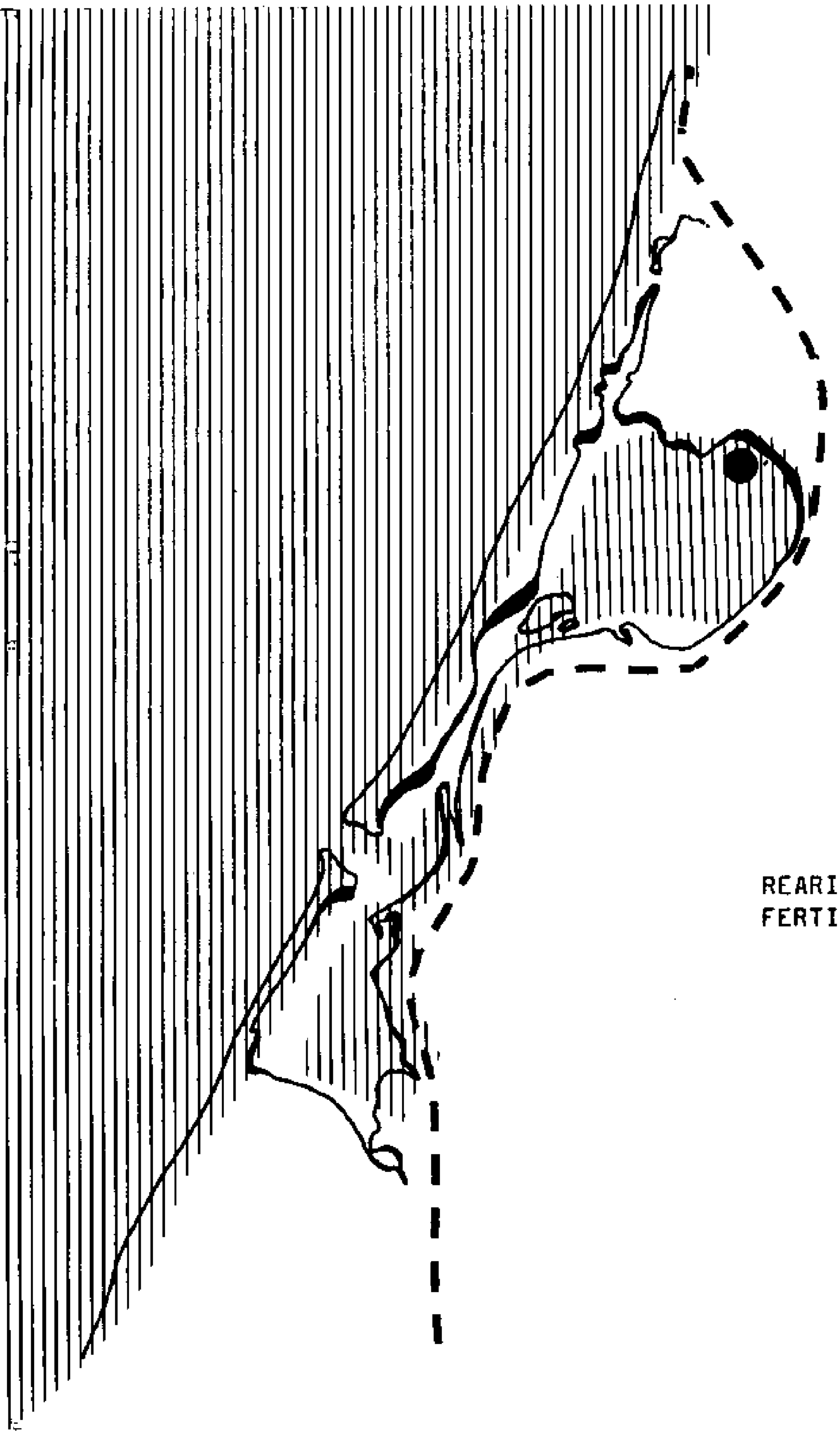

REARING PACIFIC SALMON IN SALTWATER PONDS FERTILIZED WITH DOMESTIC WASTEWATER

MARINE ADVISORY EXTENSION SERVICE
SEA GRANT PROGRAM
HUMBOLDT STATE UNIVERSITY

Errata

Rearing Pacific salmon in saltwater ponds fertilized with domestic wastewater.

Titles to Figures 2, 4, 5, 6, and 11 should read June-September, 1974.

In Table 18, data for Oxidation Pond and Jolly Giant Slough should read, "more than" 2400, and for North and South Ponds, Fecal Coliforms should read "less than" 3.

REARING PACIFIC SALMON IN SALTWATER PONDS FERTILIZED WITH DOMESTIC WASTEWATER

July - September 1974

By

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Humboldt State University

Partially Supported by National Oceanic and Atmospheric Administration, National Sea Grant Program, Coherent Area Project: Development of Living Marine Resources of Northern California

Data Report

January, 1975

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Report on Summer Rearing of Salmonids in Brackish Waters Fertilized with Domestic Wastewater

July - September 1974

BACKGROUND

In July 1971, two 0.15 hectare ponds located within the perimeter of an oxidation pond operated by the City of Arcata, northern California, were placed in operation to test empirically the potential of rearing salmon and trout on natural food chains produced by effluent-fertilized seawater (Allen, Conversano and Colwell 1972). As of January, 1975, nine rearing experiments have been completed. The results of the first six experiments have been reported by Allen and Dennis (1974). Data reports giving details on most studies undertaken during our first two rearing experiments are now completed (Allen, 1973). The results of our seventh experiment were briefly summarized in Calif. State Uni. (1973).

During the summer of 1974, yearling coho salmon (Oncorhynchus kisutch), fingerling chinook salmon (O. tshawytscha), yearling cutthroat trout (Salmo clarki), and steelhead trout fry (S. gairdneri) were reared in the system (Experiment VIII). This is the third attempt at summer rearing. Our first experiment in the summer of 1971 was completely unsuccessful, while our second attempt in the summer of 1972 (Experiment III) produced a 4 percent survival of coho fingerlings reared over a 45-day period.

The results of warm-weather rearing successfully completed during the summer of 1974 are of major importance to an assessment of the system as an alternate culture method for salmonids to be made at the completion of the 74-75 project year. This data report covers only studies completed during the summer of 1974 (Experiment VIII).

OPERATION AND DESCRIPTION OF PONDS

The system consists of two ponds (North Pond and South Pond, Figure 1). Each pond has a bottom either of mud, gravel, oyster, shell, or Hookton soil (a yellow, sandy soil). Two-meter square pens were constructed in each pond on each of the four soil types for use either to exclude fish from the substrates or to confine known numbers of fish over each substrate. To establish periods of catastrophic mortalities in the ponds, and to obtain independent estimates of survival rates, known numbers of salmon were reared in floating pens (live cars).

North Pond has always been involved in salmon rearing, whereas in earlier experiments South Pond was theoretically to operate as a comparison by use of seawater only in rearing experiments. Early attempts at rearing salmon in these high salinities were not successful as salmon were not properly acclimated and showed total mortalities either immediately on or shortly after planting. The rearing program was changed subsequently to having both ponds at roughly the same salinities (15 $^{o}/oo$), and modifying North Pond in several ways, while keeping South Pond unmodified. With the beginning of Experiment VIII reported here, North Pond was fitted with 2-foot vertical banks placed around most of the pond, forced-air pipe laid just outside this bank, and a major part of the mud bottom covered with gravel. Modifications to South Pond involved covering about one-third of mud bottoms with gravel, primarily to fill several low spots that developed in the center of the pond and caused difficulty in recovering fish.

Figure 1-A North Pond

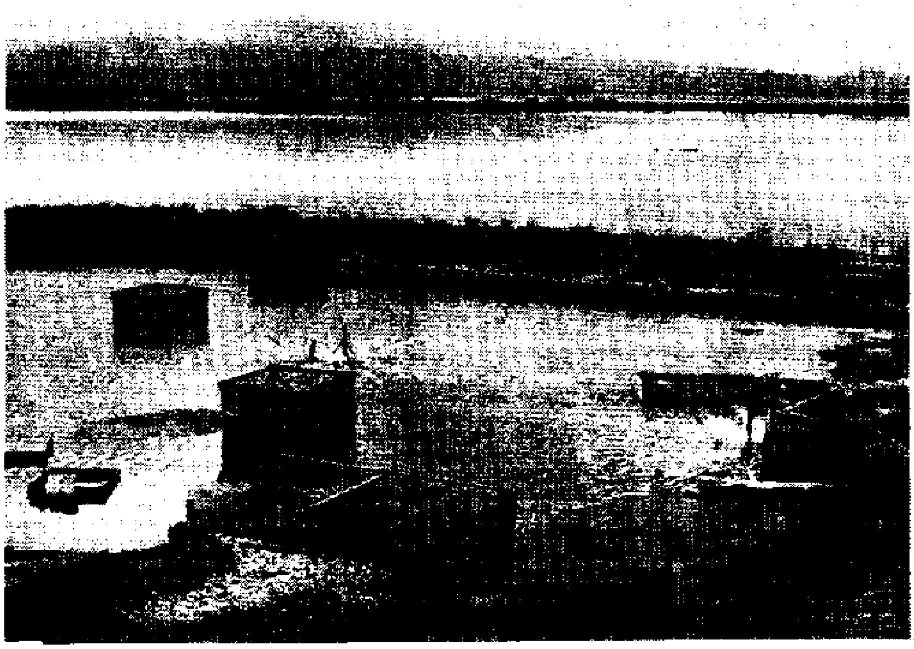

Figure 1-B South Pond

Following draining of the ponds on May 7 on completion of rearing Experiment VIII, the ponds were immediately refilled to a shallow depth in order to maintain a brood stock of amphipods in the ponds. Although the two ponds were refilled on the same day, and thus with the same seawater from Humboldt Bay, two different sets of conditions developed in the ponds as recorded on May 21 (Table 1). Similar conditions remained until June 17-19, when oxidation pond effluent and Humboldt Bay water were used to fill up each pond and produce salinities of about 18-20 $^{o}/_{oo}$. On June 25-27, a survey of the two ponds showed sharply differing conditions continued to exist (Table 1). Bioassay with salmonids on June 21 showed almost instant mortalities in North Pond water, and no mortality in South Pond. Undoubtedly the high pH values combined with the ammonium levels produced water in the toxic range for salmonids (Spotte 1970). North Pond water remained toxic to salmon until August 13 when the pond was drained for repairs and further modifications.

On July 3, about 1,200 salmonids of four species were placed in South Pond (Table 2). These fish were reared until September 20. During this period the pond received about 5" of oxidation pond water on two occasions to maintain water levels, and an additional 3" of Humboldt Bay water on one occasion to maintain salinity levels.

PHYSICAL-CHEMICAL PROPERTIES

During June and July, morning water temperatures consistently ranged between 21 and 23°C. During this period, a series of water temperatures taken in the afternoon or evening periods, showed surface temperatures reaching 25-26°C range. With the arrival of high overcast or fog conditions

Table 1. Comparison of Changes in Gross Conditions Recorded Between North and South Ponds in Late May and Late June, 1974.

Date of Observations	Properties	South Pond	North Pond
May 21	Color	Clear	Brown
	Plants	Dense *Ulva* stands	Dense diatom-copepod bloom
	pH	8.5	9.0
	Temperature (C)	22-23	24
	Salinity ($^o/oo$)	35	35
June 25-27	Color	Light brown	Green
	Plants	*Ulva, Enteromorpha*	Phytoplankton
	pH	7.6-7.7	9.2-9.6
	NH_3 (mg/l)	3.5-6.0	1.5-4.0
	Si (mg/l)	Trace	5
	PO_4 (mg/l)	1.1-1.8	2.0-4.2
	NO_2 (mg/l)	1.5	0.2
	Animals	Amphipods	Isopods
	Salinity ($^o/oo$)	18	20

Table 2. Kind, Number, and Place of Planting of Salmon and Trout South Pond, July 3, 1974 (Experiment VIII).

Species	Size: Av. Fk. Len (mm)	Size: Av. Wt. (gms)	Place of Rearing	Number
Silver Salmon	143	47	Pond	613
Chinook Salmon	88	15	Pond	431
Cutthroat Trout	168	69	Pond	136
Total Ponds				1180
Steelhead Trout	46	1.4	Four 4-square meter pens	400

during late July (Figure 2), water temperatures tended to remain below 20°C. (Figure 3).

Dissolved oxygen concentrations in South Pond were mainly from 5 to 9 mg./l, with much higher values reported from North Pond due to its excessive phytoplankton bloom (Figure 4). In early August with the advent of fog conditions, both ponds dropped to around 4 mg./l, then gradually rose during the remainder of the experiment. Surprisingly, a heavy period of fog in late August did not influence oxygen levels which kept steadily rising until the end of the experiment.

Hydrogen ion concentration (pH) showed a drastic difference between the ponds as first recorded in late June. High pH values (9 or higher) always occurred in North Pond, while South Pond varied only slightly around a mean value of about 7.5 (Figure 3).

Salinity values remained relatively stable in North Pond, beginning at around 20 °/oo and rising slowly to 22 °/oo, and varying between 16 and 20 °/oo until late August when the pond salinities were allowed to rise to 22-23 °/oo. Additions of oxidation pond effluent on 15 July and 6 August, reduced pond salinities by 3 °/oo, while addition of Humboldt Bay water on 12 August, raised the salinity by 3 °/oo.

Ammonia (NH_3) values were around 4-6 mg./l in both ponds, and both gradually decreased slowly to low or trace values. Nitrite values began in the 0.1-0.6 range in both ponds, dropping to less than 0.1 mg./l in early July, and remaining at low values for the rest of the experiment.

Phosphate (PO_4) was lower in South Pond (1.8 mg./l) at the start of the experiment than North Pond (4.2 mg./l). North Pond values dropped rapidly to less than 0.5 mg./l, while South Pond slowly increased to around

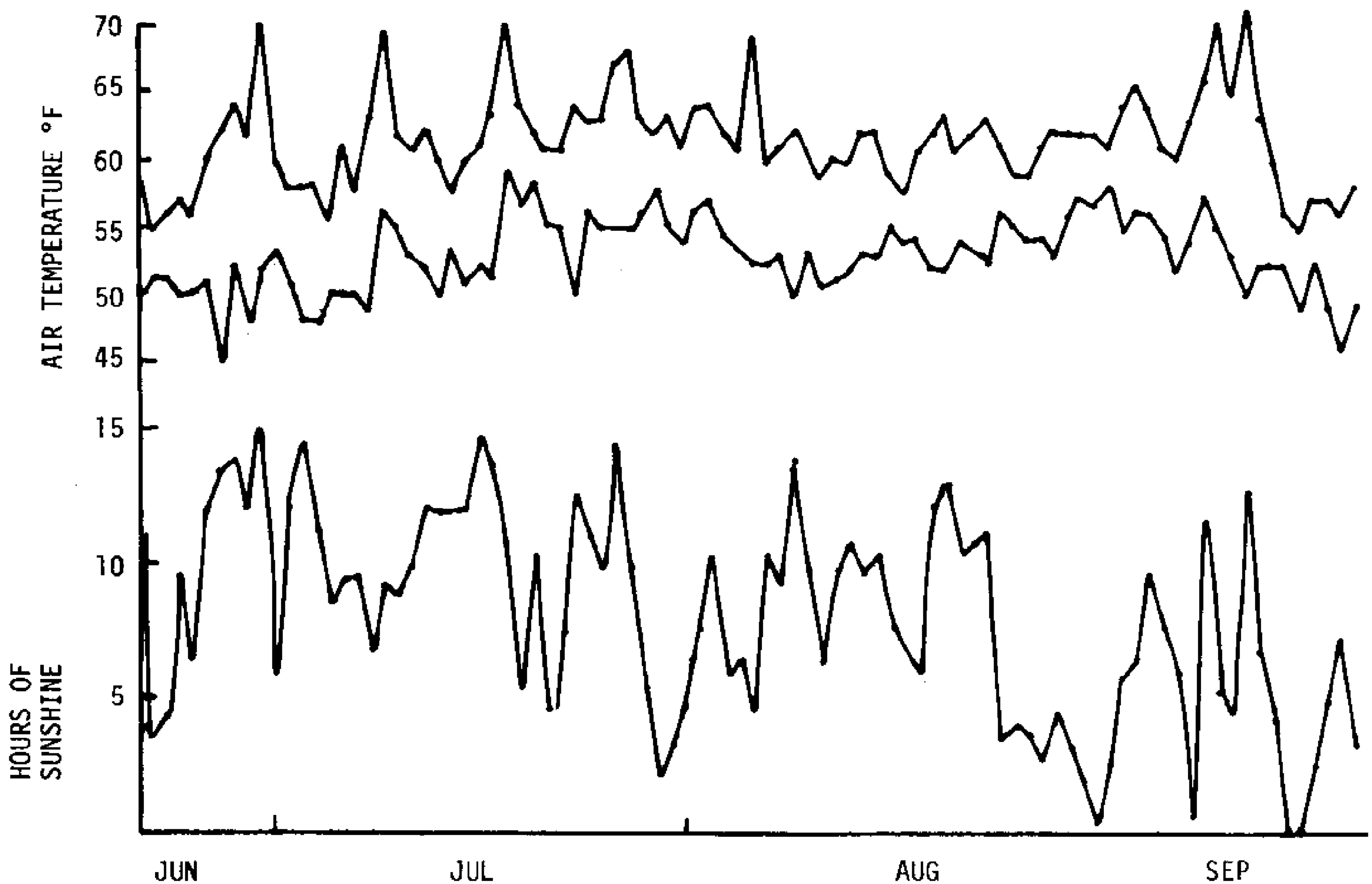

Figure 2. Average air temperature and hours of sunshine as determined by U.S. Weather Service station located at Eureka, California, June-September, 1975.

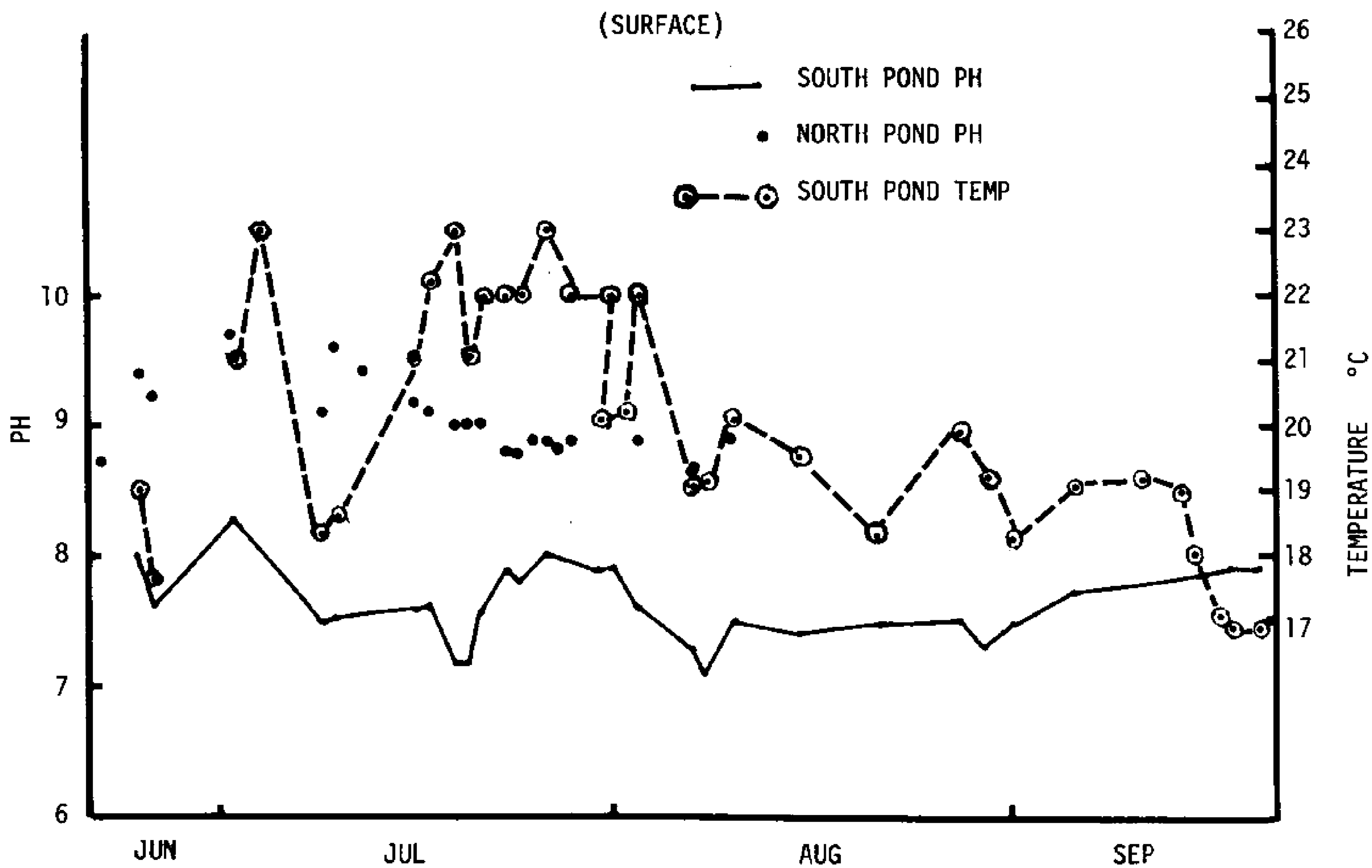

Figure 3. Temperature and hydrogen ion concentration (pH) of North and South Ponds, June-September, 1974 (Experiment VIII).

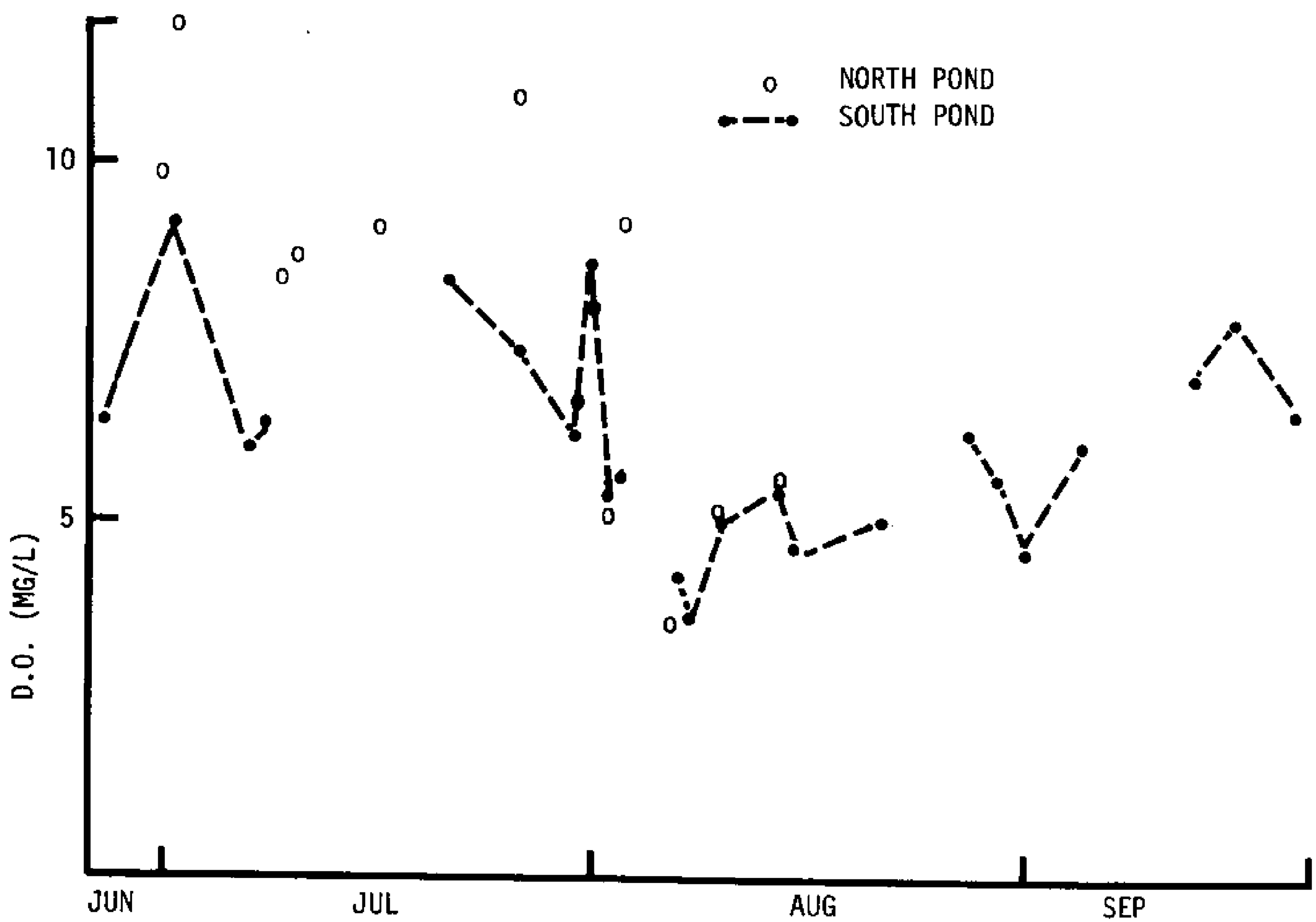

Figure 4. Dissolved oxygen (D.O.) in surface waters of North and South Ponds, June-September, 1975 (Experiment VIII).

3 mg./l. This was a very curious finding. North Pond effluent was introduced via an intake pipe located under the North Pond dike. This inflow carried initially a considerable amount of pond sediments. South Pond effluent was added by pumping, with very little sediment added. In addition to Ulva and Enteromorpha, algal mats formed on the bottom of South Pond, and during late August broke loose and floated to the surface. When the mats became excessively thick, they were removed from the ponds to temporary sludge beds. Decomposition of this material may have caused the consistently high phosphate values, whereas in North Pond the phytoplankton bloom either fixed the nutrient, dropped it out on the bottom as dead cells, or in some other way took the phosphate out of circulation.

RESULTS OF TROUT AND SALMON REARING

The survival of yearling silver salmon planted into the ponds was highest of the four types of salmonids reared (Table 3), while cutthroat trout was least. Small lots of silver salmon, chinook salmon, and cutthroat trout were reared simultaneously in two 50-square feet crab-rearing pens fitted with nylon mesh (East and West Pens, Table 4). Unfortunately, at the end of the experiment, a small hole near the top of one corner of the East Pen was large enough to allow escapement of fish. The West Pen was secure. The pen-reared fish in all cases but one (chinook, East Pen) showed much higher survivals. The difference between survival in pens versus that in the ponds was possibly due to bird predation. Although no formal study was made of this source of mortality during the experiment, night-crowned herons were known to come to the ponds just after sundown, and several scattered observations reported up to four birds on the pond

Table 3. Survival of Pond-Reared Silver, Chinook, and Cutthroat Trout, and Pen-Reared Steelhead Trout, 3 July - 20 Sept., 1974 (Experiment VIII).

Species	Size Av. Fk. Len (mm)	Size Av. Wt. (gms)	Rearing Area	Number Planted	No. Recov.	% Surv.
Silver Salmon	156	50	South Pond	613	395	64
Chinook Salmon	125	28	South Pond	431	248	58
Cutthroat Trout	196	78	South Pond	136	23	17
Steelhead Trout	70	5.2	4 - 4 square meter pens	400	110	28

Table 4. Survival of Pen-Reared Silver, Chinook, and Cutthroat Trout in Two 50-Square Feet Pens, 28 June - 20 Sept., 1974 (Experiment VIII).

Rearing Area	Silver			Chinook			Cutthroat			Combined		
	Start	End	% Surv	Start	End	% Surv	Start	End	% Surv	Start	End	% Surv
E. Pen	10	7	70	10	4	40	5	2	40	25	13	52
W. Pen	10	11	100	10	7	70	5	3	60	25	21	84

at one time. Additional notes on possible losses from bird predation are given in the section on results of steelhead rearing in pens.

The average size of the silver salmon increased little during the experiment either in the ponds or in the pens (Table 5). Cutthroat showed an apparent increase in size in the pens, but as individual fish were not weighed initially, the result may be more apparent than real. Chinook salmon showed an increase in length and weight in both the ponds and in the pens. This increase in length was also reflected in an obvious deep-bodied condition of the chinook salmon observed during recovery. No systematic sampling of chinook salmon was conducted during this experiment for growth studies; however, mortalities recovered from the pond tended to show a slight increase in length (Figure 5).

Fry and fingerling salmonids planted into the ponds (chinook salmon, steelhead trout) showed much greater percentage gains in both length and weight than did the larger yearling fish (silver salmon, cutthroat trout) (Table 6).

STEELHEAD EXPERIMENTS

Pen Rearing

The first rearing of steelhead trout in our pond system was conducted during the present experiment (Table 7). Two 2-meter square exclusion pens were modified by hanging five stringers of 1-foot square experimental astroturf suspended by wires stretched across the top of the pens (Hookton soil and gravel pens). Two 2-meter square pens were modified by floating a rectangular piece of plastic turf in each of the pens (mud and shell pens). On July 3, 1974, 100 fry (1.4 grams and 46 mm fork length) were placed into

Table 5. Average Growth in Fork Length of Silver, Chinook and Cutthroat Trout in Two 50-Square Foot Pens, 28 June - 20 Sept., 1974 (Experiment VIII) and Total Biomass of Salmonids at End of Experiment.

Rearing Area	Silver		Chinook		Cutthroat		Biomass of Salmonids Recovered (Grams)
	Start	End	Start	End	Start	End	
East Pen[1/]	10.8	10.6	10.5	12.4	13.5	15.2	247
West Pen[2/]	10.8	11.2	11.0	11.9	13.8	16.0	411

1/ 80% water surface covered by floating 2 pieces of 3' x 7' astroturf material with 1" depth nape; 3 underwater reefs of four 6-12" pine cones weighted with brick. Gravel and sand bottom.

2/ No cover or shelters. Bottom unbroken oyster shells.

Table 6. Average Gain in Length and Weight of Four Species of Salmonids Reared in South Pond, July - September 1974. (Experiment VIII).

Species	Average Gain		Percent Gain Over Initial Value	
	Fork Length (mm)	Total Weight (gms)	Length	Weight
Silver Salmon	13	3	1	6
Cutthroat Trout	28	9	17	13
Chinook Salmon	37	13	42	87
Steelhead Trout	24	4	52	286

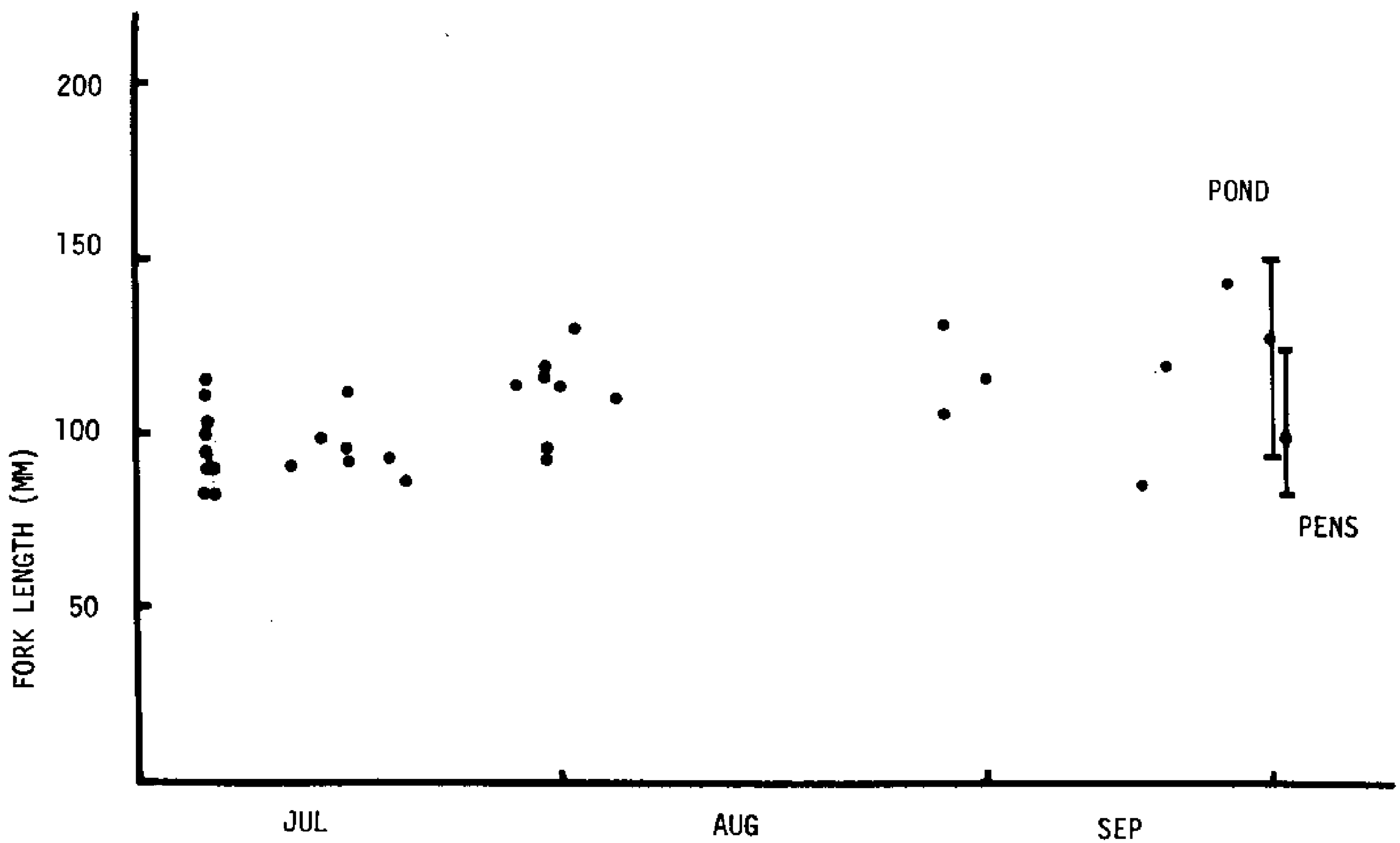

Figure 5. Length of chinook salmon mortalities recovered from all sources, South Pond, July-September 1975 (Experiment VIII), with mean and range of salmon recovered from pond and pens in length.

Table 7. Physical Features and Experimental Modifications of Four 4-Square Meter Pens, South Pond, Used for Rearing Steelhead, 3 July - 20 September, 1974. (Experiment VIII).

Substrate of Pen	Modification	Distance from Top of Pen to Water Surface in Inches	Evidence of Susceptibility to Night Crown Heron Predation
Hookton	Five stringers of 1-foot square plastic turf suspended from wires across top of pen.	31	Slight
Shell	5' x 3' square of plastic turf floated at surface. Nape 3/4" deep.	28	Strong - turf with bird droppings; feathers.
Mud	Same as Shell Pen	36	Same as Shell Pen
Gravel	Same as Hookton Pen	41	Slight

the pens. On 19 and 20 September, the fish were recovered, and the length and weight of each fish recorded.

Survival of steelhead in the pens varied from 18 to 40 percent (Table 8). The two highest survivals (Hookton and Gravel pens) were pens modified with hanging stringers of astroturf. Lower survivals were in pens with astroturf mats (mud, shell). Visual observation of feathers floating in these pens, and a considerable accumulation of bird feces on the astroturf mats indicated that the lowered survivals in these pens may have been due to bird predation. Night herons were alwasy present on South Pond during the experiment, and used the exclusion pens for roosts. Although no intensive study of their feeding success was undertaken, several nights of observation showed night crown herons were utilizing exposed edges of fish shelters as feeding stations.

In previous experiments, salmon from pens over Hookton soil always showed the least growth and lowest survival, while Shell pens produced fish with the best growth and high survivals. Examination of the height of pens above water showed that the shell pen extended the shortest distance above the pond surface (Table 7), thus facilitating access to the astroturf mat from outside the pen. Support wires across the top of the Hookton and gravel pens, plus the unsuitablility of the 1-foot square astroturf units for perching, probably minimized predation by night crown herons on these two pens.

Considerable observations of the behavior of the steelhead in the pens was made during the course of the summer. Daphnia blooms in the main oxidation pond provided a source of highly desirable food to use in studies on feeding behavior. Observations could be made directly into the South Pond

Table 8. Number, Average Fork Length, and Average Weight of 100 Steelhead Fry Planted 3 July into Each of Four South Pond Exclusion Pens and Recovered on 20 September 1974 (Experiment VIII).

Substrate of Pen	Number Recovered[1/]	Length			Weight		
		Min	Mean	Max	Min	Mean	Max
Hookton Soil	27	55	69	100	1.7	4.5	12.2
Shell	18	57	73	95	2.7	5.7	12.0
Mud	25	52	72	120	2.6	6.4	22.3
Gravel	40	40	67	100	1.1	4.6	14.4

[1/] 100 fry planted into each pen with average length 46 mm and average weight 1.4 grams.

Hookton pen, which is sufficiently close to a pond retaining wall that direct observation could be made from shore. The water is also relatively shallow in this pen. The steelhead took full advantage of the cover offered by the stringers of astroturf. Only after several minutes of feeding portions of live Daphnia would the steehead move out into the water column to take the live Daphnia. In the early portion of the experiment when the 100 fry were in the 4-square meter area, rarely could more than 4 or 5 fish be observed. Later, the steelhead began to concentrate quickly when Daphnia were offered.

Difference in size of steelhead between pens was difficult to interpret because of the differences in final densities. In all past experiments, however, growth has been the lowest over Hookton soil. This was duplicated for steelhead in this experiment, but the results cannot be totally due to less food because of the two-fold differences in densities in the pens at the termination of the experiment. The two pens with lowest survival had the largest mean length, while pens with highest survival showed the lower mean lengths. The differences were slight and the overlap in range in lengths considerable (Figure 6).

The production of steelhead in the ponds based on the increase in weight of fish surviving (Table 9) showed three pens producing at about the same level, with the gravel pen producing at a much higher rate. For production based on net growth, two pens showed a net loss, and two had a net gain. The net production rate of fish flesh in the gravel pen was over 500 kilo/ha/year (Table 9). The differences in the survival rates were the over-riding factor in determining net production. This was especially so for the Shell pen which was most susceptible to night crown heron predation and showed the greatest net loss.

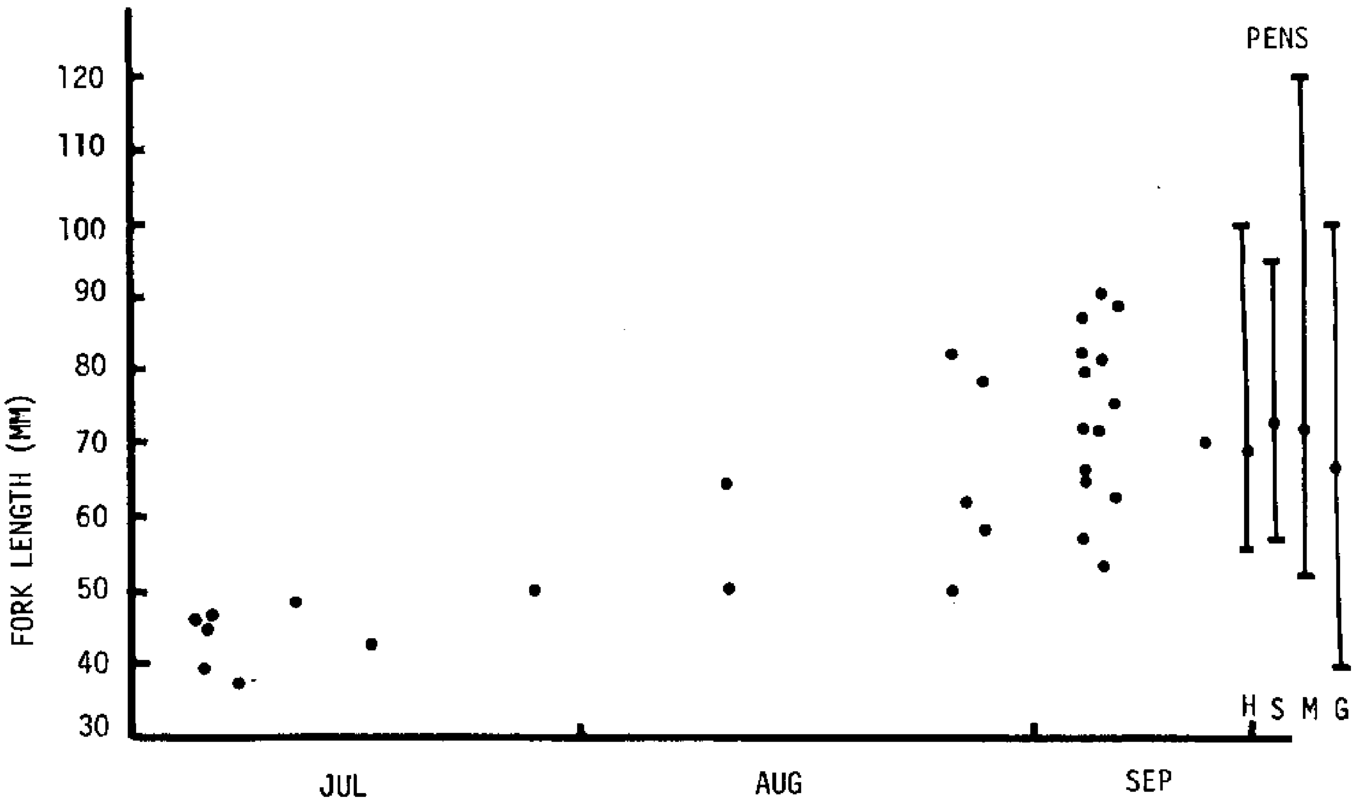

Figure 6. Length of steelhead-rainbow trout mortalities recovered from all sources, South Pond, July-September, 1975 (Experiment VIII), with mean and range in length of trout recovered from four pens (Hookton soil (H); oyster shell (S); mud (M); river-run gravel (G)).

Table 9. Steelhead Biomass Produced in Four 4-Square Meter Fixed Pens on Four Different Substrates Based on Fish Surviving and Net Biomass, 3 July - 20 September 1974 (Experiment VIII).

A. Biomass of Survivors

Substrate of Pen	Average Gain in Grams	Kilo/ha/yr	Kilo/ha/day
Hookton Soil	3.1	967	2.6
Shell	4.3	894	2.4
Mud	5.0	866	2.4
Gravel	3.2	1478	4.0

B. Net Production

Substrate of Pen	Net Biomass Produced over Rearing Period in Grams	Kilo/ha/yr	Kilo/ha/day
Hookton Soil	-19	-219	-0.6
Shell	-38	-439	-1.2
Mud	+21	+242	+0.7
Gravel	+46	+531	+1.4

<u>Comparative Growth</u>

Length of steelhead trout from two streams in Humboldt County were available for comparison with growth attained by pond-reared steelhead. These fish were obtained by electro-fishing in September and October 1974. Length of steelhead in Manzanita Creek (tributary to Trinity River, Klamath River drainage) were from four sampling sections from 160-210 feet in length located within 1½ miles from the Trinity River (Figure 7). This area is available to steelhead trout (migratory section). About 4½ miles upstream from the mouth of Manzanita Creek a large log jam prevents spawning by anandromous fish and only resident rainbow trout are present (resident section). Length of steelhead in Jacoby Creek (tributary to Humboldt Bay and entering bay about 1/3 mile south of Arcata oxidation pond) were from samples by electro-fishing taken about 1½ miles from the mouth (Figure 8). About a 300-foot section of Jacoby Creek was sampled.

The modal lengths of young-of-the-year steelhead reared in pens in South Pond and in Jacoby Creek were similar (65 mm) (Figure 8); however, a small number of pen-reared steelhead attained the size of yearling fish in the creek (roughly greater than 100 mm). The modal length of steelhead found in the migratory section of Manzanita Creek was also 65 mm (Figure 7); however, the percentage of young-of-the-year reaching the 75-100 mm range was much lower than in Jacoby Creek and South Pond. The much-reduced size attained in the resident section of Manzanita Creek is clearly evident, with possibly fish of mean length of 100, 130 and 160 mm representing resident fish of 1, 2, and 3+ years of age.

Examination of length frequencies of steelhead by millimeter intervals, clearly showed young-of-the-year being less than 85 mm in Manzanita

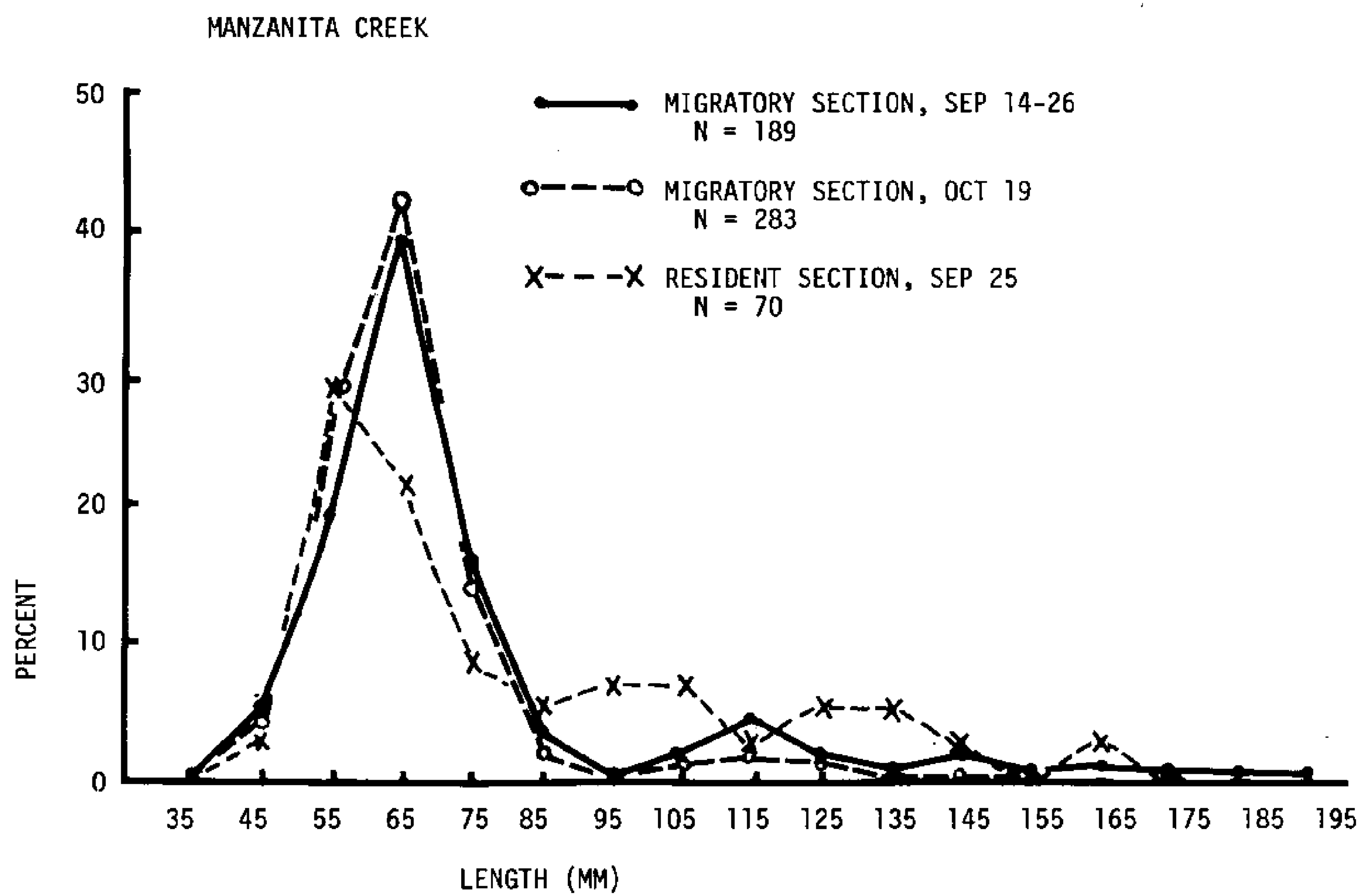

Figure 7. Length of steelhead-rainbow trout in Manzanita Creek, Trinity River, Humboldt County, recovered by electrofishing, September-October, 1974.

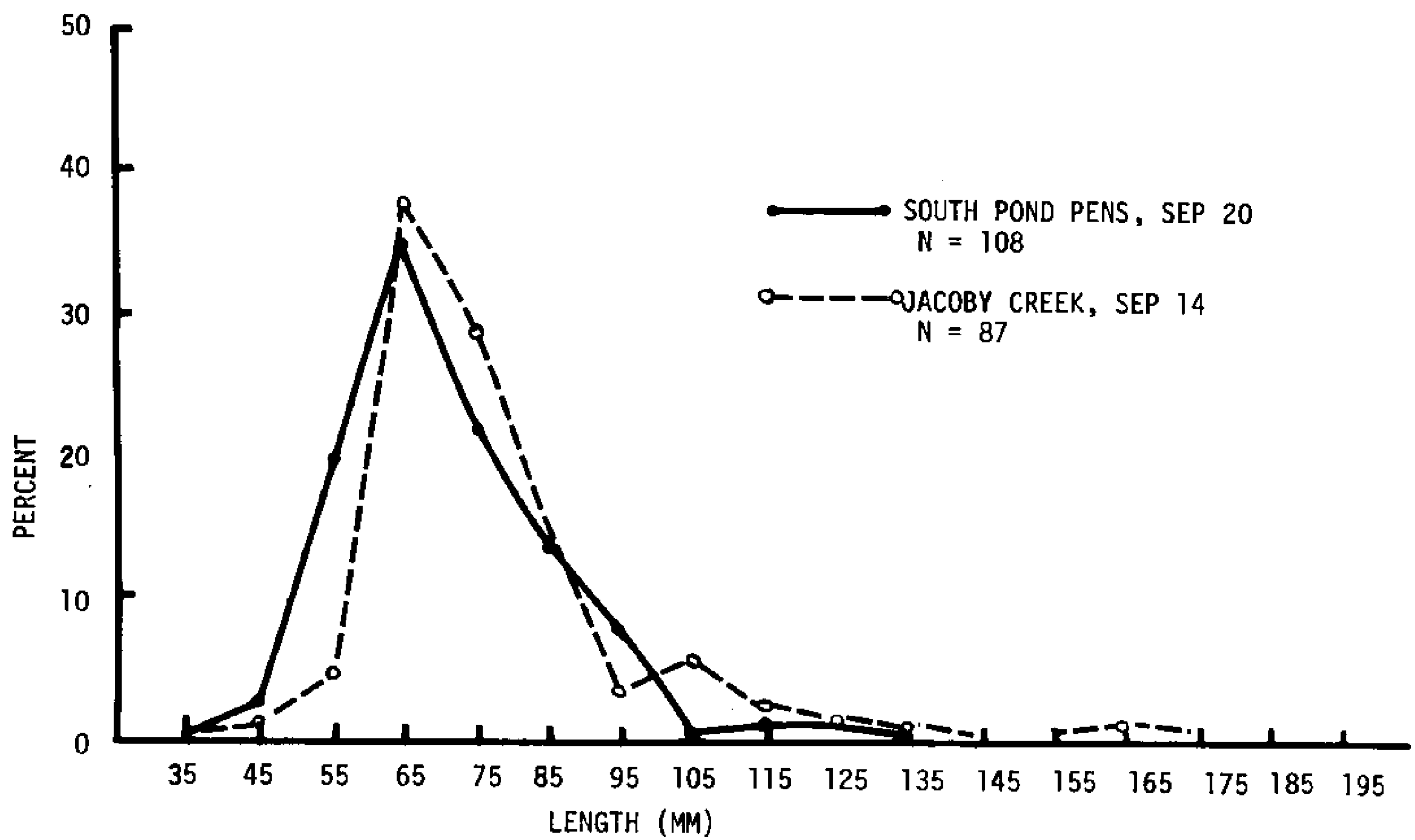

Figure 8. Length of steelhead-rainbow trout in South Fish Pond and Jacoby Creek, north Humboldt Bay, September 1974.

Creek and less than 90 mm in Jacoby Creek. Thus the relatively large number of steelhead attaining over 90 mm in the pens in South Pond indicated the fast growth attained by this group. This growth was attained under at least a ten-fold higher density of fish than in the natural environment (Table 10).

OTHER STUDIES

Amphipod Populations

The relative abundance of amphipods (gammarid) between ponds was studied by the use of small basket traps of cylindrical 2-quart polyethylene refrigerator containers (surface area 200 cm^2 and volume 1600 cc). Traps were baited with a single anchovy and fished about 12 hours overnight.

Single traps were fished in each of the fixed pens (A, B, C, D; representing Mud, Hookton, Gravel, Shell substrates), one each in the east and west portions of the crab pen, and two traps in the open pond, one under a floating raft and one away from the raft.

The initial study of amphipods on 9 July, with basket traps, showed in North Pond only 9-22 amphipods per trap and from 3-9 isopods per trap. In contrast, South Pond basket traps took from 500-1,500 amphipods and no isopods (Table 11). Surveys after 9 July were confined to South Pond. Mud substrate (Pen A) showed consistently higher levels of amphipods, as compared with the other pens all of which showed about the same level of abundance. Previous studies of benthos on soil types generally showed Hookton soil less productive than other soil types. It is possible that the astroturf stringers in these pens improved the amphipod populations as compared to pens containing a single surface mat of astroturf. This idea is supported

Table 10. Comparison of Density of Steelhead Trout Recovered from Four Types of Rearing Area, September, 1974.

Rearing Area	Number Fish Recovered	Surface Area (Sq. Ft.)	Number of Fish per Sq. Foot
4 Pens, South Pond	110	150	0.73
Jacoby Creek	87	1500	0.06
Manzanita Creek			
Migratory Section (4 areas sampled)	189	5800	0.03
Resident Section (1 area sampled)	70	2500	0.03

Table 11. Relative Number and Size of Gammerid Amphipods in South Pond, July-September 1974, as Indicated by Basket Traps.

Sampling Location	9 July	14 Aug.		27 Aug.		18 Sept.	
	No.	No.	No./gm	No.	No./gm	No.	No./gm
Pens over Bottom Types							
Mud (A)	-	1610	78	1710	114	800	57
Hookton (B)	650	250	56	1370	57	300	43
Gravel (C)	550	590	76	660	39	580	48
Shell (D)	700	270	64	670	35	610	51
Under Culture Raft	1450	1470	92	650	92	960	64
Away from Raft	-	180	100	2240	70	1170	57
East Crab Pen	50	80	63	340	64	380	35
West Crab Pen	10	20	100	120	42	50	25

by higher counts of amphipods in the east section of the crab pen (with astroturf surface mat) as compared to the west crab pen (no mat). Consistently high amphipod populations were found under or near the culture raft. Feeding experiments being conducted by suspending fish in pens suspended from culture rafts may have concentrated amphipods under the raft from waste food dropping to the pond bottom.

We have always felt that the gammarid amphipod population of the pond may be only fractionally available to feeding salmonids. Consequently, a number of different types of amphipod traps have been constructed to ascertain if large numbers of these food items could be easily caught and fed directly to the fish. One of the simplest, most inexpensive, and potentially useful of these was made by cutting off the top of the inside dividers of plastic egg cartons. The cartons were baited with several small pieces of fish. The cartons were fished at the edge of the pond by placing them under a rock.

Four trials were run with these sampling devices (Table 12). Only the total weight of the amphipod catch was recorded. A mud substrate was not available at the pond's edge for this study. These traps averaged from 3-10 grams of amphipods per trap during four trials. Hookton soil produced the least catch, shell the greatest, and gravel intermediate. Range in catch was from 1.5 grams (Hookton) to 16 grams (gravel) per carton. 100 traps might be expected to produce 1000 grams of amphipods if fished in the most productive substrates. At the level of amphipods and techniques used in South Pond during the 1974 summer rearing period this would not be practical for feeding large groups of fish. However, such potential methods for capturing large quantities of amphipods cheaply and effectively is still being explored.

Table 12. Catch of Amphipods in Grams in Egg-Carton Traps Fished on Three Types of Substrate at Edge of South Pond, July-August, 1974.

Date of Sampling	Substrate											
	Shell			Hookton			Gravel			Combined		
	A	B	C	A	B	C	A	B	C	A	B	C
22 July	2	12	6	2	18	9	2	32	16	6	62	10
29 July	10	62	6	10	15	1.5	9	27	3	29	104	3
30 July	10	133	13.5	10	43.5	4	9	88	10	29	264.5	9
1 August	10	101.5	10	9	41	3.5	10	42	4	29	184.5	6
	32	308.5	9.5	31	117.5	4.0	30	189	6.0	93	615	6.5

A - Number of Traps

B - Weight of Amphipods to Nearest 0.5 Gram

C - Average Weight of Amphipods per Trap to Nearest 0.5 Gram.

Astroturf in Fish Rearing

During Experiment VIII, ten 1-square meter shelters made of astroturf were submerged into South Pond. These units were heavily colonized by gammarid amphipods during the course of the experiment. Modification of exclusion pens included hanging 1-square foot pieces of astroturf from stringers or floating a mat of the material on the surface (Table 7). An experiment combining astroturf plus the use of fish carcasses was undertaken with steelhead fry. Rockfish and whole trout carcasses were each floated in a pen covered with astroturf. We hoped that attracting amphipods to the carcasses would populate the astroturf and provide additional food to fry in the pens. The survival and growth of steelhead in this experiment (Table 13), was less than that recorded for steelhead reared in fixed pens (Table 8).

Live-Car Studies

In past experiments, groups of salmon reared in the ponds have been monitored by rearing samples of fish from the same stock in small live-cars. We only carried steelhead fry in one such live-car during Experiment VIII (Table 14). Survival was less than steelhead reared in pens, and both growth in length and weight were less. These fish were not fed but had to live on food items colonizing the webbing of the live-car.

Chinook salmon from the same stock as planted into the ponds were also used in physiological studies involving the effects of nitrite on chinook salmon. Chinook fingerlings from these studies were transferred to a floating pen on our culture raft, then split into three lots and placed in three 1-square meter pens. The pens were placed in water shallow enough that their bottoms were in contact with the bottom. Survival was higher

Table 13. Growth and Survival of Steelhead Trout Reared in 12-Square Foot Floating Pens Covered with Astroturf Mat and Baited with Fish Carcass, 3 July - 19 Sept. 1974 (Experiment VIII)

	Type of Food			
	Rockfish 1/		Trout 1/	
	Start	End	Start	End
Number	50	11	50	11
Average Length	46	70	46	67
Average Weight	1.4	4.7	1.4	3.6

1/ 500 gram rockfish and 500 gram trout carcasses.

Table 14. Growth and Survival of Steelhead Trout Reared in 1-Meter Square Floating Pen 3 July - 19 Sept. 1974 (Experiment VIII) (No Feeding).

	Start	End
Number	25 1/	4
Average Length	46	62
Average Weight	1.4	3.1

1/ One fish escaped during live count on 25 July - thus survival 17%.

than in the ponds but growth in both length and weight (Table 15) was less than the same fish reared in the ponds (Table 3).

Salinity Tolerance of Salmonids

The success of any releases of juvenile salmonids from the aquaculture ponds into Humboldt Bay depends on the degree to which the salmon can successfully adjust to the higher salinities generally present in the bay. During winter months, heavy rains lower the salinities of the bay, especially those areas of the bay near stream mouths. During the summer, Humboldt Bay salinities will often become more saline than open waters of the Pacific Ocean, primarily due to high evaporation rates and lack of freshwater addition to the bay in summer. Thus, the degree to which salmon being released from the pond system in the summer of 1974 could acclimate to Humboldt Bay salinities was undertaken by simple standing water bioassays in 20-gallon aerated tanks.

Three aquaria were filled with South Pond water and two tanks with Humboldt Bay water. The tank with pond water (23 $^{o}/oo$) was the control, with silver salmon and chinook salmon tested in Humboldt Bay water (34 $^{o}/oo$). The tanks were checked daily for mortalities, with the lengths and weights of dead fish measured as mortalities were recovered. With fish remaining from the control tank, plus four steelhead trout, a second bioassay was run at an intermediate salinity (28 $^{o}/oo$).

After 11 days of observation, the control tank showed 20% mortality. Silver salmon and chinook salmon both showed 70% mortality, mainly suffered within the first 3 days of the test. For both silver and chinook salmon, smaller fish predominated in the mortalities, with the smaller fish dying first (Table 16). At 28 $^{o}/oo$, there were no mortalities in either the

Table 15. Growth and Survival of Chinook Salmon Reared in Three 1-Square Meter Pens over Gravel Substrate 15 July - 19 September 1974 (Experiment VIII).

Pen	Number Start	Number End	Avg. Length (mm.)	Avg. Weight (gm)	Percent Survival
Control	18	13	10.9	11.9	72
Covered	18	7	10.9	12.4	39
Reflectors	18	11	10.5	10.5	61

Table 16. Acclimation Studies by Standing Water Bioassay of Chinook and Silver Salmon, and Steelhead Trout, September, 1974.

(Experiment started September 20, terminated September 30. 5 chinook and 5 coho in control; 10 chinook and silver salmon in bay water. Measurement given as fork length in millimeters.)

Species Tested	Control (23 °/oo)	Bay Water (34 °/oo)
Coho		
Mortalities	89	101, 111, 111, (144, 151, 189, 198)[2/]
Survivors[1/]	103, 109, 125, 210	130, 150, 191
Chinook		
Mortalities	88	90, 105, 114, 119, 120, (121, 122)[3/]
Survivors[1/]	123, 133, 134, 139	128, 137, 150

[1/] Survivors from control tank were placed in tank with chlorinated oxidation pond effluent and Humboldt Bay water (1:8.5 parts) to form mixture of 28 °/oo. There were no mortalities after 7 days of bioassay.

[2/] Mortalities occurring on day 3.

[3/] Mortalities occurring on day 2.

chinook or silver salmon through seven days of testing. Half the steelhead died, however.

Silver salmon recovered from South Pond on 20 September 1974 were transported to a low salinity estuarine environment at the College of the Redwoods in the southeastern section of South Bay portion of Humboldt Bay for release. There was a salinity gradient available in this location which should assure acclimation of these fish. Chinook salmon were released into Humboldt Bay at the outlet of the fish ponds. These salmon would not be expected to have a high survival due to the high bay salinities. A recirculating fish holding facility is currently under construction to allow retention and acclimation of juvenile fish not found to be physiologically adapted to Humboldt Bay salinities available at the time of release. A variety of planting locations will be employed for pond-reared salmon in future experiments.

Miscellaneous Observations

Six other species of fish inhabited South Pond during the rearing of salmon and trout (Table 17). These are all species that have regularly developed in the pond. Of special note is the large number of arrow goby present which previously had only made up a small portion of incidental fishes in the pond. Only one staghorn sculpin was recovered whereas in other drainings of South Pond fairly large numbers have been taken. This reduction in staghorn sculpin was undoubtedly due to the elimination of several low spots in South Pond which previously could not be completely drained.

During draining of the pond, there was a very definite sequence of recovery of salmonids. Most of the chinook were taken early in the seining

Table 17. Number, Length, and Weight of Fish and Shrimp Collected from South Pond, 20 September 1974 (Experiment VIII).

Common Name	Scientific Name	Total Weight (Grams)	Av. Weight (Grams)	Number
Stickleback	Gasterosteus aculeatus	3,940	1.6	2,500*
Arrow Goby	Clevlandia ios	293	0.7	400*
Jack Smelt	Atherinopsis californiensis	2,380	12.7	187
Staghorn Sculpin	Leptocottus armatus	72	72	1
Starry Flounder	Platichthys stellatus	41	41	1
Herring	Clupea pallasi	26	4.4	6
Shrimp	Crago	48	1.0	49
	Total Weight	6,800		

* Estimated from average weight per individuals from sub-samples.

conducted in the collection basin immediately in front of the headgate. In contrast, most of the silver salmon only entered the collection basin when practically no water remained in the pond. The last silver salmon collected actually had to be netted out of a few low spots in drainage channels leading to the collection box. Cutthroat trout were taken at an equal rate during all stages of pond draining.

In order to be certain that coliform counts would meet water quality standards, samples of pond water, oxidation pond, and surface waters from Humboldt Bay were taken to the Humboldt County Public Health Department for analysis. Analysis of pond waters sampled on August 5 showed extremely low coliform counts (Table 18). The oxidation pond traditionally has high counts, while the freshwater draining into the bay along the west bank of the oxidation pond adjacent to the fish ponds (Jolly Giant Slough) also showed high coliform levels.

DISCUSSION

The success of rearing juvenile salmonids in the wastewater-fertilized system has showed steady improvement for all species during the past four years (Table 19).

Experiments with rearing chinook fry to smolts conducted during the late winter to spring periods showed a steady improvement, with the 27 percent survival in South Pond during Experiment VII equaling the survival for the same lot of chinook salmon reared in the Humboldt State University hatchery (Table 19 A). This was accomplished without feeding, and without the application of drugs for disease control. Although the 58 percent survival of chinook salmon in Experiment VIII is a dramatic increase over past

Table 18. Coliform Levels in North and South Pond Surface Waters and Adjacent Areas on August 5, 1974, as determined by Humboldt-Del Norte County Department of Public Health Laboratory, Eureka, California.

Location of Sample	Coliform Value (MPN/100 ml). Total	Fecal
Oxidation Pond	2400	2400
Jolly Giant Slough	2400	2400
North Pond	9	3
South Pond	4	3

Table 19. Summary of Survival of Salmonids Reared in Sea Water Fertilized with Secondarily-Treated Domestic Wastewaters, July 1971 - January 1975.

A. Chinook Salmon, Fry to Smolt

Exp. No.	Period of Rearing	Days of Rearing	Percent Survival of Salmon Planted	Remarks
II	Spring 1972	45-111	3	North Pond
V	Spring 1973	30-119	1-6	North Pond
			0.1-2	South Pond
VII	Spring 1974	90	17	North Pond
		"	27	South Pond
VIII	Summer 1974	79	58	South Pond (Fingerlings)

B. Coho Salmon, Fingerlings

Exp. No.	Period of Rearing	Days of Rearing	Percent Survival of Salmon Planted	Remarks
IA	Summer 1971	-	None	North Pond. Unstable water conditions.
IB	Winter 1971-72	45	55	North Pond. 25% of loss due to birds.
III	Summer 1972	45	4	North Pond. Outcompeted by marine species.
IVA	October 1972	-	None	North Pond. One period unstable water conditions.
IVB	November 1972	14	84	North Pond. Experiment primarily to assist bird predation study

Table 19.

B. Coho Salmon, Fingerlings (Cont'd)

Exp. No.	Period of Rearing	Days of Rearing	Percent Survival of Salmon Planted	Remarks
VI	Fall 1973	43	96	North Pond
		"	78	South Pond
VIII	Summer 1974	79	64	South Pond. Yearlings.
IX	Fall 1974 - Winter 1975	82	56	North Pond
		"	85	South Pond

C. Trout - South Pond

Exp. No.	Species	Period of Rearing	Days of Rearing	Percent Surv. of Trout Reared	Remarks
VII	Cutthroat	Spring 1974	92	100	Yearlings, pen-reared.
VIII	Cutthroat	Summer 1974	79	17	Yearlings, pond-reared.
	"	"	83	50	Yearlings, pen-reared.
VIII	Steelhead	Summer 1974	79	28	Fry, pen-reared.
IX	Steelhead	Fall 1974 - Winter 1975	82	55	Fingerlings, North Pond.
			"	63	Fingerlings, South Pond.

experiments, the data are not strictly comparable as a different life-history stage was studied (post-smolt estuarine feeding stage).

Experiments rearing coho fingerling during summer periods showed the most dramatic increase in survival rates. Beginning with unsuccessful experiments during the first year of operation of the system (1971), survival increased to 4 percent in 1972, and then to 64 percent in the summer of 1974. This latter result occurred using larger (yearling) coho and a rearing period double that of previous experiments (Table 19 B).

Results of our initial steelhead fry rearing (pens only) during the summer of 1974, indicated good potential for summer rearing on a larger scale (Table 19 C). Survival rates in the Gravel pen indicated a potential production of 15,000 fingerlings might be attainable from one of our 0.15 hectare (0.33 acre) ponds.

Survival rates with coastal cutthroat trout were high for pen-reared fish, but low in the single experiment using pond rearing (Table 19 C).

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