>180
	35	1.2- 3.2	92.5->180
	36	0.4- 1.0	21.2-25.1
	37	0.2- 0.9	9.8-10.6
	38	0.1- 0.8	1.1- 1.3

Gulf menhaden tested on 19 April 1975 had been exposed to temperatures as high as 22.2 C for a few days at most; those tested in late September had experienced 27-29 C a week or so earlier. Therefore, Gulf menhaden tested in the late September showed acclimation temperatures only a little lower than those of late summer (August-early September), while animals tested on 19 April 1975 reflected the lack of recent high-temperature experience. In summer, animals tested in late June were about as heat tolerant as those tested in August, indicating that organisms tested in June were already acclimated to summer temperatures. The above patterns were found for most organisms tested at various test temperatures.

When correlations of size and capture temperature are discounted, crustaceans and fishes—except grass shrimp (*Palaemonetes pugio*), brown shrimp, bay anchovy and rough silverside (*Membras martinica*)—showed no distinct relationship between heat resistance and total length (carapace width for crabs). This species of grass shrimp appeared to have a negative relationship between resistance time and total length; i.e., mature adults (36-43 mm) were less resistant than smaller shrimp (7-35 mm). Brown shrimp, bay anchovy, and rough silverside appeared to have a positive relationship between resistance time and total length. All 4 of these species were tested using individuals ranging from juveniles to adults. Only juveniles were tested for most species. Mosquitofish (*Gambusia affinis*) did not show a correlation between size and temperature-resistance time such as reported by Hagen (1964). Hagen found that 2 wk old fry of about 1 cm were much more resistant than the adults; however, mosquito-fish fry were not tested in our study. Variance of resistance times for small organisms appeared greater than that of larger ones.

Among the species with the longest resistance times at the higher test temperatures (38-41 C) were grass shrimp (*P. pugio* and *vulgaris*), blue crab, sheepshead minnow, Gulf killifish (*Fundulus grandis*), Bayou killifish (*F. pulvereus*), sailfin molly (*Poecilia latipinna*), striped mullet (*Mugil cephalus*), and white mullet (*M. curema*).

Among the species with the shortest resistance times at the lower test temperatures (34-37 C) were striped anchovy (*A. hepsetus*), bay anchovy, Atlantic cutlassfish, Atlantic bumper (*Chloroscombrus chrysurus*), spot (*Leiostomus xanthurus*) and Atlantic croaker (*Micropogon undulatus*).

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