Seasonal Change in Thermal Tolerance of Common Estuarine Crustaceans*¹

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The common estuarine crustaceans (*Palaemonetes pugio*, *P. vulgaris*, *Penaeus setiferus*, *P. aztecus*, and *Callinectes sapidus*), collected in the intake canal of the P. H. Robinson Generating Station, Bacliff, Texas, were tested for 180 minutes at various discharge canal temperatures during June 1974 through September 1975 to determine if they could survive passage through a discharge cooling system.

Three-h LD₅₀ temperatures were significantly higher, throughout the year, than the temperatures in the discharge canal downstream from the cooling towers, indicating that crustaceans should survive passage to Galveston Bay. However, they have survival problems during June-September in the discharge canal above the cooling towers.

The increasing demand for electricity has resulted in widespread of nuclear and fossil fuel power plant. These plants release vast quantities of waste heat to the estuarine environment under present operating procedures. Thermal loading and the effects of temperature on aquatic organisms have been increasing and accelerating. Also, pressure and turbulence with the tunnels leading to and from the generating units have been increasing. To protect the natural quality of environment, we should know about the response of organisms to elevated temperatures and impingement in discharge water of power plants. Thus, much researches have been focused on industrial usage of water for cooling purposes, effects of heated effluent and injury rates on aquatic organisms.¹⁻¹¹⁾ Thermal effects can be studied both in the discharge area of a power plant and in a physiology laboratory with each approach providing valuable insights into important aspects of environmental alteration.¹⁰⁾ Most published data report on laboratory studies of the thermal tolerance of aquatic organisms acclimated to temperature or combination of temperature and salinity. Few studies give data on thermal resistance times of organisms acclimated in natural environments.¹²⁻¹³⁾ These data are needed to predict survival of organisms passing through a power plant and its discharge system.

Relationship between temperature tolerance and lake temperature were established by BRETT¹²⁾ for fish living at Algonquin Park, Ontario. HOLLAND *et al.*¹³⁾ reported thermal tolerance of bluegill from a reservoir receiving heated effluent.

Previous studies at the P. H. Robinson Generating Station, Bacliff, Texas, indicated that numerous entrained and entrapped organisms were killed during summer by heat and impingement in the discharge canal system.¹¹⁾ Reduced temperatures in the discharge canal between the cooling towers and Galveston Bay should aid survival of entrained organisms. However, entrained organisms may die of heat shock in the discharge canal between the plant and the cooling towers.

This study was designed to determine the heat resistance of common estuarine crustaceans directly taken from the intake canal of the P. H. Robinson Generating Station and to predict survival of the organisms in the discharge effluent both above and below the cooling towers.

The results should be valuable for establishing regulatory standards of temperature for aquatic organisms. Also, these types of data would provide the basis for engineers to design power plants with either predetermined kill rate or with no heat-related death of entrained organisms in the discharge effluent.

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Materials and Methods

The experiments were performed over a period of 16 months, June 1974 through September 1975 using 5 species of the crustaceans collected from the intake canal of the P. H. Robinson Generating Station, Bacliff, Texas, one of the Houston Lighting & Power Company (Fig. 1). Four Generating units (2,215,000 kilowatt) are capable of pumping a total of 265,056 cubic meters of cooling water per hour through the condensers. The plant uses the Galveston Bay estuarine system as a cooling water source. The cooling towers are located on the discharge canal between the plant and Galveston Bay and operate during June through September when discharge temperatures are high. Cooled water from the towers is mixed with hot discharge-canal water, reducing canal temperatures to approximately 35°C or less between the cooling towers and Galveston Bay (Fig. 1).

Drift-bottle studies indicated that surface water passed from the plant discharge to the cooling towers in approximately 30 minutes. It was assumed that discharge water from the plant would be arrived at Galveston Bay and mixed with Bay water in approximately 180 minutes. Thus, crustaceans were exposed to pre-heated constant temperatures for 180 minutes to mimic exposure of the plant. All glass, 38-l aquaria were used to thermal shock tanks, which were filled with water from the intake canal, filtered by Diatom Filter and heated to temperatures between 25 and 42°C in 1°C increments to simulate discharge canal temperatures during the year. A Silent Giant model 120 pump was used to circulate and aerate the water providing a uniform temperature

throughout the bath. Water temperature and salinity in the intake and discharge canals were measured at conjunction with each experiment. The materials and methods are essentially the same as those given by Chung and Strawn.¹⁴⁻¹⁶⁾

Cessation of movement of appendages was the criterion used to determined the death of crustaceans. When one died, the time was recorded to the nearest 0.1 minute with an elapsed time meter and total length (from the tip of the rostrum to the end of the telson) of shrimp and carapace width of crab were measured in mm; they ranged 12-47 mm (mostly 20-30 mm) for grass shrimp *Palaemonetes pugio*, 12-35 mm (20-25 mm) for *P. vulgaris*, 18-168 mm (40-70 mm) for white shrimp *Penaeus setiferus*, 14-120 mm (60-80 mm) for brown shrimp *P. aztecus*, and 9-146 mm (20-30 mm) for blue crab *Callinectes sapidus*. Total numbers of the crustaceans tested were 7,849 individuals; *P. pugio* (3,620), *P. vulgaris* (1,032), *P. setiferus* (1,307), *P. aztecus* (850), and *C. sapidus* (1,040 individuals). Survivors were released.

Null hypotheses (H_0) were:

$$H_0: 3\text{-h LD}_{50}\text{-DTA} \geq 0$$

$$H_0: 3\text{-h LD}_{50}\text{-DTE} \geq 0$$

where 3-h LD_{50} was mean temperature at which 50% of the crustaceans survived for 180 minutes; DTA was discharge-canal temperature afferent to the cooling towers; and DTE was discharge-canal temperature efferent to the cooling towers. In this analysis, the year was divided into two parts, summer (June-September) and non-summer (October-May).

Fig. 1. Map showing study area.

Results and Discussion

As shown in Table 1, temperature ranged from 13.0 to 31.1°C in the intake canal, from 14.4 to 42.2°C in the discharge canal above the cooling towers, and from 22.3 to 37.8°C below the cooling towers. Average monthly temperatures in the intake canal and in the discharge canal afferent and efferent to the cooling towers ranged 27–30, 37–40, and 33–35°C during June–September, 23–26, 33–35, and 32–34°C during May and October, and 13–19, 26–30, and 23–28°C during November–April, respectively. Before June and after September effluent temperatures were usually under 35°C and the cooling towers were not operated. The difference between average water temperature in the intake canal and upper part of the discharge canal was approximately 10°C during the day. Average water temperature reductions from the upper part of the discharge canal to below the cooling towers were approximately 4.5 and 5.5°C in summer months (June–September) of 1974 and 1975, respectively. The difference between average water temperatures in the summer months of 1974 and 1975 was due to four cooling towers in operation in 1974 and five cooling towers functional in 1975.

Salinity values ranged from a low of 2‰ on 11 June 1975 to a high of 25‰ on 12 August 1974. Salinities lower than 5‰ were recorded during early June and July 1975. These low readings were caused by several days of heavy rain. High salinities more than 10‰ occurred from June to

mid-November 1974 and after late July 1975. There is a striking difference in salinity between the 2 years, with salinities ranging from 7 to 25‰ in 1974 and from 2 to 14‰ in 1975.

Seasonal comparisons of 3-h LD₅₀ temperatures, temperatures of the intake canal and of the discharge canal above and below the cooling towers, and temperature difference between 3-h LD₅₀ and intake canal during June 1974 through September 1975 are presented in Table 1.

All crustaceans tested, except 3 of 15 grass shrimp *P. pugio* and 3 of 10 grass shrimp *P. vulgaris* on 9 January 1975, 2 of 4 white shrimp on November 1974 and one white shrimp on 12 November 1974, lived past 180 minutes at 34°C or lower; intake canal temperatures were 13.0°C or higher.

Maximum resistance times of the organisms tested at average discharge-canal temperature of 40°C during summer months were: more than 180 minutes (*P. pugio*) on 27 June 1974; 49.5 minutes (*P. vulgaris*) on 8 August 1974; 29.5 minutes (white shrimp) on 28 July 1974; 103.5 minutes (brown shrimp) on 30 June 1975; and past 180 minutes (blue crab). In the summer, except late September, most resistance times of the crustaceans tested were greater than 180 minutes at 38°C or lower. Almost all individuals of grass shrimp *P. pugio* and *P. vulgaris* and brown shrimp at 37°C, blue crab at 38°C, and white shrimp at 36°C survived more than 180 minutes; intake canal temperatures ranged from 20.0 to 30.8°C. Almost all brown shrimp, white shrimp, and grass

Table 1. Seasonal comparisons (non-summer, October–May; summer, June–September) of the temperatures of the intake canal, discharge canals before and after towers, 3-h LD₅₀ (mode), and minimum and maximum differences measured, during a day of testing, between 3-h LD₅₀ and intake canal temperatures during June 1974 through September 1975 for 5 common estuarine crustaceans collected in the intake canal of the P. H. Robinson Generating Station, Bacliff, Texas.

Species	Season	Temperature (°C)				
		Intake canal	Pretowers	Past towers	3-h LD ₅₀	Difference
<i>Palaemonetes pugio</i>	Oct–May	13.6–26.6	24.4–35.5	22.8–35.0	34–38 (35)	11.4–21.0
	Jun–Sep	20.0–30.5	30.0–41.6	30.0–37.8	37–39 (38)	8.0–17.0
<i>Palaemonetes vulgaris</i>	Oct–May	13.0–26.6	24.4–35.5	22.8–35.0	34–37 (35)	10.4–21.0
	Jun–Sept	20.0–30.0	30.0–40.5	30.0–37.8	36–38 (38)	8.0–17.0
<i>Penaeus setiferus</i>	Oct–May	16.1–25.0	28.3–34.4	25.5–33.3	34–36 (35)	11.0–16.2
	Jun–Sep	20.0–31.1	30.0–42.2	30.0–37.8	36–38 (37)	6.9–16.0
<i>Penaeus aztecus</i>	Oct–May	21.1–24.0	32.8–35.5	31.1–35.0	35–36 (36)	12.0–13.9
	Jun–Sep	20.0–30.8	31.6–40.5	30.0–37.8	35–38 (38)	6.7–14.0
<i>Callinectes sapidus</i>	Oct–May	13.0–26.6	14.4–35.5	22.3–35.0	37–38 (38)	11.4–15.9
	Jun–Sep	20.0–30.8	30.0–41.6	30.0–37.2	37–40 (39)	9.5–18.0

shrimp *P. vulgaris* died in less than 30 minutes at the average-summer-discharge-canal temperature (40°C) above the cooling towers, indicating that individuals entrained and entrapped from intake water and transported to the discharge canal would die of heat shock in the canal afferent to the cooling towers during summer months. Almost all grass shrimp *P. pugio* and most blue crabs died within 180 minutes at 40°C indicating that they would be expected to die in the discharge canal afferent to the cooling towers, if they stayed there as long as 180 minutes. However, many of them would survive passage between the plant and the cooling towers, since discharge water from the plant passed through the cooling towers in approximately 30 minutes.

Nearly all individuals entrained and entrapped from the intake into discharge canal would be expected to survive more than 180 minutes during non-summer (October-May), because all but a few survived at 34°C, a temperature higher than average-non-summer-discharge-canal temperature of 32°C (May and October) and 27°C (November-April). However, most individuals of all five species would be expected to survive 180 minutes or longer in the discharge canal effluent to the cooling towers during all seasons, since the cooling towers reduce summer-water temperatures to approximately 35°C or less.

During the summer, modes of 3-h LD₅₀ temperatures of the crustaceans were about equal to or lower than average monthly discharge-canal

temperatures (37–40°C); however, non-summer modes of 3-h LD₅₀ temperatures were higher than average monthly discharge-canal temperatures (26–34°C). Most 3-h LD₅₀ temperatures for grass shrimp *P. pugio* and *P. vulgaris* and blue crabs were about equal to or slightly higher than average discharge-canal temperatures above the cooling towers during the summer; however, all 3-h LD₅₀ temperatures of the crustaceans tested were higher than mean discharge-canal temperatures below the cooling towers. Most summer 3-h LD₅₀ temperatures from the white and brown shrimp were about equal to or slightly lower than discharge-canal temperatures afferent to the cooling towers (Table 1).

Paired t-statistics indicated that 3-h LD₅₀ temperatures of both species of grass shrimp and blue crab were significantly higher than discharge-canal temperatures both afferent and effluent to the cooling towers throughout the year. Three-h LD₅₀ temperatures of the white and brown shrimp were not significantly higher than summer-discharge-canal temperatures above the cooling towers, but they were significantly greater than non-summer-discharge-canal temperatures afferent to the cooling towers (Table 2). Some summer experiments with grass shrimp and blue crabs yielded 3-h LD₅₀ temperatures lower than discharge-canal temperatures above the cooling towers, indicating that these crustaceans would have survival problems if they remained there as long as 180 minutes. However, 50% or more

Table 2. Paired t-statistics comparing 3-h LD₅₀ temperatures versus discharge-canal temperatures for five common estuarine crustaceans collected in the intake canal of the P. H. Robinson Generating Station, Bacliff, Texas

Species	Season	Degrees of freedom		Paired t-value	
		LD ₅₀ vs DTA	LD ₅₀ vs DTE	LD ₅₀ vs DTA	LD ₅₀ vs DTE
<i>Palaemonetes pugio</i>	Oct-May	8	8	5.59**	7.46**
	Jun-Sep	61	61	2.35*	21.65**
<i>Palaemonetes vulgaris</i>	Oct-May	11	11	5.25**	7.65**
	Jun-Sep	24	24	2.54*	13.38**
<i>Penaeus setiferus</i>	Oct-May	8	7	4.47**	8.62**
	Jun-Sep	50	50	0.25	16.57**
<i>Penaeus aztecus</i>	Oct-May	5	5	9.26**	13.78**
	Jun-Sep	64	64	-1.39	17.57**
<i>Callinectes sapidus</i>	Oct-May	5	5	11.57**	9.66**
	Jun-Sep	53	53	3.92**	23.74**

LD₅₀ : temperature at which 50% of the crustaceans survived for 180 minutes (3-h LD₅₀)

DTA : discharge-canal temperature afferent to the cooling towers

DTE : discharge-canal temperature effluent to the cooling towers

* : 5% level of significance

** : 1% level of significance

Fig. 2. Seasonal ranges of discharge canal temperatures, mean daily temperature at which 50% of the crustaceans survived for 3 hours (3-h LD₅₀), and 3-h LD₅₀-intake temperature at the P. H. Robinson Generating Station on Galveston Bay, Texas. A represent temperatures afferent to the cooling towers, E efferent and ○ and ● respective means. ΔT is approximate rise in temperature across the power plant.

of the individuals of each crustaceans tested would survive in the canal efferent to the cooling towers during both seasons.

Temperature difference (ΔT) between the intake canal and the upper part of the discharge canal was approximately 10°C during the year. Temperature difference (TD) between 3-h LD₅₀ and intake canal (Fig. 2) indicated that non-summer TD 's were always higher than ΔT across the condensers of the generating units; however, some summer TD 's were lower than ΔT . This, again, indicates that 50% or more of the crustaceans would be expected to survive in the discharge canal even though they stayed there as long as 180 minutes during non-summer months, but they will have a survival problem during the summer, since minimum TD 's were lower than ΔT . The greater TD 's in non-summer than in summer indicate that the practice at some power plants of reducing water flow through the condensers and raising the ΔT during the winter is not neces-

sarily harmful to organisms. However, increased supersaturation of dissolved gases with a greater ΔT can be harmful.¹⁶⁾

Overall information indicates that themrally critical period of the year for the crustaceans entrained and entrapped from intake water and exposed to hot discharge effluent is the summer (June-September), especially June-August when discharge canal temperatures are nearly 40°C or greater.

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