HYDROLOGICAL PARAMETERS AND GAS BUBBLE DISEASE IN A MARICULTURE POND AND FLOW-THROUGH AQUARIA RECEIVING HEATED EFFLUENT

by

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ABSTRACT

Total dissolved gas, dissolved oxygen, dissolved nitrogen, pH, conductivity, temperature, and turbidity were monitored to determine diel and annual changes in a mariculture pond and in aquaria supplied with water discharged from a power plant. The diel and annual ranges of all hydrological parameters were greater in the pond than in aquaria. Diel patterns were similar in both cases but the amplitude was attenuated in the laboratory aquaria.

Gas bubble disease (GBD) developed in 17 marine and estuarine fishes and in grass shrimps in the laboratory. GBD was more prevalent in aquaria at higher temperatures than in aquaria at lower temperatures. The disease occurred only in the winter months and was simultaneously found in fish in aquaria and in fish cultured in cages in the discharge canal. GBD was attributed to nitrogen supersaturation produced as water passed through the power plant and also to pump cavitation and to changing fish from water of high saturation to water of low saturation during cleaning of tanks.

Degassing technology must be applied to heated effluents and aquaculture facilities incorporated into power plant design if their full potential for aquaculture is to be realized.

The potential for fish production in the heated effluents of power plants is tremendous. Gaucher's (1968) conservative estimate for U. S. production by year 2000 was 4.5 billion pounds annually. If this prediction were to hold, the value of cultured fish would soon surpass that of the U. S. fishery catch. While research and pilot programs have initiated development of this under-utilized resource, commercial ventures are rare.

Competition for investment capital, regulations for effluent pollution control, availability of seed organisms, and lack of a packaged technology for system design have been major deterrents for expansion of aquaculture in heated effluents. Biological problems, one of which is gas bubble disease (GBD), have also been of prime concern.

GBD was first related to pressure in 1899 (Gorham 1899), then to supersaturation of nitrogen in 1905 (Marsh and Gorham 1905) and by 1913 the disease had been experimentally induced in the laboratory by raising water temperature while maintaining a constant gas pressure (Shelford and Allee 1913). Supersaturation of gases, especially nitrogen, has been attributed to mechanical processes such as leaking water-intake lines (Marsh and Gorham 1905), cavitation of pumps (Westgard 1964) and entrainment below dams (Ebel et al. 1974). In addition, oxygen supersaturation may also result from photosynthesis during algal blooms (Woodbury 1941; Renfro 1963). Nitrogen has produced signs of the disease in fish at lower levels of saturation (103-118%) than did oxygen (200-285%) (Rucker 1972). Therefore, as a cause of GBD, nitrogen supersaturation is of greater concern to aquaculturists than is oxygen supersaturation.

Wolke et al. (1975) reviewed GBD in relation to heated effluents and energy production. They discussed the physical and environmental factors of supersaturation and GBD as well as the histology and pathology of the disease. DeMont and Miller (1971) were the first to report mortalities of fish from GBD in a thermal effluent. Since then several attempts to culture fish in power plant discharges have been thwarted by losses attributed to GBD (Strawn et al. 1973; Marcello and Strawn 1973).

This study was an investigation of diel and seasonal variations in the dissolved gases, conductivity, turbidity, pH, and temperature in the effluent from a steam generating power plant. These hydrological parameters were measured in a mariculture pond and in

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flow-through aquaria both of which received the heated effluent. Seasonal and diel fluctuations were related to development of GBD in cultured fish.

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MATERIALS AND METHODS

The Houston Lighting & Power Company's Cedar Bayou Generating Station is located east of Baytown, Texas in Chambers County. The three 750-megawatt units at the power plant have a combined maximum usage of 76,840 m^3 cooling water per hour. The maximum designed temperature change (Δt) in the cooling water is 11.1 C. The plant receives its cooling water from Cedar Bayou, and, via a cut-off canal, from Tabbs Bay in Upper Galveston Bay. The heated effluent is discharged via a 9.8-km discharge canal to a 1053-ha (surface area) cooling lake. Research facilities consisting of 25 0.1-ha ponds and a laboratory with 60 240-liter aquaria and 6 4,900-liter concrete troughs were located adjacent to the upper end of the discharge canal.

A 3000-gpm pump supplied water from the discharge canal to the flow-through ponds and to the flow-through aquaria and troughs in the laboratory. In addition to this "hot" water, two other sources were available in the laboratory (Fig. 1). "Warm" water was pumped directly from one of the mariculture ponds to the aquaria and also flowed across a refrigerant unit to produce a "cold" water supply. The warm and cold waters were blended by mixing valves to selected temperatures for the aquaria. Final thermal regulation was achieved in the aquaria by using contact thermometers to control submersible electric heaters via a relay box. The aquaria and troughs were aerated with compressed air forced through airstones placed in the water.

Procedure

Hydrological parameters were measured for 10 months from July 1974 through June 1975. Data were collected at 3 hour intervals beginning at noon central standard time one day and ending after the noon collection the following day. Dial measurements were made in the 0.1-ha pond (pond-1 which supplied water to the laboratory) and in one of the aquaria (tank-31). In addition, measurements of total gas saturation were made at irregular intervals in the other aquaria from November through May. Incidences of GBD which developed in fish cultured in the flow-through aquaria were related to water temperature and degree of supersaturation. Normally 10 to 20 fish or crustaceans were stocked per aquarium. Fish species stocked were marine and estuarine organisms common in the Galveston Bay System.

Hydrological Measurements

A Hydrolab Surveyor Model 6 (Hydrolab Corporation; Austin, Texas) was used to measure conductivity, dissolved oxygen and temperature. Turbidity was measured using a Bausch and Lomb Spectronic 20. A Corning Series 500 pH meter was used to measure pH.

The total pressure of gases in the water was measured by a Weiss Saturometer (Eco Enterprises; Seattle, Washington). Readings were taken after the saturometer equilibrated while being pumped and shaken. When the saturometer needle was stable for 3 minutes, at low or moderate levels of saturation, and for 5 minutes, at high levels of saturation, it was assumed that the equilibrium point had been established. Two, sometimes three, commercial saturometers were simultaneously used as checks against each other.

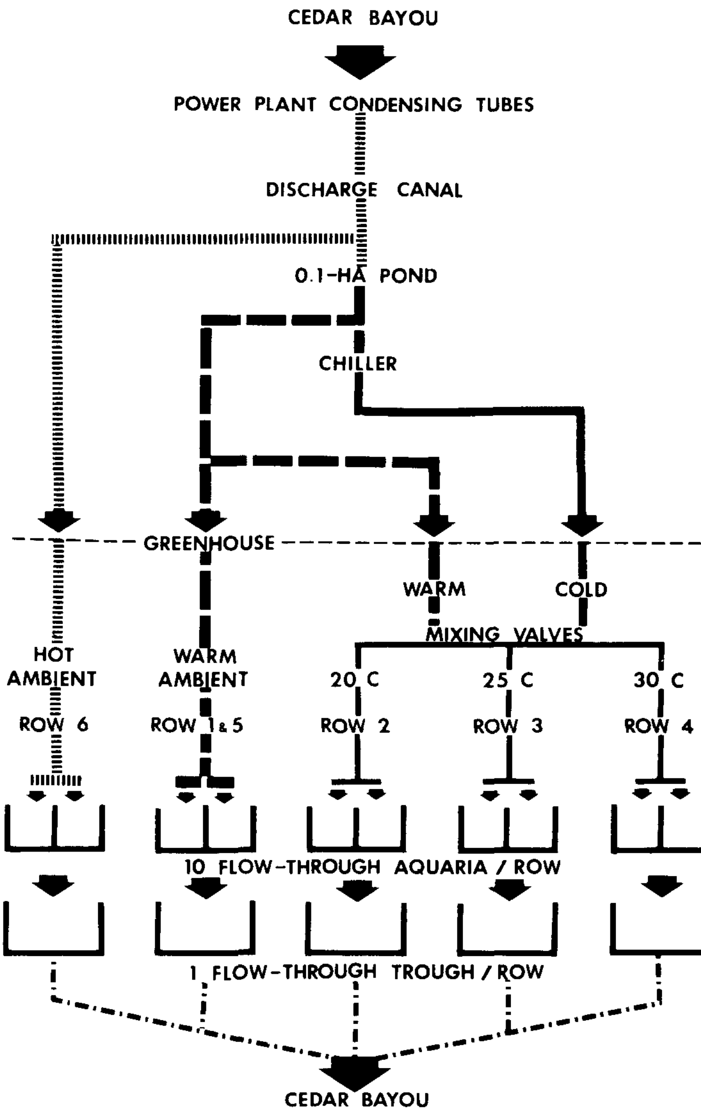

Figure 1. Water supply for the 60 flow-through aquaria and the 6 concrete troughs in the greenhouse laboratory.

The percent saturation of oxygen was calculated according to the following equation:

$$\% \text{ saturation of oxygen} = O_2 \times 100\%/O_s$$

where O_2 = observed oxygen concentration, and O_s = oxygen saturation value at the observed temperature and salinity. The O_s values were computed according to the formula of Weiss (1970). The percent saturation of total gases was calculated according to the following equation:

Percent saturation of total gases = $(P \times 100/P_{atm}) + 100$ where P = observed value (mmHg) from the Weiss saturometer and P_{atm} = atmospheric pressure in mmHg (Environmental Protection Agency 1973). Because the study site was at sea level, P_{atm} was assumed to be 760 mmHg.

The equation for the calculation of percent saturation of nitrogen and argon (Environmental Protection Agency 1973) was as follows:

Percent saturation of nitrogen and argon =

$$\frac{(P_{atm} + \Delta P) - \left\{\frac{O_2}{\beta O_2}\,(0.5320)\right\} - P_{H_2O}}{(P_{atm} - P_{H_2O})\quad(0.7902)}$$

where P_{atm} = 760 mmHg, ΔP = observed value from the Weiss saturometer, βO_2 = Bunsen solubility coefficient for oxygen at the observed temperature and salinity (Weiss 1970), and P_{H_2O} = partial pressure of water vapor in mmHg at the observed temperature (Weast 1973). The constant 0.5320 was derived from the following:

$$\frac{22.41 \text{ ml } O_2/\text{m mole}}{32.00 \text{ mg } O_2/\text{m mole}} \times \frac{760 \text{ mmHg}}{1000} = 0.5320$$

and the constant 0.7902 in the percentage of nitrogen and argon in the air by volume. Since argon is normally a small part of the nitrogen and argon reading, it was included in the percent nitrogen saturation.

RESULTS

Pond 1

Diel variations of dissolved gases in the 0.1-ha pond were greater during the summer months than during the winter months (Fig. 2). Dissolved oxygen was more variable than either nitrogen or total gas and it had a maximum saturation value of 219% (Table 1). Nitrogen and total gas saturation peaked at 114 and 128%, respectively. Dielly the total dissolved gas pressure declined between approximately 1800 and 0600 hours and increased from 0600 to 1800 hours. The variation in pH (Fig. 2) was synchronous with the oxygen cycle both dielly and seasonally.

Water temperature varied up to 5.5 C in 24 hours and 18.9 C throughout the year (Table 1; Fig. 3). Generally, conductivity and turbidity were inversely related; however, turbidity had a slightly greater diel variation. During July, September, and June temperature and turbidity appeared to be positively correlated while during August, November, December, February, and April the relationship was negative (Fig. 3).

Aquarium

Diel variations of dissolved gases in the aquarium (tank-31) were rather modest with no distinct seasonal differences (Fig. 5). Oxygen saturation averaged 90% with a maximum of 138% (Table 1). Average nitrogen saturation (106%) was greater than the average total gas saturation (102%) but the annual extremes were very similar. The diel variations of dissolved gases were relatively consistent. A rhythmic variation of pH was also apparent with the peak at approximately 1800 hours. The curves for the dissolved gases and pH obtained on 17 December (Fig. 4) were not typical of other dates. On this date the warm water supply pump was cavitating due to a faulty relay in the water level control circuit.

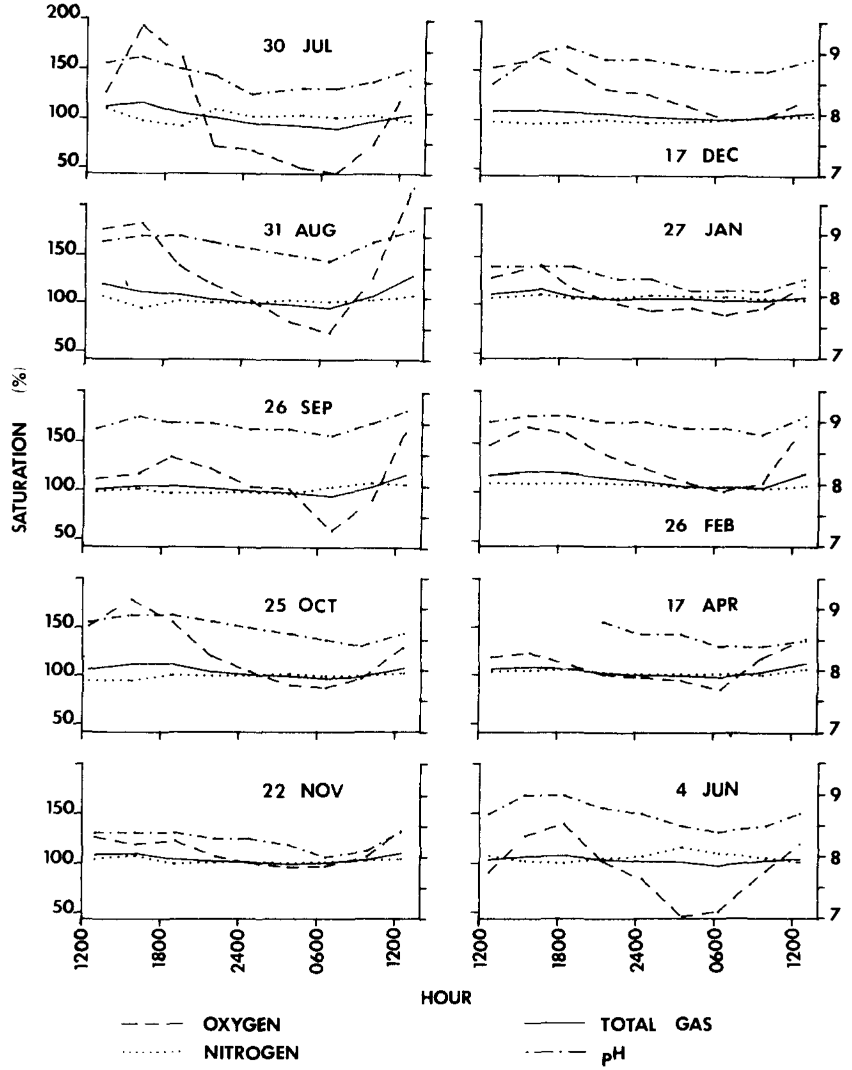

Figure 2. Monthly diel oxygen, nitrogen, total gas saturations (%) and pH in pond-1.

Temperature averaged 27.2 C in tank-31 with a maximum diel range of 6.6 C (Table 1). A consistent diel pattern was evident with a decline of temperature during the night and an increase during the day (Fig. 5). Air temperature, as recorded with a maximum-minimum thermometer, varied as much as 21 C (range, 19-40) in a single day (4 June 1975) and 25.5 C seasonally from 14 November 1974 to 14 June 1975. Conductivity and turbidity were inversely related and varied seasonally but were fairly constant dielly.

GBD

High levels of total gas supersaturation and GBD, both fatal and non-fatal, were more common in the winter months than in the spring (Fig. 8). Maximum total gas saturation

Table 1. Averages, diel and annual ranges for hydrological parameters in pond - 1 and tank - 31.

	Pond-1	*Tank-31*
Oxygen saturation (%)		
Average	114	90
Diel range	68-219	18-65
Annual range	41-219	18-138
Nitrogen saturation (%)		
Average	101	106
Diel range	98-114	100-120
Annual range	92-114	99-121
Total gas saturation (%)		
Average	103	102
Diel range	93-128	104-120
Annual range	87-128	94-120
Oxygen (ppm)		
Average	9.3	6.9
Diel range	4.8-14.9	8.0-12.2
Annual range	2.8-15.9	1.4-12.2
Temperature (C)		
Average	24.3	27.2
Diel range	23.0-28.5	22.9-29.5
Annual range	13.1-32.0	19.1-34.0
Conductivity (mmhos/cm)		
Average	12.6	12.8
Diel range	5.9-8.7	22.0-24.8
Annual range	1.3-24.0	1.0-25.5
Turbidity (JTU)		
Average	136	115
Diel range	168-217	112-172
Annual range	54-217	42-197
pH		
Average	8.4	8.2
Diel range	8.5-9.1	7.9-8.8
Annual range	8.0-9.2	7.9-8.9

was 138% but the minimum total gas was lower than the detection limit (−100 mmHg, approximately 87%) of the Weiss saturometer. The greatest number of fish mortalities per row of aquaria from GBD was 59 in row-4 (30 C) and fewest (2) were in row-2 (20 C). In row-6 there were 73 (41 fatal; 32 non-fatal) cases of GBD at ambient (12-32 C) temperature. However, in rows 1 and 4, also at ambient temperature, there were only 25 and 20 cases, respectively. Seventeen species of fish and 1 crustacean species exhibited external signs of GBD (Table 2).

During the monthly cleaning of the aquaria total gas saturation was often depressed (tanks 43 and 54, Fig. 7) to the lowest detectable limit of the saturometer. These values were plotted at approximately 87% but in actuality were probably much lower. Fish, which were moved from tanks to 13.2-liter (3.5 gal) buckets during cleaning, developed gas emboli in the fins and occasionally even exophthalmia while in the buckets. Total gas saturation was not so drastically reduced during cleaning in some other tanks (tanks 14 and 53, Fig. 6). Compressed air, passed through airstones in the water, did not aerate the water sufficiently to maintain saturated conditions in the buckets which held the fish.

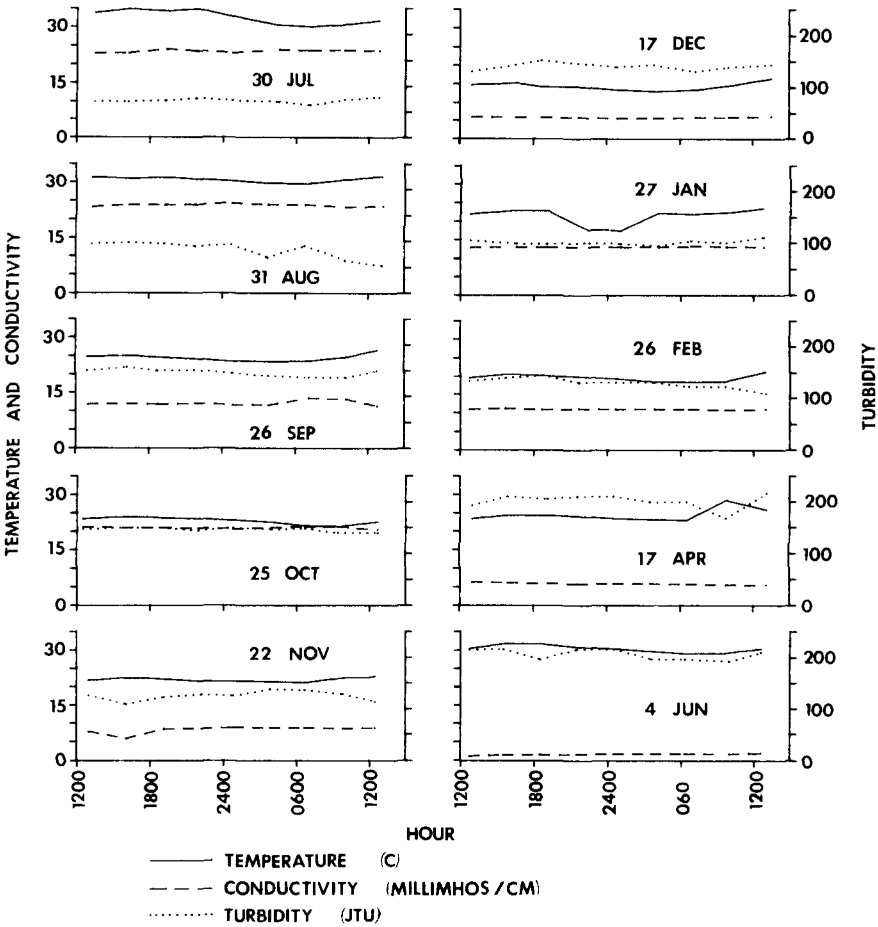

Figure 3. Monthly diel temperature, conductivity and turbidity in pond-1.

DISCUSSION

The diel changes in oxygen concentration and pH are indicative of the trophic state of the water (Hem 1970) and are affected by photosynthesis and biological decomposition. Dissolved oxygen is usually inversely related to CO_2, as CO_2 in the form of carbonic acid increases, pH decreases; thus, diel variations in pH may also reflect photosynthetic activity. The cyclic patterns of oxygen saturation and pH in the pond reflected the liberation of oxygen and uptake of CO_2 by photosynthesis. These same patterns were also evident in tank-31; however, amplitudes were attenuated (Fig. 4). Aeration through airstones moderated the higher levels of supersaturation by allowing the excess gases to escape and introduced those gases which were below saturation.

Turbidity affects dissolved gas levels by limiting photosynthesis. In turbid water sunlight does not penetrate to as great a depth as in clear water due to absorption, diffraction and diffusion of the light by suspended particulates. Turbidity was more

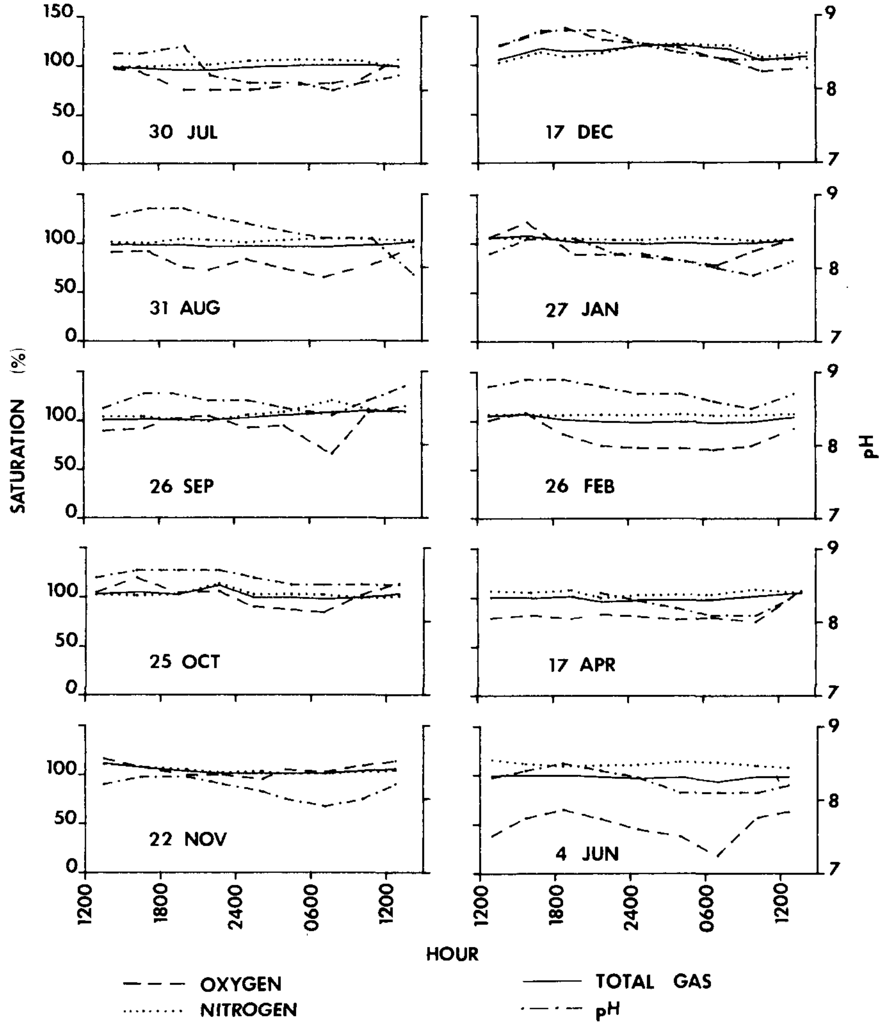

Figure 4. Monthly diel oxygen, nitrogen, total gas saturation and pH in laboratory tank-31.

closely related to rainfall and thus conductivity than to any other factor. The runoff from local rains stratified on the pond surface, flowed out the standpipe and had little effect on conductivity or turbidity in the pond or in the laboratory. A local rain from 1800 to 0300 hours on 30 July had only a slight affect on conductivity and turbidity but on 4 June conductivity was depressed by rains in the Trinity River and Cedar Bayou water-sheds (Fig. 3). This decrease in conductivity was accompanied by an increase in turbidity. Conductivity in the laboratory was nearly identical to that in the pond except when water flow to the aquaria was interrupted (Fig. 5). Turbidity patterns in the laboratory aquaria were similar to that in the ponds but the amplitude was attenuated.

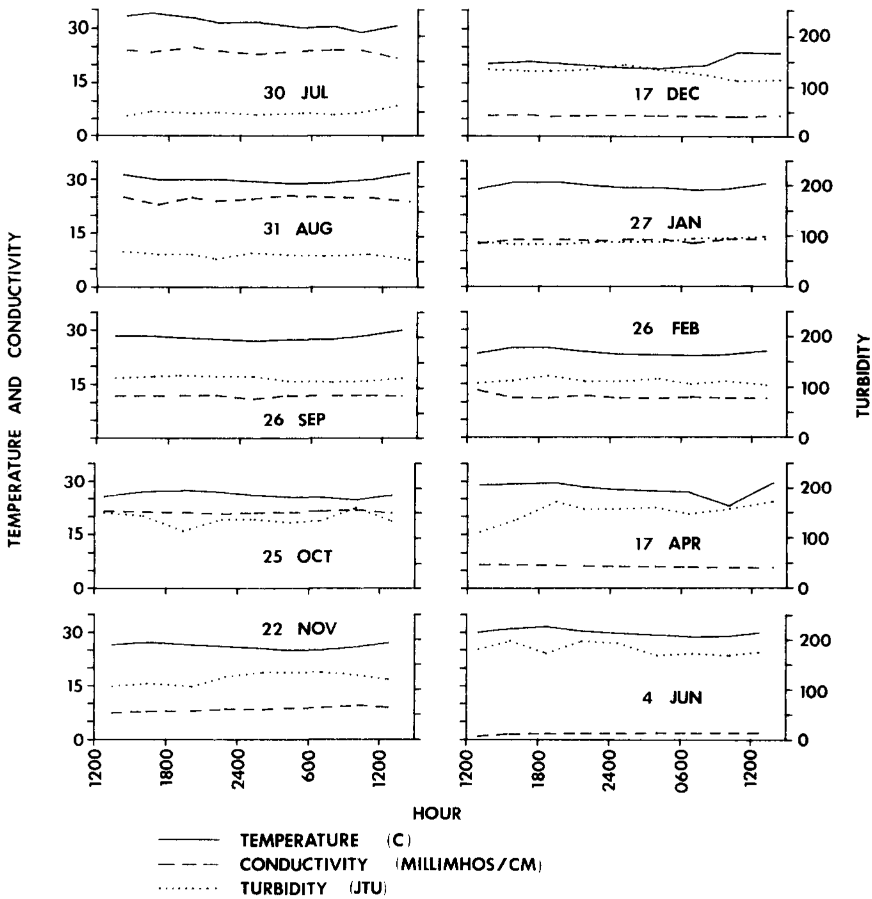

Figure 5. Monthly diel temperature, conductivity and turbidity in laboratory tank-31.

The maximum diel fluctuations of total gas saturation and dissolved oxygen in ponds was much greater than in either the discharge canal or at the intake area of the power plant (Kaehler et al. In Review). These differences are probably due to the more lentic and fertile conditions found in the ponds and aquaria as opposed to the more lotic conditions of the discharge system. The 24-hour extremes in total gas saturation for pond-1, tank-31, the Cedar Bayou intake, and the discharge canal were, respectively, 93-128%; 104-120%, 92.6-109.6; and 99.0-114.5%. The slight depression of total gas saturation which was evident (Fig. 2 and 4) from about 2000 hours to 1200 hours was attributed to the diel variations in dissolved oxygen and barometric pressure.

Temperature and conductivity are both inversely related to the solubility of gases in water; as temperature and conductivity increase the ability of water to hold gases decreases. During the winter months the low temperature and reduced light intensity limit photosynthetic activity (Rudolfs and Heukelekian 1967) and result in the weak diel variation of dissolved gases and pH. However, it was during the colder months that gas saturation was lowest in the Cedar Bayou intake and highest in the discharge canal (Kaehler et al. In Review). During this period fish held in cages in the discharge canal and

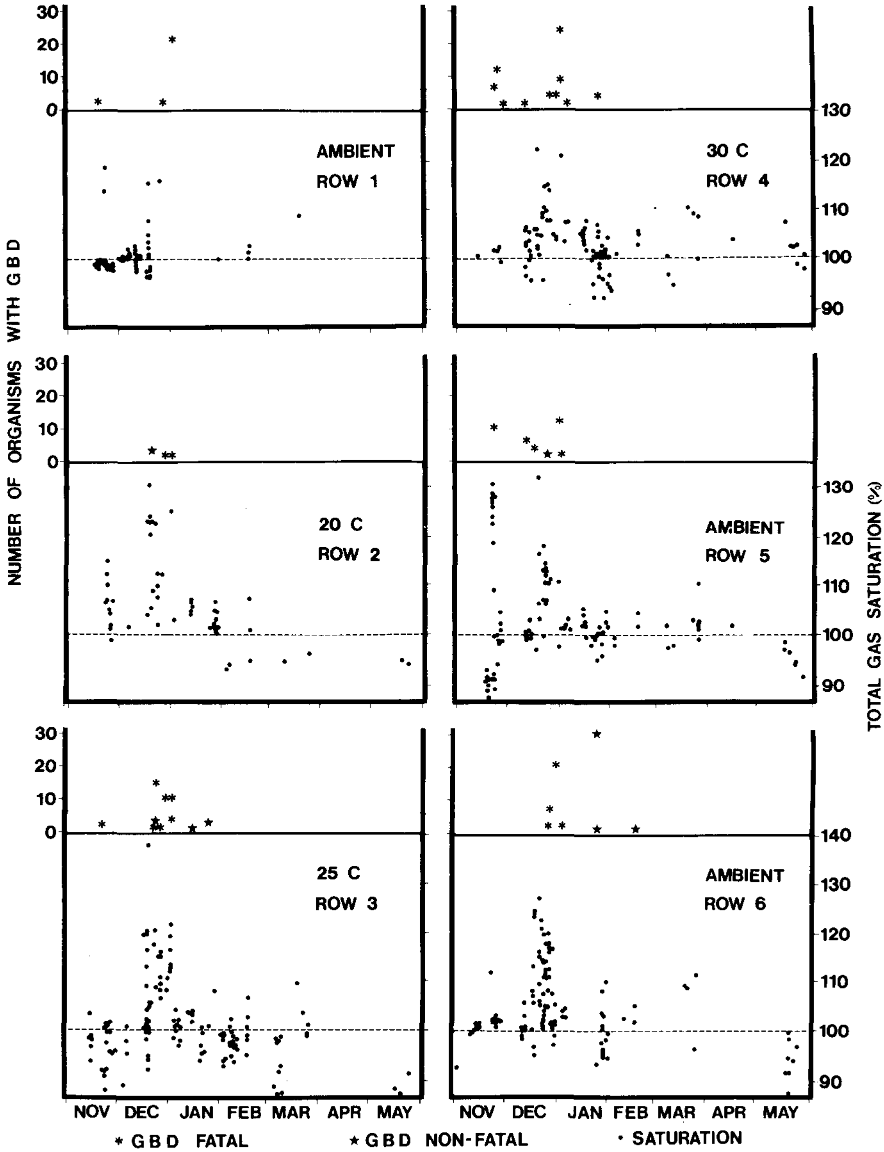

Figure 6. Total gas saturation and occurrence of gas bubble disease (GBD) in the 6 rows of aquaria in the laboratory.

in aquaria in the laboratory developed gas bubble disease while fish held similarly in Cedar Bayou and in the mariculture ponds remained free of this disease (Strawn et al. 1973). GBD has been observed only once in the Cedar Bayou mariculture ponds (Linder 1974). The absence of GBD in the mariculture ponds while present in the discharge canal was

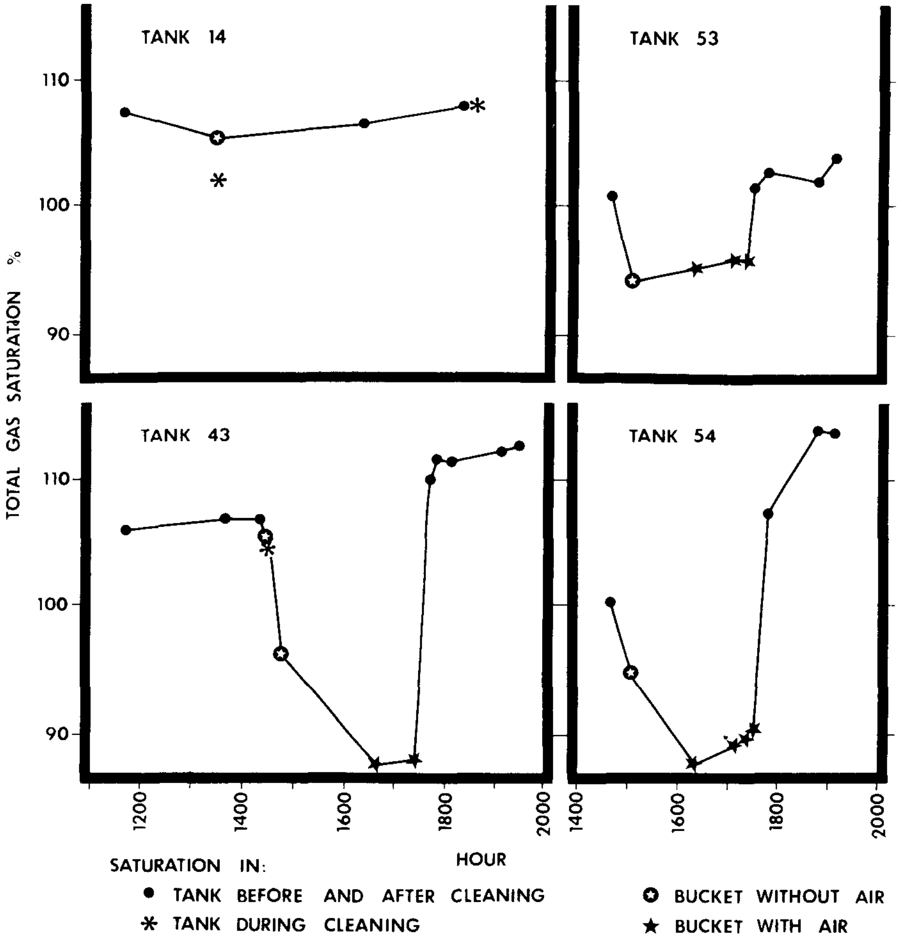

Figure 7. Total gas saturation exposure of fish in tanks (before and after cleaning) and in buckets during the December cleaning of the tanks. Tank 14 (row 2), 20 C; tanks 43 (row 5), 53, and 54 (row 6), ambient (19 C). Tanks 14, 43, 53, and 54, respectively stocked with 18, 18, 17, and 20 striped mullet.

attributed to the restricted inflow of heated effluent which was limited by the small size of pond drains.

GBD was more prevalent in aquaria at higher temperatures, where gas solubility was less than in aquaria at lower temperatures (Fig. 6). In December 1973, fish stocked in aquaria in row-6, which received hot-water directly from the discharge canal, developed GBD (Strawn et al. 1973). Fish in cages in the discharge canal simultaneously developed GBD. Mechanical problems precluded further use of the hot-water supply and warm-water was supplied to row-6. The cavitating of the warm-water pump on 17 December 1974 because of a faulty relay in the water level control circuit produced supersaturation in the aquaria. Pump cavitation was immediately corrected by manually adjusting the water level in the sump. The faulty relay was repaired on 2 January but mortalities from GBD

Table 2. Species exhibiting external signs and mortalities from gas bubble disease.

1.	Grass Shrimp	*Palaemonetes pugio*
2.	Hardhead catfish	*Arius felis*
3.	Sheepshead minnow*	*Cyprinodon variegatus*
4.	Gulf killifish*	*Fundulus grandis*
5.	Sailfin molly*	*Poecilia latipenna*
6.	Chain pipefish*	*Syngnathus louisianae*
7.	Gray snapper	*Lutjanus griseus*
8.	Pigfish	*Orthopristis chrysoptera*
9.	Sheepshead*	*Archosargus probatocephalus*
10.	Spotted seatrout*	*Cynoscion nebulosus*
11.	Spot*	*Leiostomus xanthurus*
12.	Atlantic croaker*	*Micropogon undulatus*
13.	Black drum*	*Pogonias cromis*
14.	Atlantic spadefish*	*Chaetodipterus faber*
15.	Striped mullet*	*Mugil cephalus*
16.	Naked goby	*Gobiosoma bosci*
17.	Lined sole	*Achirus lineatus*

*Exophthalmia

continued throughout the month (Fig. 6). During March, April, and May gas saturation levels were never as great as during the winter and were often below 100%. Apparently the biochemical oxygen demand was high in the aquaria and occasionally dissolved oxygen was very low (Table 1; Fig. 4).

Depression of gas saturation during cleaning of the tanks was attributed to metabolic activity of the fish and chemical oxidation of the accumulated substrate deposits. Fish, held in buckets while the tanks were being cleaned, lowered the dissolved oxygen content by respiration.The reduction in oxygen content produced a corresponding drop in the total gas pressure. During December when saturation levels were measured (Fig. 7) while tanks were being cleaned, the disease did not occur. However, it did occur during the November cleaning cycle in fish from tanks with saturation levels from 118% to 130%.

In grey snapper (*Lutjanus griseus*), pigfish (*Orthopristis chrysoptera*), sheepshead (*Archosargus probatocephalus*), pinfish (*Lagodon rhomboides*) and Atlantic spadefish (*Chaetodipterus faber*) the external signs of GBD were exophthalmia; whereas, in Atlantic croaker (*Micropogon undulatus*), black drum (*Pogonias cromis*) and striped mullet (*Mugil cephalus*), the disease was more frequently manifest as gas emboli in fin tissue. This may be due to a differential secretion of gas within the eye by the *rete mirable* found in the choroid layer. Wittenberg and Wittenbery (1962) reported oxygen tensions in the eyes of marine fishes ranged from 2-1,320 mmHg and varied with the species, being greater in the eyes of fast-swimming, sight dependent, predaceous fish.

GBD is a recurring problem in thermal effluents and especially so in sea water. Supersaturation can be controlled by using degassers to reduce the gas pressure in water. The gas content of water falling through the air or across baffles (Rucker and Hodgeboom 1953), agitated on the surface (Wold 1973), passed through vacuum chambers (Mount 1964) or through U-tubes and vacuum chambers (Speece 1969) will eventually reach equilibrium with the atmosphere and be suitable for fish culture. Mechanical problems increase as the complexity of an aquaculture system increases. Thus, aquaculture in ponds which utilize a gravity flow water system would be much more reliable than the more highly manipulated and artificial conditions of the laboratory. When aquaculture facilities are added to existing plants, compromises may have to be made in the optimum design. Gaucher's (1968) estimate for fish production in heated effluents would be more easily attained if power plant cooling systems were initially designed to accomodate aquaculture facilities.

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