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USE OF CORN DISTILLER'S SOLUBLES FROM AN ETHANOL PLANT FOR AQUACULTURE

Final Report

By
Christopher C. Kohler

June 1984

Work Performed Under Contract No. FG02-81R510295

Southern Illinois University—Carbondale
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Use of Corn Distiller's Solubles From An Ethanol Plant for Aquaculture

Final Report

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INTRODUCTION

Ethanol is increasingly being used as an alternative to fossil fuels. However, profitable uses for the by-products of the distillation process need to be identified if ethanol is to become a significant and economical fuel supply. The small size and rural location of most ethanol plants suggest that it would be best to identify uses for the by-products that could feasibly be incorporated at or near the site of the plant. The principal by-products are carbon dioxide (CO_2) and stillage (a mixture of non-fermentables and water). Although dried stillage has proven to be a suitable animal feed (Beeson 1975; Brethour 1974; Harmon 1975, Schingoethe et al. 1983), the energy costs of drying the material preclude any wide-spread usage. The wet stillage can economically be separated into two fractions: distiller's grain and distiller's solubles. Wet corn distiller's grain has shown potential as a feed supplement for ruminants, swine, and poultry (National Research Council 1981). However, the soluble fraction (with suspended particles) is of little food value to terrestrial animals because of its high water content; it is not generally economically feasible to concentrate it further. We concluded that the solubles by-product could potentially be used as a food source in an aquatic environment where its high water content would not necessarily pose an impediment. Many aquatic organisms are capable of utilizing suspended materials in the water column as a food. Primary among these are microcrustaceans, which are at times a major source of food for nearly all fish species. Furthermore, planktophagus fishes such as golden shiners (*Notemigonus crysoleucas*) are also capable of directly assimilating particulates from the water column. Freshwater shrimp (*Macrobrachium rosenbergii*) are extremely efficient at feeding on organic materials that settle on pond bottoms.

The use of corn ethanol distiller's grain for feeding livestock has been highly successful. Use of the solubles by-product, in addition to the grain, may prove to be equally successful for aquaculture. Thus, in addition to fuel, ethanol plants can provide feed for aquatic and terrestrial animals which are ultimately consumed by humans.

The feasibility of recycling agro-industrial wastes into aquatic organisms of commercial value has been demonstrated by several researchers. Diluted sugarbeet factory wastes were used in Poland for carp production; results compared favorably with yields in the same region where commercial fertilizers were used (Thorslund 1971). The effluent of a rubber processing factory in Malaysia was successfully used by John (1975) to cultivate fish. Nugent (1978) used brewery wastes for rearing Tilapia sp. and reported a yield of 2500 kg/ha/year. In Puerto Rico, rum distillation wastes and pharmaceutical wastes were successfully used for culturing Tilapia aurea (Kohler and Pagan-Font 1978; Pagan-Font et al. 1980). Survival and mean standing crop were comparable to results from fish which received commercial fish feed.

In the early 1960's, Shao Wen Ling (1969) developed a successful technique for rearing larvae of freshwater shrimp (giant Malayasian prawn), M. rosenbergii (de Man). Fujimura (1966) was the first to standardize mass production of juvenile prawns. The procedure, which was perfected in Hawaii, is practiced at low density (10 post-larvae/liter) in large tanks (18 m^3), and utilizes green water (uni-cellular algae) as a feed (Fujimura and Okamoto 1970).

M. rosenbergii possesses attributes favorable for large-scale commercial aquaculture, such as successful reproduction in captivity, established techniques for larval rearing, good growth rate and survival, absence of major disease problems, and a wide consumer acceptability and high market value (Balazs and Ross 1976). Commercial interest in prawn culture is currently being developed in Central and North America, the Caribbean, Southeast Asia, Australia, and Hawaii (Smith et al. 1976).

There are few locations in the continental United States which possess suitable growing conditions for M. rosenbergii. The upper and lower lethal temperatures for the shrimp are approximately 36°C and 15°C, respectively (Taylor 1980). M. rosenbergii require a temperature range of 25 to 30°C for optimum growth and development (Ra'anan and Cohen 1981). The temperate climate of southern Illinois is able to sustain suitable temperatures for a 4 month period. Sandifer and Smith (1976) concluded that the indoor rearing of larvae and juveniles during the cooler months, with pond culture restricted to the period from late April or early May to late October, would benefit prawn culture in South Carolina. This scheme would also hold true for southern Illinois, although the growing season would be about one month shorter.

Culture procedures for golden shiner (Notemigonus crysoleucas) are well established, and have been outlined by several authors (e.g., Allan 1952, Prather et al. 1953, Dobie et al. 1956, Guidice 1968, Meyer et al. 1973, Johnson and Davis 1978). The general culture scheme is presented in Stickney (1979).

METHODS

Laboratory Studies

Fresh samples of corn distiller's solubles (composition shown in Table 1) were obtained as a by-product of laboratory distillation of ethanol using crushed corn, dehydrated yeast, and commercial enzyme mixtures. Golden shiner (Notemigonus crysoleucas) and crayfish (Procambarus sp.) were used as test fish and test macrocrustacea, respectively. Twelve 110-liter aquaria were used in the assessment of toxicity of corn distiller's solubles on the test organisms. Corn distiller's solubles were applied in replicated treatments at rates equivalent to 0, 1000, 1800, 3200, 5600, or 10,000 ppm. Survival of test organisms was recorded over a 96-hour period for determination of a 96-hr LC_{50} (lethal concentration where 50% of test organisms survive over a 96-hr period). Two identical bioassays were conducted.

A culture of Daphnia was maintained in a 110-liter aquarium. Several 300 ml Erlenmyer flasks were used as an experimental units for conducting a 96-hr LC_{50}. Flasks were filled with 200 ml of reconstituted freshwater. Three identical bioassays were conducted in which flasks were treated with corn distiller's solubles at rates equivalent to 0, 1000, 1800, 3200, 5600, or 10,000 ppm. One hour following by-product application, 10 Daphnia were stocked in each flask. Survival was recorded over a 96-hr period.

Effects of corn distiller's solubles on a representative alga were assessed by comparing O_2 levels in experimental units receiving various concentrations of the by-product. Tests were conducted by placing a 200 ml homogeneous sample of Chlamydomonas in each of six 300 ml Erlenmyer flasks. Flasks were then supplied with corn distiller's solubles at rates equivalent to 0, 1000, 1800, 3200, 5600, or 10,000 ppm. Treatments were maintained under an alternating photic schedule of 15-hr light and 9-hr darkness for a 96-hr period. Dissolved oxygen and pH measurements were obtained prior to application of the by-product and after each subsequent 15-hr light period. Measurements were taken using a YSI Model-57 oxygen meter and a Corning Model-12 pH meter.

The 96-hr LC_{50}'s were calculated by plotting percentage of survival of test organisms during a 96-hr period against concentrations of corn distiller's solubles. The analysis was conducted using the Statistical Analysis System (SAS) Proc Probit Analysis. The procedure yields a "best-fit" log-normal curve and also includes a 95% confidence band.

Water quality variables of pH, dissolved oxygen, ammonia nitrate, alkalinity, and hardness were measured during the fish/crayfish bioassays. Dissolved oxygen and pH were measured with previously described meters, whereas the other measurements were taken using standard chemical procedures (American Public Health Association 1976).

Field Studies

Five 0.1 ha earthen ponds were constructed (Fig. 1) in proximity to an ethanol distillery located on the grounds of the Vienna Correctional Center, a minimum-security state prison at Vienna, Illinois. The facility produces ethanol which is utilized in vehicles of the Illinois Department of Transportation; the facility is also used for vocational training of inmates in fuel-production technology. The plant was designed to produce 500,000 gallons of ethanol per year using nearly 250,000 bushels of corn.

On 25 May 1982, each pond was stocked with 2000 post-larval freshwater shrimp (0.02 g mean weight). Three of these ponds were also stocked with 75 adult golden shiners (27.0 g mean weight). Chopped hay was added to ponds containing shiners to provide spawning substrate, and to the other two ponds in order to keep pond treatment similar.

Because the distillery was undergoing its "shake-down" period during the course of the pond trials, corn distiller's solubles were only available for one application (~ 2000 ppm) to each pond. Three applications of dried corn distiller's mash (~ 5 kg/application) were made to each pond over the course of the yield trials. No other food or fertilizer was added to the ponds.

On 8 June 1983, three ponds were each stocked with 3000 post-larval freshwater shrimp (0.02 g mean weight). On 30 June 1983, the other two ponds were each stocked with 5000 post-larval freshwater shrimp (0.02 g mean weight). Because the distillery cooker cracked during the summer of 1983 and was not replaced until September, 1983, no ethanol distillery by-products were available. In an attempt to simulate project conditions, by-products from a St. Louis beer brewery (see Table 2 for proximate analysis) were obtained and applied to all ponds in nine applications (15 to 30 kg/application/pond) over the course of the yield trials.

Major water quality variables were monitored during both yield trials using standard instrumentation and chemical techniques (American Public Health Association 1976). Zooplankton populations were also sampled during the 1983 trials. Cultured organisms were harvested after approximately 120 and 105 days in 1982 and 1983, respectively. Weights and lengths of all individuals were measured and recorded.

Approximately 5 kg of frozen shrimp tails from the 1983 production season were sent to a major midwestern seafood distributor for food quality and economic appraisal.

RESULTS

Laboratory Studies

Corn distiller's solubles were apparently not acutely toxic to fish or crayfish at concentrations up to 10,000 ppm (Table 3). Only one mortality occurred among each test group during the two separate 96-hr test periods. Both deaths were apparently due to crayfish predation/cannibalism.

Acute toxicity tests indicated that corn distiller's solubles may be toxic to Daphnia (Fig. 2). A 96-hr LC_{50} was estimated at 2271 ppm, and the upper and lower 95% confidence values were 1859 ppm and 2762 ppm, respectively.

Dissolved oxygen declined precipitously in the algal cultures following application of the corn distiller's solubles (Table 4). However, alkalinity, hardness, nitrates, ammonia, and pH were not significantly altered by the addition of the ethanol by-product (Table 5).

Golden shiners were observed to actively consume the particulates of the corn distiller's solubles. Following the bioassays, stomach contents of several shiners were examined, and the visual observations confirmed.

Field Studies - 1982

Mean production of shrimp in the experimental ponds in 1982 was 104 kg ha^{-1} (Table 6). Survival ranged from 34 to 75%. Although shrimp averaged approximately 11 g each, weights and lengths were highly variable within (Figs. 3 and 4) and among (Figs. 5 and 6) ponds. Shrimp were considerably smaller in the two ponds with the highest density (survival) at harvest (Table 7).

Golden shiner mean production was 130 kg ha^{-1} (Table 6). Production was primarily the result of offspring, with the majority of these fish obtaining lengths of a approximately 7.5 cm TL and mean weights of 6.2 g (Table 8).

Based on the limited sample size, the presence of shiners did not appear to impede shrimp production.

Major water quality variables remained within acceptable ranges for aquaculture over the course of the yield trials (Table 9). No significant alteration in water quality was noted following the one application of corn distiller's solubles or the three applications of corn distiller's mash.

Because the ponds were new they had minimal natural productivity. Moreover, grass was not fully established on the watershed, and the ponds became turbid (low secchi disc readings summarized in Table 9 were due to turbidity rather than primary productivity). One exception was Pond 3, where turbidity cleared by mid-summer and the waters became green with algae for the remainder of the study. Shrimp production was highest in this pond (Table 6).

The desirable temperature range for freshwater shrimp production is considered to be between 24 and 30°C (Ling 1969). Bottom waters were rarely near this level (Fig. 7).

Field Studies - 1983

Mean production of shrimp in the experimental ponds in 1983 was 228 kg ha^{-1}, and ranged from 181.5 to 291.2 kg ha^{-1} (Table 10). Survival ranged from 46.7 to 77.3%. Mean weight of shrimp at harvest was approximately 10.5 g, but as in 1982 weights and lengths were highly variable within (Figs. 3 and 4) and among (Figs. 5 and 6) ponds. As in 1982, shrimp were smaller in ponds with higher density (Table 11). Although densities of crustacean zooplankters varied by pond (Table 12), in all but one case the mean density exceeded that of the reservoir which received no distillery by-products.

Major water quality variables generally remained within acceptable ranges for aquaculture over the course of the yield trials (Table 13). Although dissolved oxygen levels during late August were occasionally below 1.0 mg liter^{-1} near the bottom they remained above 4.0 mg liter^{-1} near the surface (Figs. 8 through 13) at early morning.

Market Value

The "from pond to wholesale dealer" value of shrimp of the size produced in this study was estimated by a major seafood distributor to range from $3.35 to $7.71/kg whole body or from $4.89 to $10.14/kg for tails only. Locally, retail prices for similar-sized (50-60 count/lb) range up to $24.42/kg. Using $10.00/kg as a moderate direct wholesale price, and extrapolating the production data to a hectare basis, the 1982 and 1983 shrimp crops had a gross wholesale worth of approximately $1,040 and $2,280, respectively.

Live golden shiner generally have a wholesale value of $7.75/kg on the baitfish market in Illinois. After extrapolating to a hectare basis, the 1982 golden shiner crop had a gross wholesale worth of approximately $1,984.00

DISCUSSION

Findings from several laboratory studies indicated that corn distiller's solubles are not highly toxic to aquatic organisms at concentrations ranging up to 10,000 ppm. However, the high biological oxygen demand of the material requires that it be administered to ponds at rates less than 2,000 ppm on a daily basis. In future trials, dissolved oxygen levels of ponds should be used as a guideline for determining desirable application rates.

It is noteworthy that in laboratory studies golden shiners were observed to actively consume the particulates of the corn distiller's solubles.

Direct consumption of the particulates by fish makes the use of corn distiller's solubles in aquaculture much more attractive than if the by-product only serves to increase pond fertility.

Despite the minimum amount of food material added to the ponds, production of shrimp and fish was favorable over the 4 month growing periods. In 1982, shrimp grew from an average initial weight of 0.02 g to over 11.0 g, and average production was equivalent to approximately 104 kg ha^{-1}. Golden shiners reared in the same ponds as shrimp had production rates equivalent to 130 kg ha^{-1}. In 1983, monoculture of shrimp at higher densities (3,000 to 5,000 shrimp stocked per pond versus 2,000 in 1982) resulted in an average production equivalent to approximately 228 kg ha^{-1}, with individual shrimp averaging 10.5 g.

Based on estimated wholesale prices of $10.00 and $7.75 per kilogram for frozen shrimp and live fish, respectively, the gross profit margin would have exceeded $2,000 ha^{-1} both years. In comparison, farmers growing corn or soybeans rarely obtain gross profit margins in excess of $350 ha^{-1} in southern Illinois. Net profit potentials are more difficult to assess due to the cost and availability of shrimp post-larvae and the market distribution system for live bait fish in Illinois. Post-larval shrimp are currently very expensive, costing $50/1,000. Thus with the average stocking density of 40,000 shrimp/ha in 1983, the net profit would have been only $280 ha^{-1} ignoring all other costs.

A producer of live golden shiners in Illinois would likely not be able to market his product as a direct wholesale to bait shops because of competition with large distributors. More likely, golden shiners would have to be sold to the distributors at about half ($3.90/kg) the wholesale value.

Considering that the feed (ethanol by-products) would be free or inexpensive, post-larval shrimp represent the major non-fixed cost incurred, excluding labor considerations. Consequently, economics require that post-larval shrimp be obtained at a lower cost and/or shrimp production increase. As a spin-off of this project, a master's degree student is currently conducting a thesis project aimed at developing a prototype hatchery suitable for local production of post-larval shrimp.

In addition to lowering the costs of post-larval shrimp, it is anticipated that shrimp (and fish) production can be significantly increased in future trials. Although production results of shrimp and fish in 1982 and 1983 were encouraging, several factors existed which impeded production; these included: 1) little by-product was added to the ponds; 2) ponds were new and had minimal natural productivity; 3) grass was not fully established on the watershed and ponds became turbid, further diminishing natural food supply; and 4) lower than normal temperatures prevailed over much of both growing periods resulting in pond waters rarely being at optimal temperatures. Although the present project has terminated, additional pond yield trials will be conducted in summer, 1984. The Vienna distillery has been running regularly since Fall, 1983, and sufficient by-product for the project is anticipated.

The use of corn distiller's mash for feeding livestock has been highly successful. Use of the solubles by-product, in addition to the mash, may prove to be equally successful for aquaculture. Thus, in addition to fuel, ethanol plants can produce feed and food. This is a strong argument for defusing social debates raised about using a food/feed for producing energy, especially when one considers that on a world-wide scale, food is as scarce as fuel.

Project Dissemination (see Appendix)

Publicatons:

Kohler, C.C., W.M. Lewis, and S.P. Krueger. In press. Preliminary observations on use of ethanol distiller's by-products for polyculture of freshwater prawn (Macrobrachium rosenbergii) and golden shiner (Notemigonus crysoleucus). 1st Biennial Conf. Warmwater Aquaculture--Crustacea. Feb. 9-11, 1983. Laie, Hawaii.

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News Conferences:

Kohler, C.C., panel member
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Feb., 1981
Vienna Correctional Center, Vienna, IL

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"Update on use of ethanol distillery by-products for Aquaculture"
Nov., 1982
Vienna Correctional Center, Vienna, IL

News Articles:

"Shrimp, golden shiners fed corn wastes from Illinois Ethanol Distillery program"
Aquaculture Magazine, January/February, 1982

"Using solid byproducts could get fishy"
Daily Egyptian, November 17, 1981

"The ole alcohol hole: Scientists hope fishing better with ethanol"
The Evansville Courier, September 28, 1982

News Release:

News from SIU-C University News Service, 10/13/81
Article appeared in several papers throughout the country

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Table 1. Composition of corn distiller's by-products on a dry matter basis.[a]

Component	Corn Distillers Grains with Solubles	without solubles	Corn Distillers Solubles[a]
Dry matter	100.0	100.0	100.0
Ash %	2.8	2.8	8.6
Crude fiber %	9.8	13.0	4.3
Ether extract %	10.1	10.1	9.8
Crude protein %	29.8	29.5	28.9
Digestible protein %	23.4	23.1	22.6
Ligin %	6.5	----	2.2
TDN %	88.0	84.0	88.0
Calcium mg kg	0.1	0.1	0.38
Iron %	0.02	0.02	0.06
Magnesium %	0.07	0.07	0.69
Phosphorus %	0.4	0.4	1.47
Potassium %	0.1	0.1	1.87
Sodium %	0.98	0.98	------
Cobalt mg/kg	0.1	0.1	------
Copper mg/kg	48.6	48.6	88.9
Manganese mg/kg	20.5	20.5	79.0
Biotin mg/kg	0.8	0.4	1.6
Carotene mg/kg	4.0	-----	0.8
Choline mg/kg	2686.0	2021.0	5179.0
Niacin mg/kg	72.7	45.9	123.9
Pantothenic acid mg/kg	11.9	6.4	22.5
Riboflavin mg/kg	9.3	3.4	18.2
Thiamine mg/kg	3.2	2.0	7.3
Glycine %	0.54	-----	1.18
Leucine %	2.39	3.9	2.26
Lysine %	0.76	0.98	0.97
Methionine %	0.54	0.43	0.65
Phenylalanine %	1.85	0.65	1.61
Threonine %	1.09	0.33	1.07
Tryptophan %	0.11	0.22	0.22
Tyrosine %	0.65	0.98	0.75
Valine %	1.74	1.30	1.61

[a] Information supplied by Stan Jones, Alcohol Fuels Coordinator, Vienna Correctional Center, Vienna, IL.

[b] BOD (5 day at 20°C) = 1940 mg liter^{-1}

Table 2. Percent composition of pressed beer brewer's grain on a dry matter basis.

Component	Percent
Crude Protein	27.8
Crude Fiber	18.9
Digestible Nutrients	76.0
Ash	4.1
Calcium	0.2
Phosphorus	0.6
Magnesium	0.3
Potassium	0.2

Table 3. Percent survival of golden shiner and crayfish subjected to various concentrations of distiller's solubles over two separate 96-hr periods.

	Concentration (ppm) of Corn Distillers Solubles					
Organism	0	1000	1800	3200	5600	10,000
Golden Shiner						
Test-1	100	100	100	83	100	100
Test-2	100	100	100	100	100	100
Crayfish						
Test-1	100	100	100	100	100	100
Test-2	100	67	100	100	100	100

Table 4. Dissolved oxygen and pH values in algal cultures subjected to various concentrations of corn distiller's solubles (Mean Temperature 24°C).

Parameter and Time	Concentration (ppm) of Corn Distiller's Solubles					
	0	1000	1800	3200	5600	10,000
Dissolved oxygen (ppm)						
hr after application						
0	8.0	7.8	7.8	8.0	7.9	7.9
24	4.6	0.8	0.8	0.8	0.6	0.6
48	7.4	0.8	0.8	0.6	0.6	0.6
72	7.2	1.5	1.2	0.6	0.6	0.6
96	7.5	7.8	7.8	3.3	1.0	0.6
120	---	---	---	---	---	---
144	9.5	10.4	11.6	10.6	8.2	2.9
pH						
hr after application						
0	6.5	6.5	6.5	6.5	6.5	6.5
24	6.5	6.5	6.5	6.5	6.5	6.5
48	6.4	6.5	6.4	6.4	6.4	6.3
72	6.6	6.5	6.5	6.6	6.6	6.6
96	6.6	6.7	6.7	6.7	6.9	7.1
120	---	---	---	---	---	---
144	6.7	6.9	6.9	7.0	7.2	7.7

Table 5. Mean values of water quality parameters monitored over two 96-hr studies in aquaria waters subjected to various concentrations of corn distillers solubles.

Parameter	Concentration (ppm) of Corn Distiller's Solubles					
	0	1000	1800	3200	5600	10,000
Dissolved oxygen (ppm)	8.4;8.1	8.1;8.0	7.8;7.9	7.6;7.5	6.5;7.2	6.3;7.1
pH	7.4;7.3	7.4;7.4	7.4;7.3	7.4;7.4	7.3;7.5	7.4;7.5
Alkalinity (ppm)	55;44	80;64	87;72	103;79	94;101	88;87
Hardness (ppm)	138;135	140;121	156;128	161;136	161;173	168;146
Ammonia nitrate (ppm)	2.1;4.5	1.2;2.0	0.8;1.2	1.2;0.9	1.2;1.0	0.8;0.8
Ammonia (ppm)	0.5;0.6	0.5;0.5	0.7;0.6	0.6;0.5	0.8;0.7	0.9;0.9

Table 6. Summary of 1982 summer stocking and production data for freshwater shrimp reared in ponds receiving ethanol distiller's by-products.

	Stocking Strategy			Harvest Data			
Trial Pond	Organisms Cultured	Density No. m^{-2}	Mean weight (g)	Rearing Period (days)	Survival (%)	Mean Weight (g)	Production (kg ha^{-1})
1	Postlarval shrimp	2.00	0.02	122	43.1	11.4	106
	Adult shiners	0.08	27.00	122	>90.0	--	130.0[a]
2	Postlarval shrimp	2.00	0.02	121	34.0	12.5	85.0
	Adult shiners	0.08	27.00	121	>90.0	--	130.0[a]
3	Postlarval shrimp	2.00	0.02	119	37.0	17.9	132.5
4	Postlarval shrimp	2.00	0.02	113	51.0	6.1	62.2
5	Postlarval shrimp	2.00	0.02	122	75.0	8.5	129.0
	Adult shiners	0.08	27.00	122	--	--	---[b]

[a] Fish from ponds 1 and 2 were combined at harvest.

[b] Incompletely harvested.

Table 7 . Lengths and weights of freshwater shrimp harvested from ponds receiving ethanol distiller's by-products in summer, 1982.

Trial Pond	Stocking No.	Total No. Harvest	Sample size	Total Length (mm) Mean	Range	Weight (g) Mean	Range
1	2,000	962	200	115.0	85 - 145	11.4	4 - 26
2	2,000	680	200	118.4	80 - 142	12.5	3 - 23
3	2,000	734	200	130.4	74 - 162	17.8	3 - 38
4	2,000	1,013	200	95.5	62 - 117	6.1	2 - 12
5	2,000	1,508	200	106.8	76 - 135	8.6	3 - 24

Table 8. Sizes of golden shiners harvested from ponds receiving ethanol distiller's by-products in summer, 1982.

Pond	Size class (Total Length in cm)				
	2.5	5.0	7.5	10.0	12.5
1					
Percentage	0.0	18.4	52.6	23.0	6.0
Mean weight (g)	---	3.0	6.2	14.4	27.0
2					
Percentage	0.0	12.4	68.4	12.0	7.0
Mean weight (g)	---	3.0	6.2	14.3	27.0

Table 9. Ranges of water quality measurements taken in culture ponds receiving ethanol distiller's by-products in summer, 1982.

Parameter	Pond 1	2	3	4	5
Dissolved oxygen (ppm)	6.3-9-4	5.2-9.6	9.4-9.5	6.9-10.2	7.2-10.8
pH	6.4-7.5	5.7-7.4	5.8-8.5	5.8-8.3	5.7- 8.5
Total alkalinity (ppm)	16-42	18-30	22-48	20-56	14-32
Total Hardness (ppm)	20-40	24-30	26-40	20-28	24-40
Secchi disc (m)	0.1-1.1	0.1-0.4	0.1-1.0	0.1-0.14	0.14-0.2
Temperature (°C)	14-30	14-30	14-30	14-30	14-30

Table 10. Summary of 1983 summer stocking and production data for freshwater shrimp reared in ponds receiving ethanol distiller's by-products.

Stocking Strategy				Harvest Data			
Trial Pond	Organisms Cultured	Density No. m^{-2}	Mean weight (g)	Rearing Period (days)	Survival (%)	Mean Weight (g)	Production (kg ha^{-1})
1	Postlarval shrimp	3.0	0.02	106	56.7	10.8	181.5
2	Postlarval shrimp	3.5	0.02	111	77.3	10.9	291.2
3	Postlarval shrimp	3.5	0.02	107	59.2	11.2	229.2
4	Postlarval shrimp	5.0	0.02	127	5.4[a]	9.8[a]	26.3[a]
5	Postlarval shrimp	5.0	0.02	126	46.7	9.2	212.33

[a] Shrimp died when cold weather set in after pond had been partially drained for harvest. These data not included in overall means.

Table 11 . Lengths and weights of freshwater shrimp harvested from ponds receiving ethanol distiller's by-products in summer, 1983.

Trial Pond	Stocking No.	Total No. Harvest	Sample size	Total Length (mm)		Weight (g)	
				Mean	Range	Mean	Range
1	3000	1701	248	110.9	72 - 170	10.8	2.5 - 41.2
2	3500	2704	364	111.0	82 - 148	10.9	3.8 - 28.9
3	3500	2071	366	111.0	68 - 143	11.2	2.4 - 27.0
4	5000	272	219	109.1	58 - 142	9.8	2.3 - 22.5
5	5000	2336	515	102.4	58 - 132	9.2	1.0 - 21.5

Table 12. Mean number of crustacean zooplankters[a] collected per liter sample of water in Summer, 1983.

Date	Ponds 1	2	3	4	5	Pond 1-5	Reservoir
July 6	2.7	22.1	6.6	2.2	2.0	7.1	2.1
July 26	2.6	6.1	8.7	2.7	5.0	5.0	1.6
August 24	4.9	8.1	8.5	2.1	4.7	5.7	1.4
August 29	2.9	9.2	2.8	1.2	2.4	3.7	1.1
September 8	3.1	12.5	6.2	7.7	3.5	6.6	2.0

[a] *Daphnia*, cyclopoid and calanoid copepods, *Chaoborus* larvae, ostracods.

Table 13. Ranges of water quality measurements taken in culture ponds receiving ethanol distiller's by-products in summer, 1983.

Parameter	Pond 1	2	3	4	5
Dissolved oxygen (ppm)	0.4-8.2	0.2-9.6	0.3-7.6	0.4-8.0	0.3-7.9
Total Alkalinity (ppm)	38-38	36-38	54-56	72-74	32-32
Total Hardness (ppm)	42-44	40-40	60-62	70-70	36-38
Turbidity (J.T.U.)	2.1-2.3	3.2-3.3	7.0-7.6	3.7-4.0	5.5-5.8
Temperature (°C)	26-32	26-32	25-31	25-31	26-32

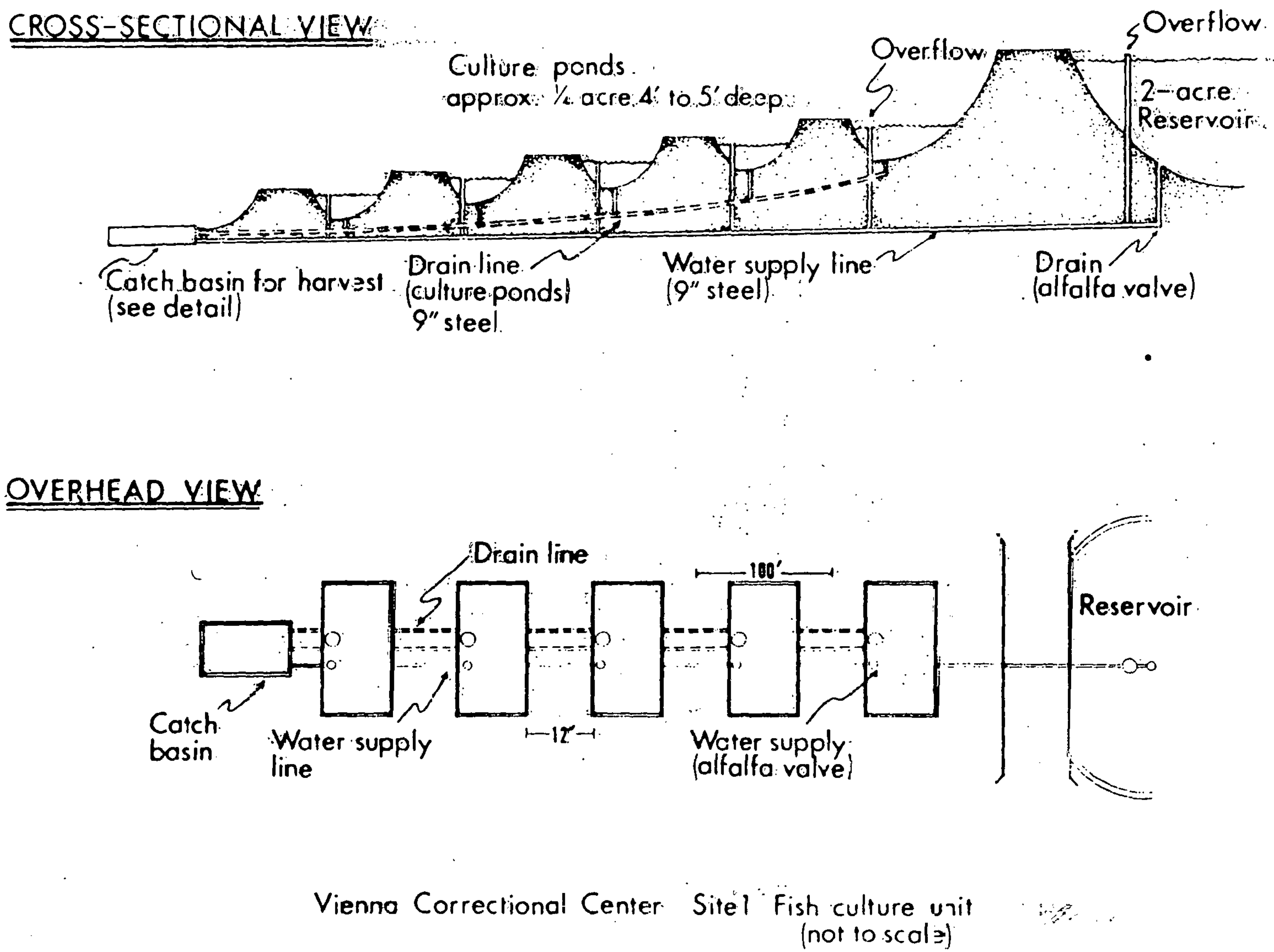


Figure 1. Schematic diagram of pond facility located in proximity to an ethanol distillery at the Vienna Correctional Center, Vienna, Illinois.

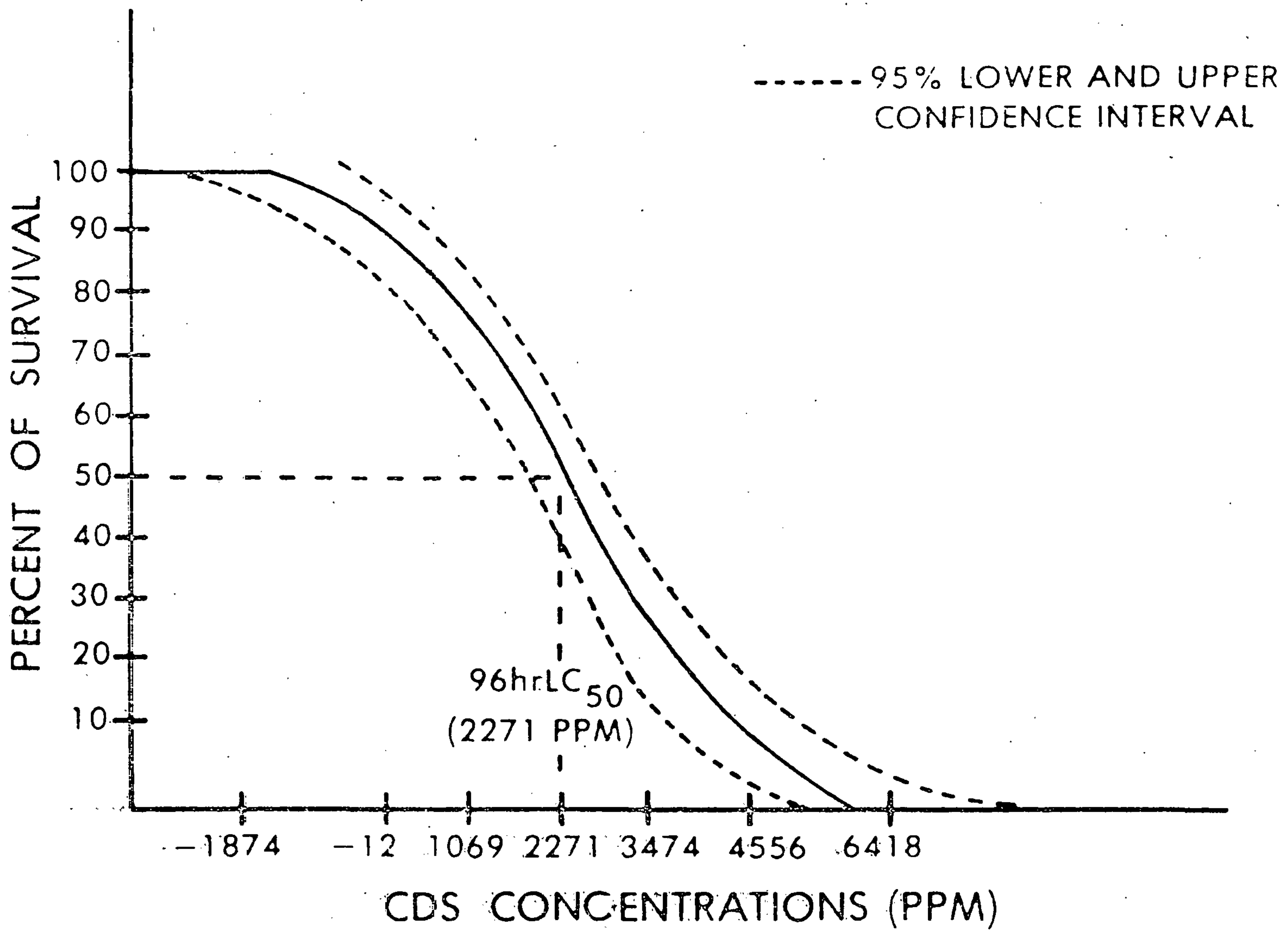


Figure 2. Relationship between percentage of survival of Daphnia for 96 hours and concentration of corn distillers solubles (C.D.S.), and the average theoretical log-normal relationship from which the 96-hr LC_{50} is estimated.

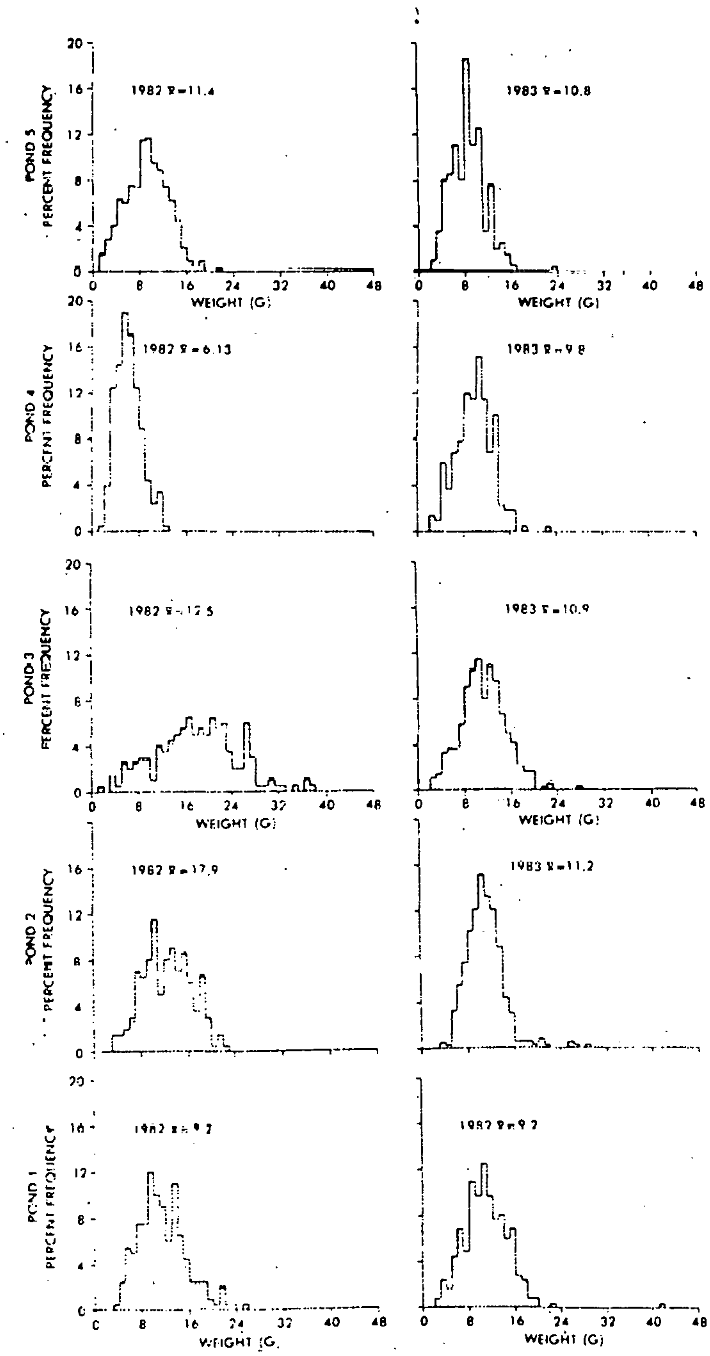


Figure 3. Percent grequency of occurrence of weight classes of freshwater shrimp harvested with each pond after the 1982 and 1983 production seasons.

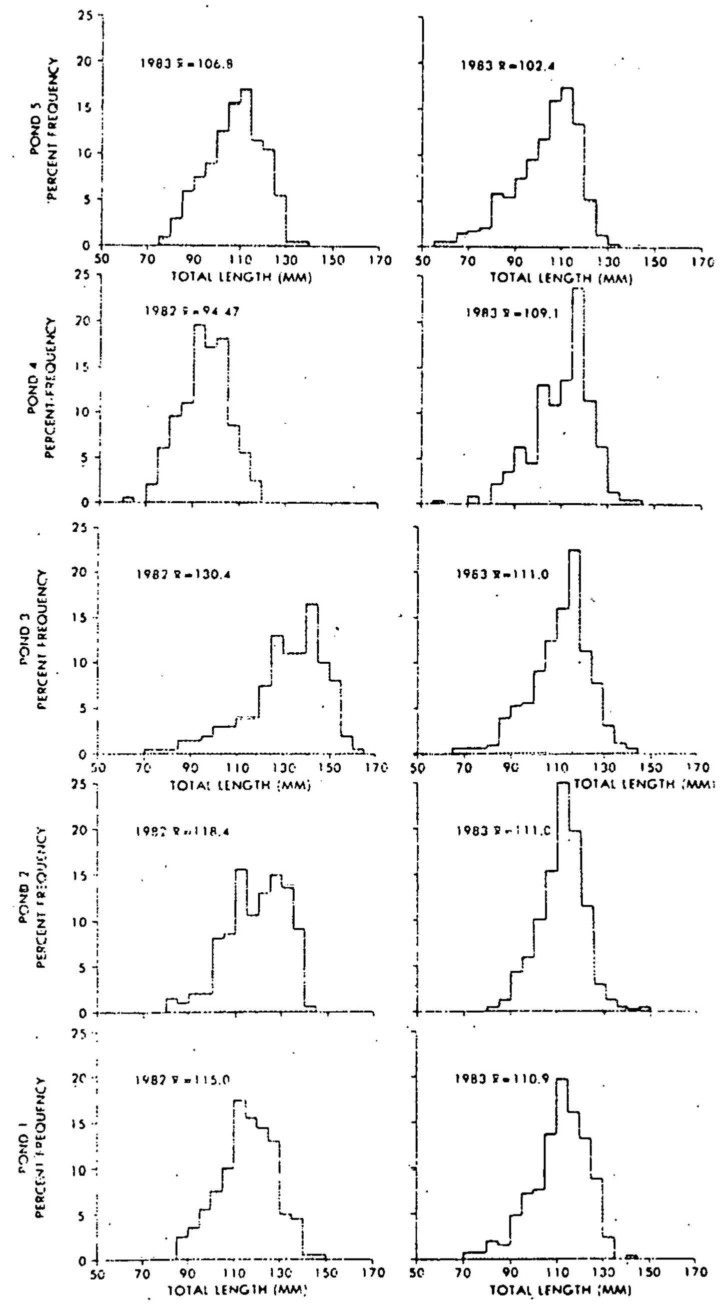


Figure 4. Percent frequency of occurrence of length classes of freshwater shrimp harvested within each pond after the 1982 and 1983 production seasons.

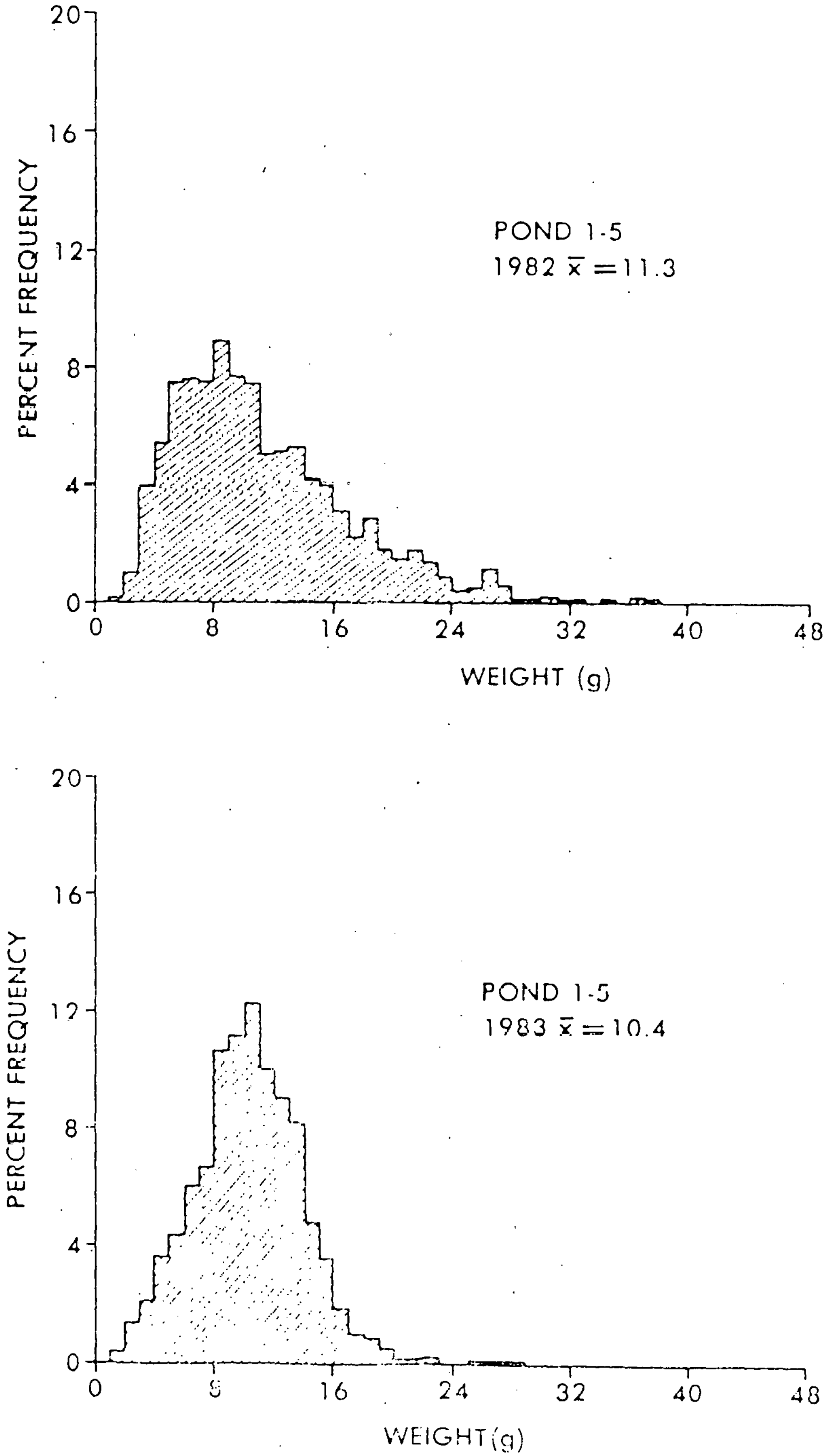
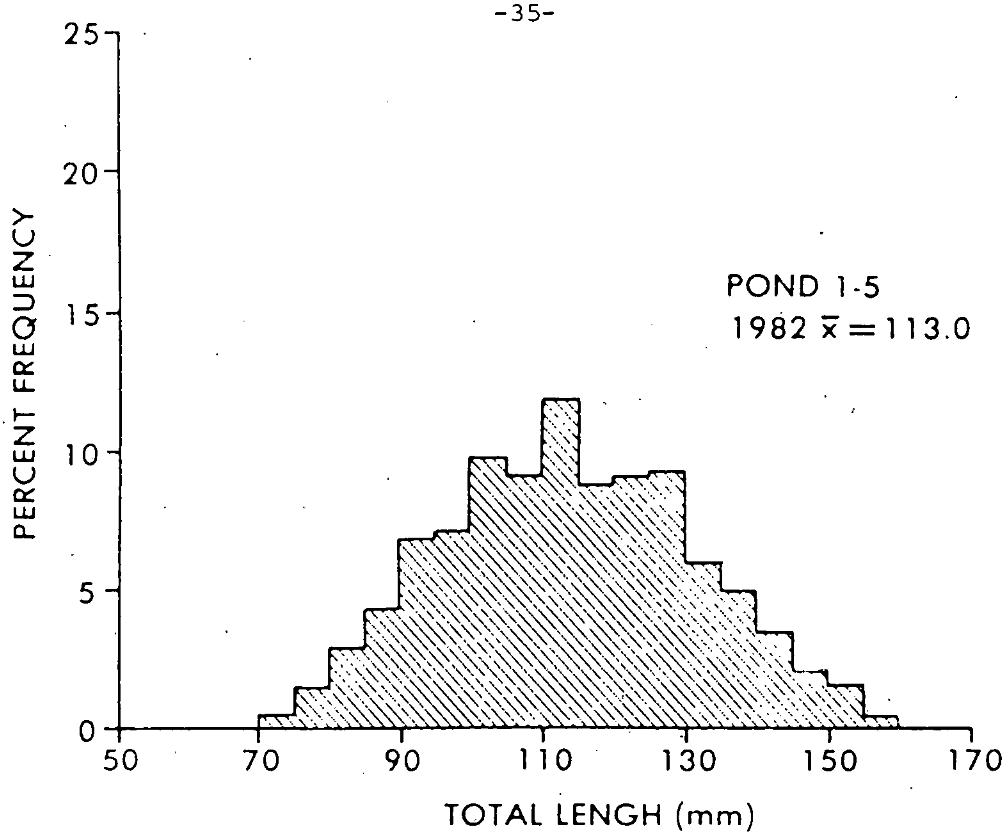


Figure 5. Percent frequency of occurrence of weight classes of freshwater shrimp harvested from among all ponds after the 1982 and 1983 production seasons.



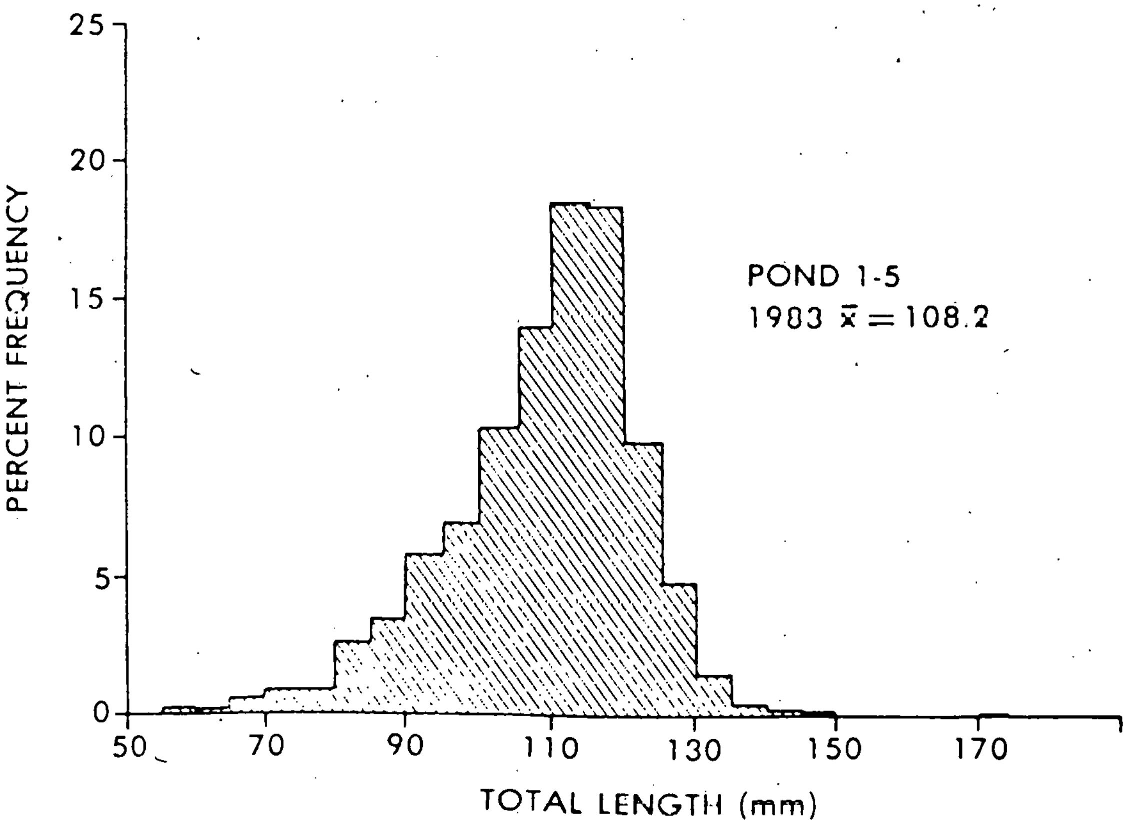


Figure 6. Percent frequency of occurrence of length classes of freshwater shrimp harvested from among all ponds after the 1982 and 1983 production seasons.

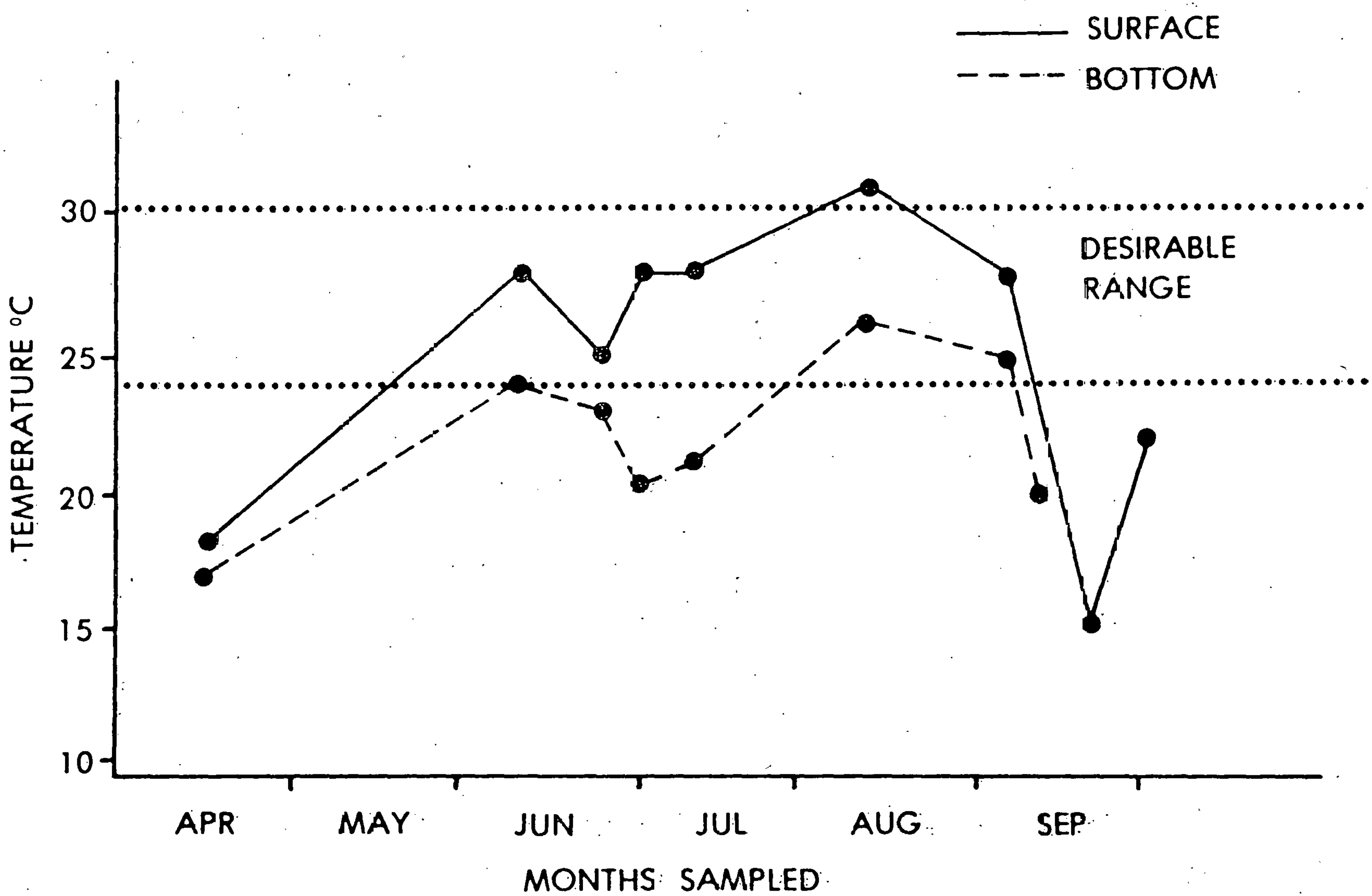


Figure 7. Mean temperature range for ponds receiving ethanol distillers by-products in summer, 1982.

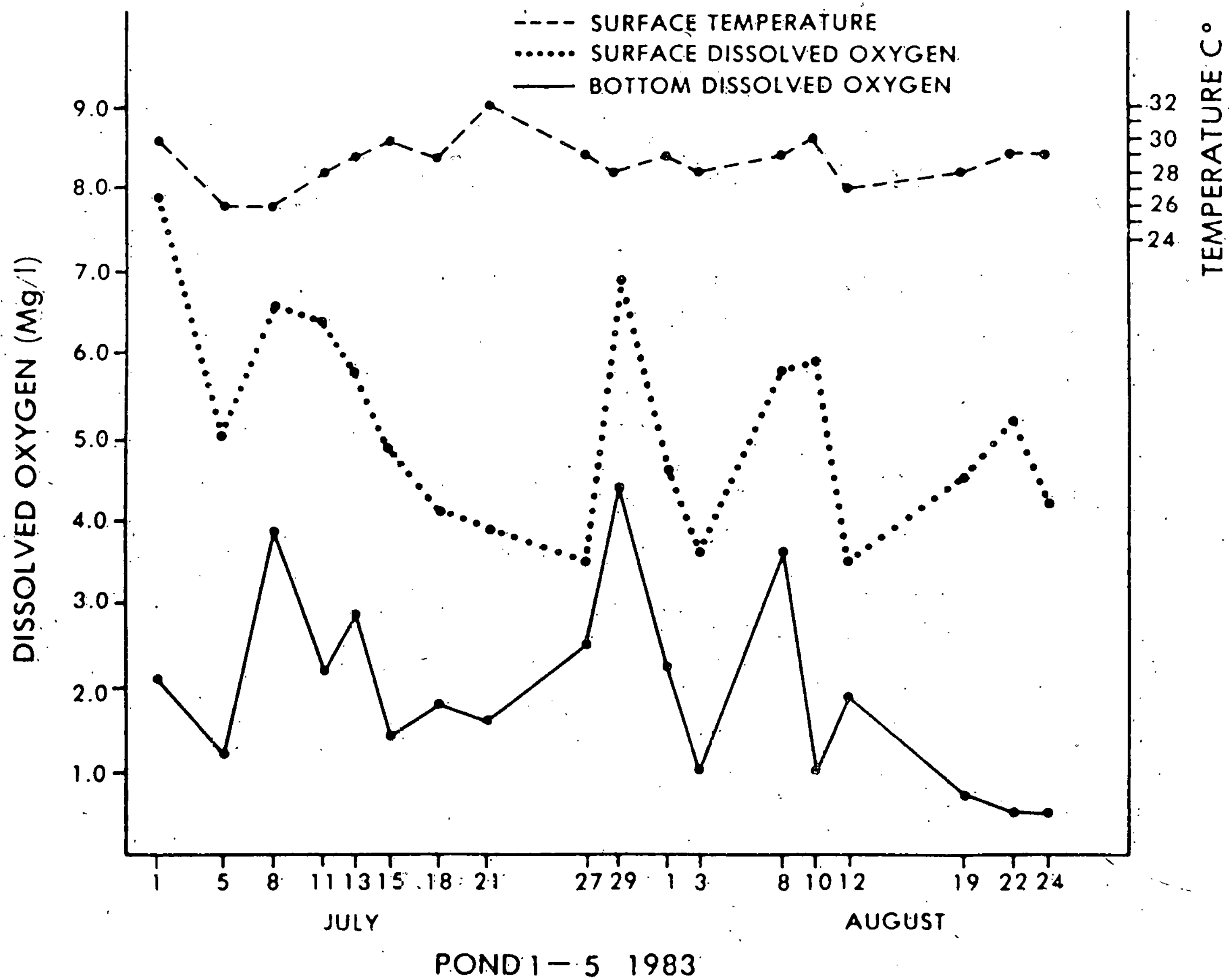


Figure 8. Mean surface temperature and mean dissolved oxygen near surface and bottom of all ponds during summer, 1983.

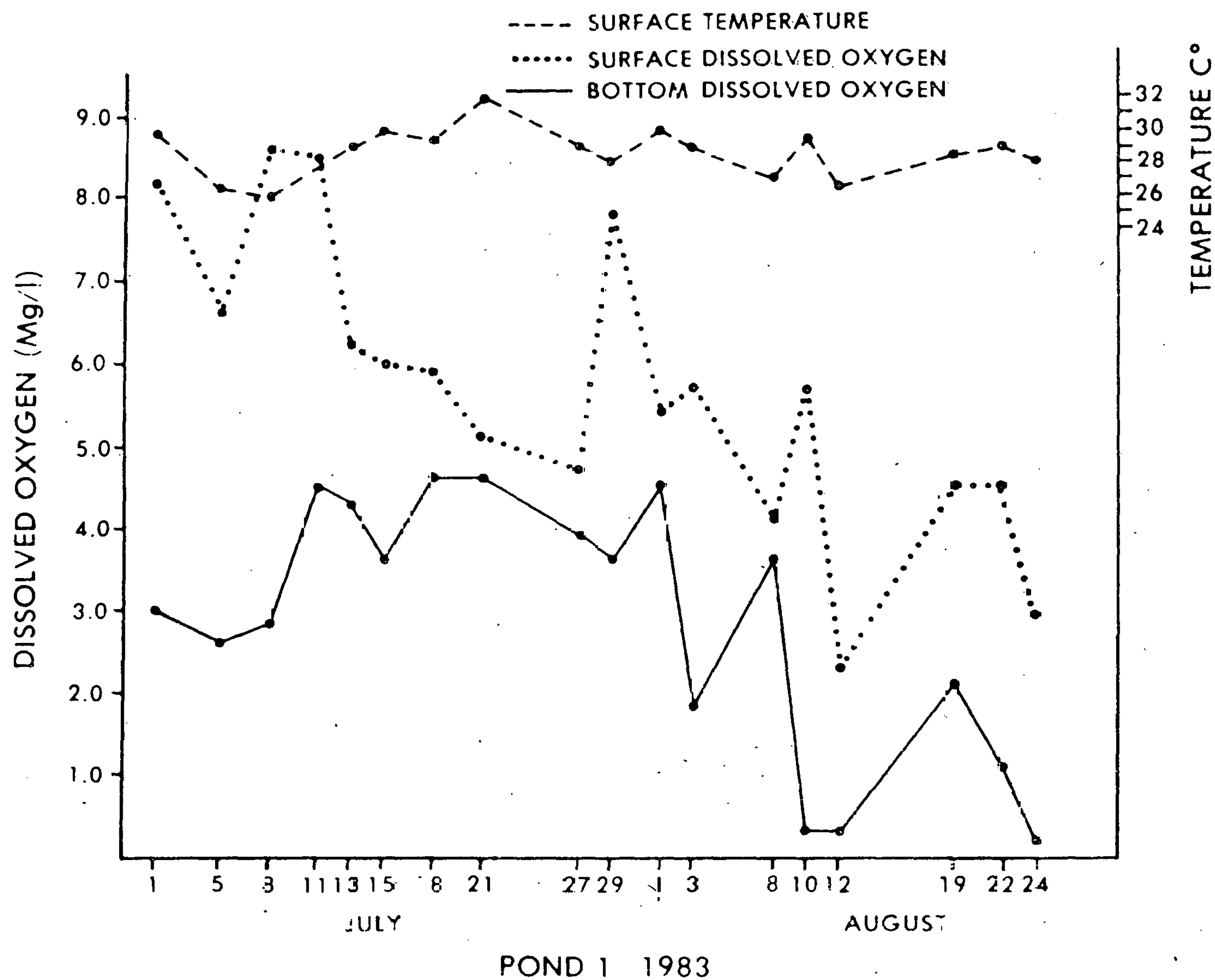


Figure 9. Surface temperature and surface and bottom dissolved oxygen levels for pond 1 during summer, 1983.

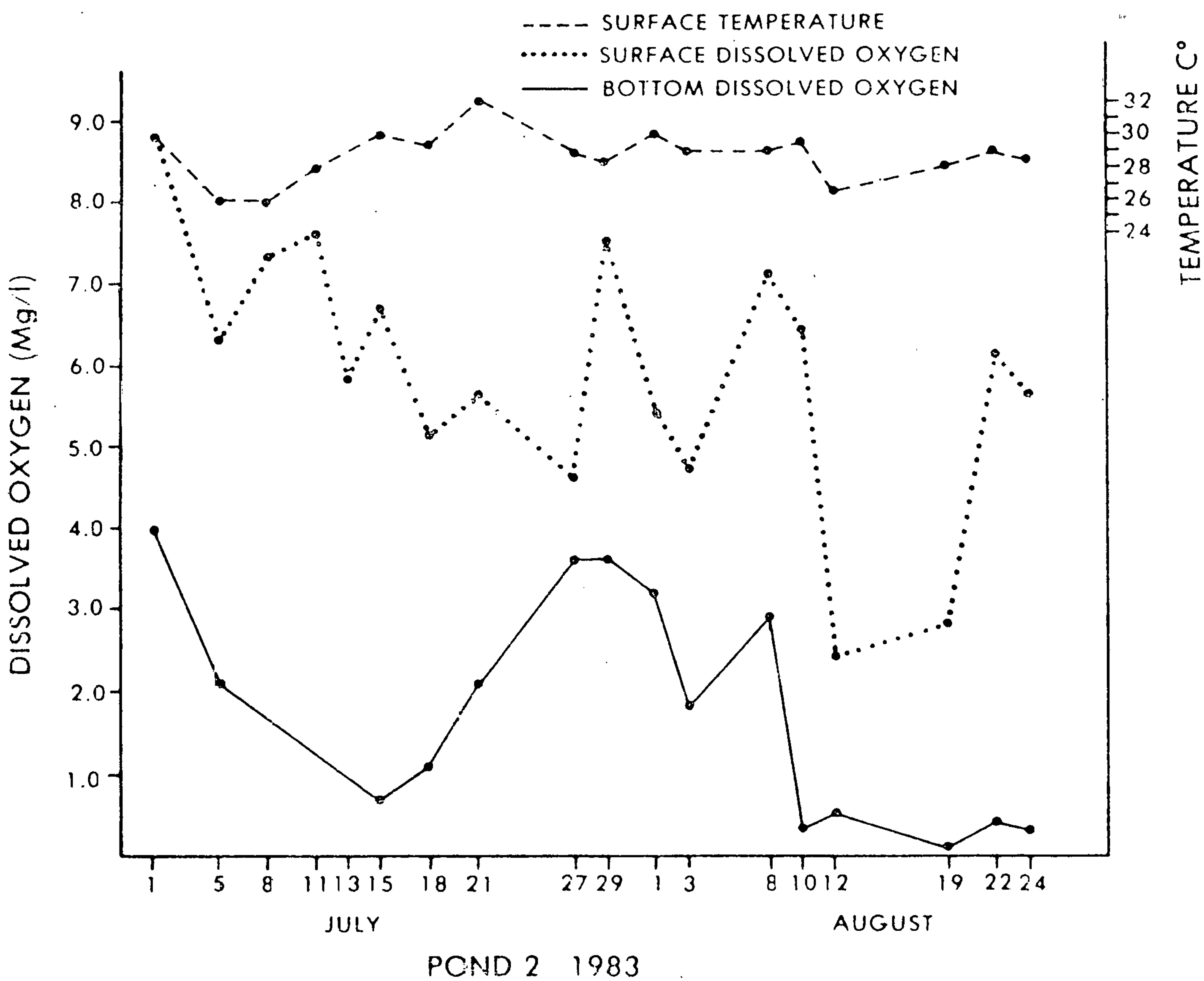


Figure 10. Surface temperature and surface and bottom dissolved oxygen levels for pond 2 during summer, 1983.

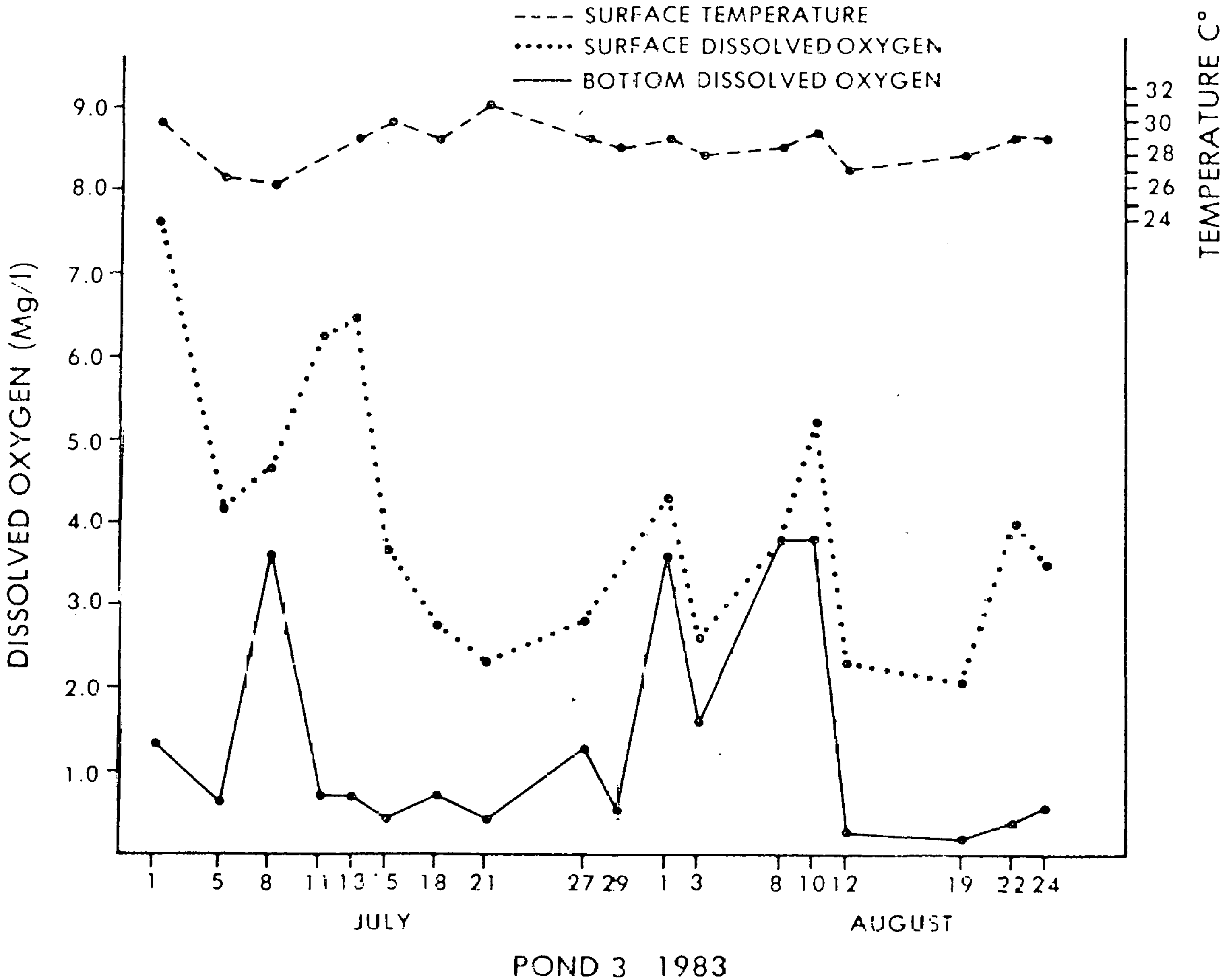


Figure 11. Surface temperature and surface and bottom dissolved oxygen levels for pond 3 during summer. 1983.

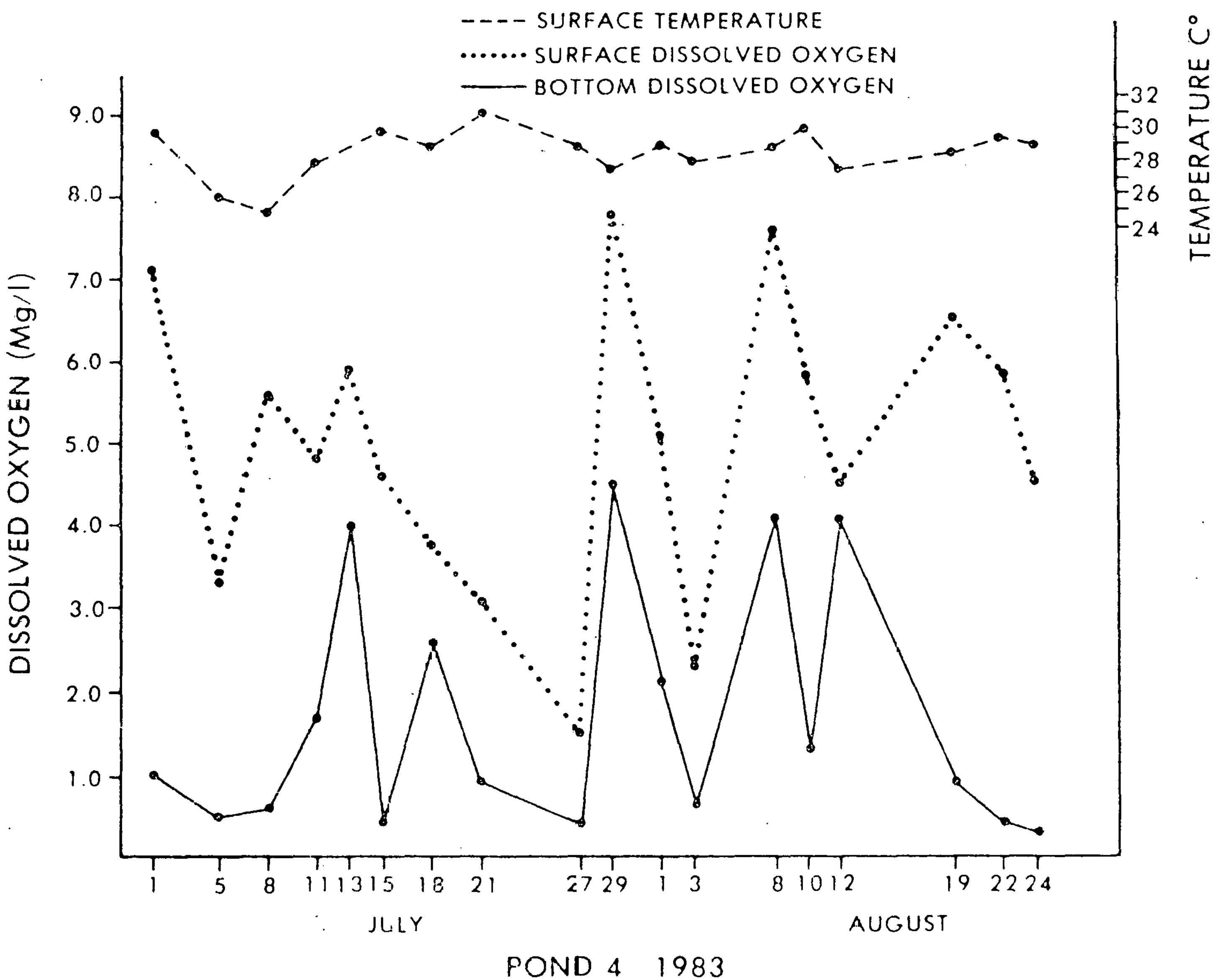


Figure 12. Surface temperature and surface and bottom dissolved oxygen levels for pond 4 during summer, 1983.

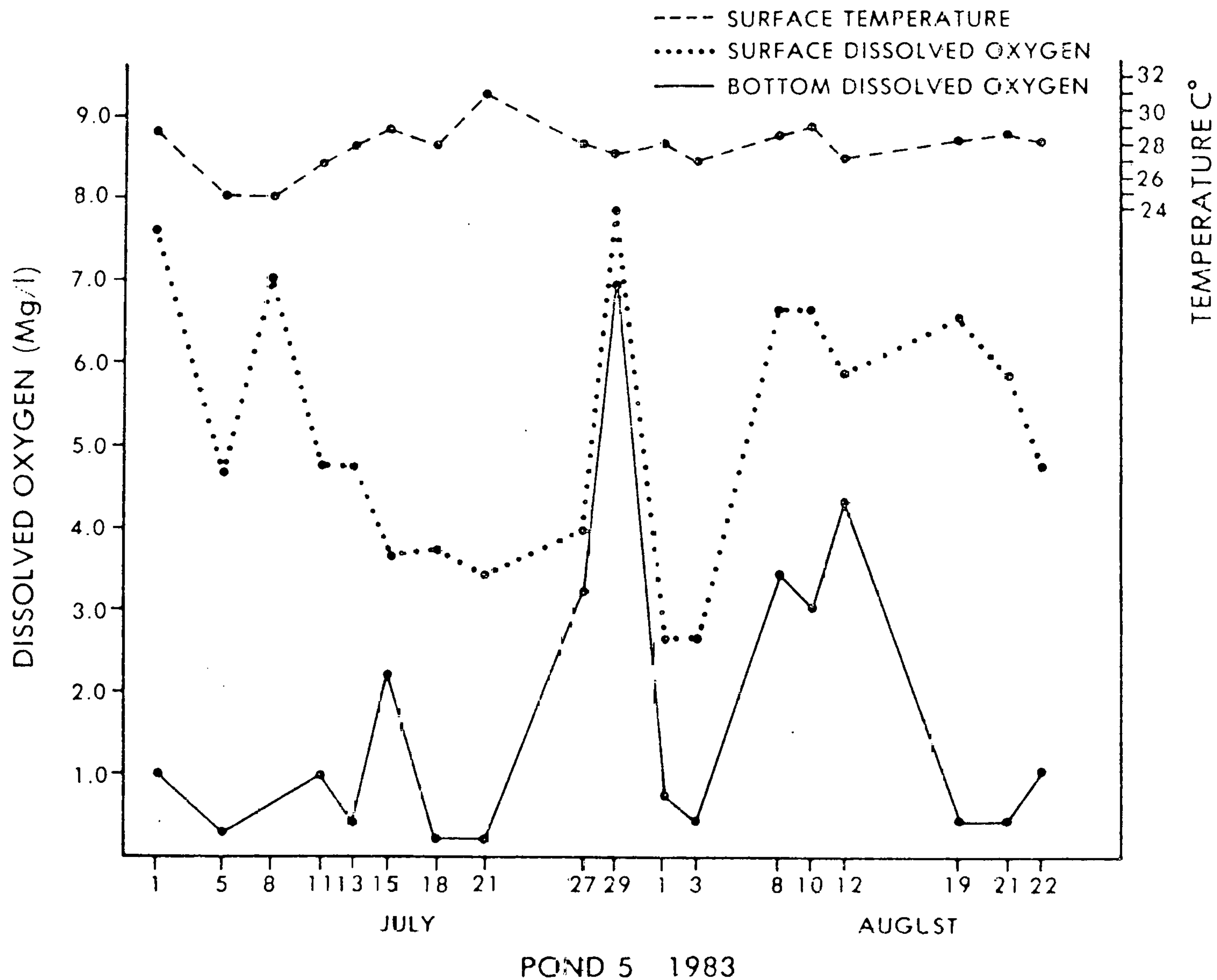


Figure 13. Surface temperature and surface and bottom dissolved oxygen levels for pond 5 during summer, 1983.

Appendix

1. Publications
2. News articles

Preprints & reprints removed and cycled separately.

*U. S. GOVERNMENT PRINTING OFFICE: 1984-746-081/10192

DOE/R5/10295-T1 USE OF CORN DISTILLER'S SOLUBLES FROM AN ETHANOL PLANT FOR AQUACULTURE DOE