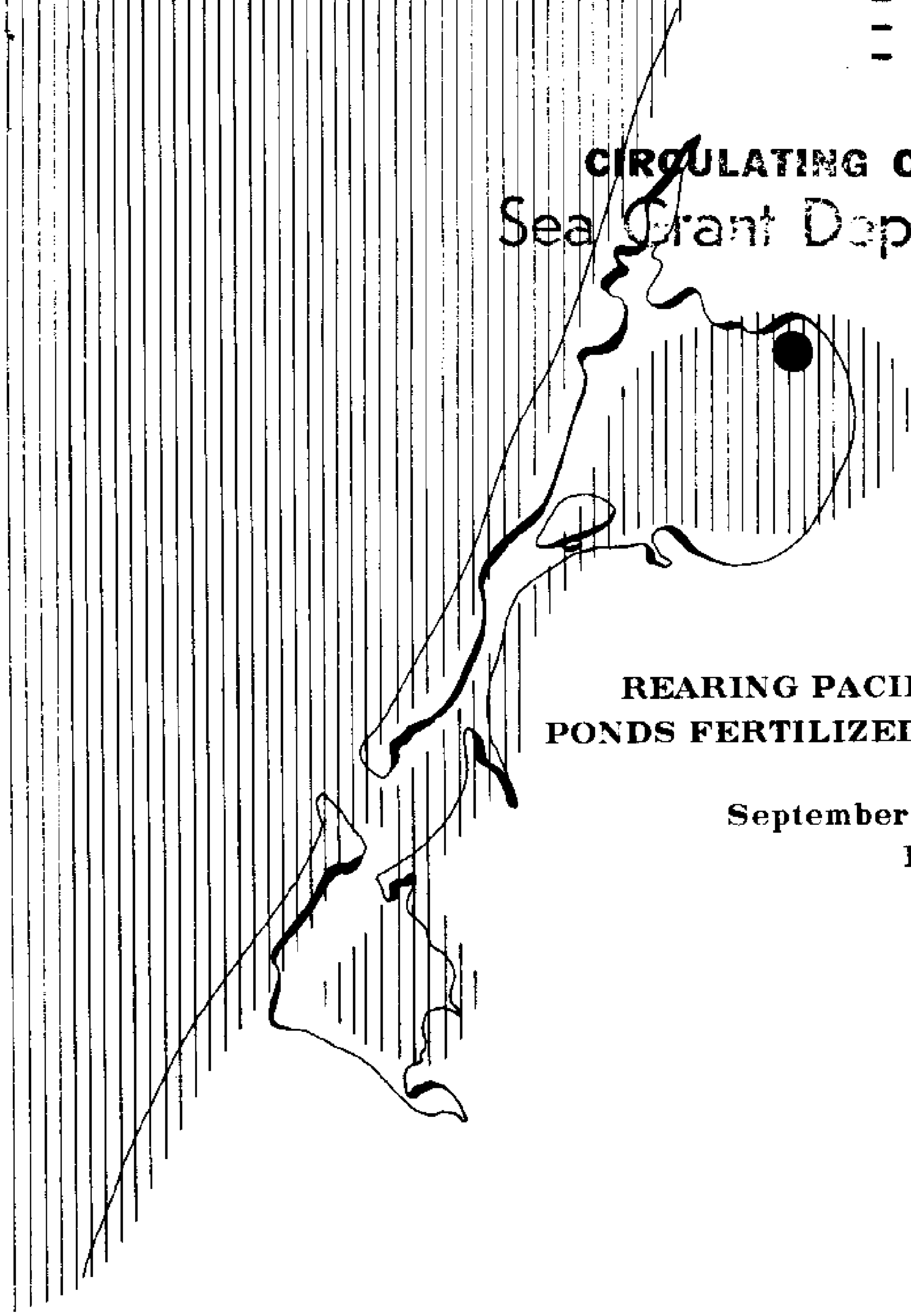

REARING PACIFIC SALMON IN SALTWATER PONDS FERTILIZED WITH DOMESTIC WASTEWATER

September 1974–November 1975
Data Report

HSU-SG-10

SEA GRANT PROGRAM
HUMBOLDT STATE UNIVERSITY

REARING PACIFIC SALMON IN SALTWATER PONDS FERTILIZED WITH DOMESTIC WASTEWATER

September 1974 - November 1975

by

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

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ABSTRACT

Two 0.15-hectare ponds (North and South Ponds) using mixtures of treated domestic wastewater and seawater were used to rear juvenile salmonids without supplemental feeding. Ponds are located within the periphery of an oxidation pond located on the north arm of Humboldt Bay, Humboldt County, Arcata, California. Forced air and surface spray systems of pond aeration and mixing of pond waters were employed to maintain water quality. Rearing experiments occurred in three seasons: October 1974 - January 1975 (Experiment IX); February - May 1975 (Experiment X), and May - November 1975 (Experiment XI).

In Experiment IX, fingerling coho salmon (Oncorhynchus kisutch) and rainbow trout (Salmo gairdneri) were reared together using both ponds. In Experiment X, fall chinook salmon fry (Oncorhynchus tshawytscha) were reared in both ponds. In Experiment XI, small lots only of fingerling chinook salmon, fry and fingerlings of rainbow trout, fingerling coho, and fingerling kokanee salmon (Oncorhynchus nerka kennerlyi) were reared in North pond only.

Polyculture of coho and rainbow trout in Experiment IX at about 5 fish per square meter planting density resulted in survival rates of 55-85 percent and a total fish production rate of about 200 kg/ha/yr in both ponds. Survival of chinook salmon in Experiment X was low due to an usual loss of fry early in the experiment (February) apparently from a combination of supersaturation of the blood with oxygen and/or high pH values. Virtually all chinook salmon fry were lost in South Pond but a considerable but unknown number survived in North Pond. Initial attempts at selectively removing downstream migrant stage fall chinook salmon from North Pond by means of directing a flow of water through a stationary trap proved successful. Lots of salmon introduced early into South Pond during Experiment XI suffered heavy mortalities due to unstable conditions in

pond waters. Survival rates of salmon introduced after May showed wide variation in survival rates (19 - 81 percent) depending on species and rearing locations. Rainbow trout generally had higher survival rates and faster growth than other species tested. Fall chinook salmon survival in Experiment X was low but the size attained by November (mean of 13 cm fk len and 27 grams) is that which presumables will insure adaptation to full-strength sea water.

Results of studies on the following topics are also included: physical and chemical properties of pond waters; possible causes of mortalities recorded; food habits and behavior of salmonids; potential for improving growth and survival of salmonids through use of artificial reefs; non-target species of fish and invertebrates in the ponds; water quality, especially bacteriological parameters; and fish diseases, especially the possibility that "green waters", principally produced by Chlorella, may reduce the virulence of vibriosis.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF TABLES (Continued)

LIST OF TABLES (Continued)

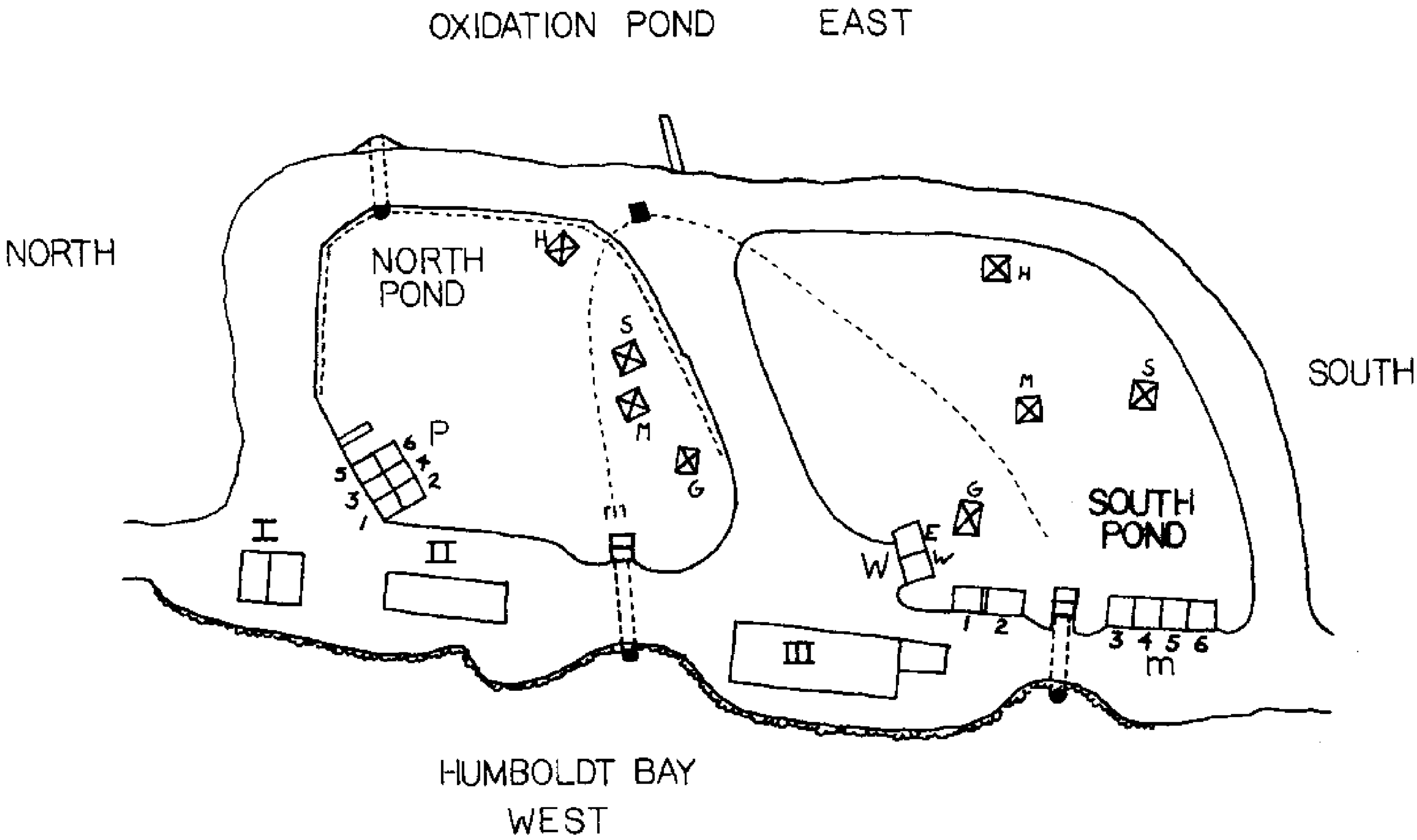
LIST OF TABLES (Continued)

LIST OF FIGURES

LIST OF FIGURES (Continued)

BACKGROUND

In July 1971, two 0.15-hectare ponds, located within the perimeter of an oxidation pond operated as the penultimate unit of the wastewater treatment system of the City of Arcata (northern California), were placed in operation to test empirically the potential of rearing juvenile salmon and trout on natural food chains produced by effluent-fertilized seawater (Allen, Conversano and Colwell 1972). Background to the project is given in detail in Allen and Dennis (1974), as well as details of the system, methods of operation, and photographs of the ponds. The location of recent additions of 4-square meter pens in North and South Ponds are shown in Figure 1. The rearing of salmonids in the system has been grouped into periods based upon the species studied and the season of rearing (Experiments). As of July 1976, 11 rearing experiments involving juvenile salmonids of five species of anadromous salmonids native to the Pacific coast of North America have been completed (Table 1). Percent survival of salmonids reared in various experiments have been recorded as follows: Experiments I-II (Allen 1973); Experiments I-VI (Allen and Dennis 1974); Experiments VII-X (Allen and Carpenter, In press); and Experiments IX-XI (This report). This data report includes the physical-chemical conditions of pond water, survival and growth of reared salmonids, production of fish, possible causes of success or failure in rearing experiments, and results of selected biological studies undertaken during each rearing experiment. Three experiments (IX-XI) covering the period September 1974 to mid-November 1975 are reported.



KEY

- I Storage and feed sheds
- II Trailer - Project headquarters
- III Fish Barn - 4 - 1,000 gallon recirculating aquaria and water tables
- ⊠ Sharp pens - H-Hookton Soil, S-Shell, M-Mud, G-Gravel
- W Welsh crab pens - E-East, W-West
- P Payne pens - Inside units (1,3,5); outside units (2,4,6)
- m Moore crab pens - units 1-6
- ═ Sampling docks
- Headgate
- ::::::• Inlet pipe
- ■ Forced-air pump
- ------- Air line

Figure 1. Plan view of Humboldt State University wastewater aquaculture system, Arcata oxidation pond, north Humboldt Bay, northern California, 1 September 1976. (Slight distortion to South Pond as sketch made from aerial photograph taken slightly north and west of ponds).

Table 1. Species, size of fish, and location of 11 rearing experiments with juvenile salmonids in Arcata wastewater aquaculture system, July 1971 to November 1975, and place of publication of experimental results.

Exp. No.	Species	Size at planting	Pond	Reference	Nature of report
I	Coho	Fingerlings	North	Allen 1973	Data report; unsuccessful operation summer 1971; first successful rearing January 72-December 73.
II	Chinook	Fry	North	Allen 1973	Data report; South Pond, operated on Humboldt Bay water only until 3 November 1972, was too saline for unacclimated juvenile salmonids.
III	Coho	Fingerlings	North	Allen and Dennis 1974	Detailed publication. Unsuccessful summer rearing experiment (1972); high production marine species.
IV	Coho	Fingerling	North	"	Detailed publication. Short-term rearing for bird predation study.
V	Chinook	Fry	North & South	"	Detailed publication. Early-run fall chinook stock produced a much higher survival than late run stock.
VI	Coho	Fingerling	North & South	"	Detailed publication. First experiments under modified pond banks and forced air aeration.
VII	Chinook	Fry	North & South	Allen and Carpenter (In Press)	Detailed report on experiment with fall chinook salmon meeting minimal survival ratios for a production unit.

Table 1. (Continued)

Exp. No.	Species	Size at planting	Pond	References	Nature of report
VIII	Chinook Coho Steelhead Cutthroat	Fingerlings Yearlings Fry Yearlings	South	Allen 1975	Data report: polyculture of salmonids; first successful summertime rearing in system.
IX	Coho Steelhead	Fingerlings Fingerlings	North & South	This report Allen & Carpenter, In press	Data report. First release to determine best point-of-return for adults. Survival results only.
X	Chinook Steelhead	Fry Yearlings	North & South	Allen & Carpenter, In press	Survival results only plus mortality study to illustrate catasyrophic effects of adverse weather conditions.
				This report	Data report. First selective trapping of chinook smolts.
XI	Chinook Rainbow Rainbow Kokanee	Fingerlings Fry Yearlings Fingerlings	North Pond	This report	Data report. Success with rainbow but not with chinook in summertime rearing.

EXPERIMENT IX

(October 1974 - January 1975)

Objectives

Previous studies have indicated that stabilization of pond waters to conditions suitable for salmonids tended to follow the same sequence as reported for recirculating systems with filter beds (Spotte 1970). Experiment IX was designed in part to see how quickly suitable water for salmonids could be developed by adding new wastewater from the Arcata oxidation pond to previously conditioned wastewater-seawater mixtures held over in the fish ponds from a previous experiment. Fingerling coho salmon plus rainbow trout were reared simultaneously in the experiment initiating polyculture techniques to salmonid rearing in the system.

Pond Operation

On 14 September 1974, high-salinity saltwater from Humboldt Bay was added to North Pond which had been left dry since spring for annual repairs and modifications. High salinity water was allowed to remain in the pond for two days, after which the pond was drained. On 19 September, dewatering of South Pond for completion of Experiment VIII was begun (Allen 1975). This South Pond water was pumped into North Pond. South Pond was completely dewatered by the afternoon of September 20. Half of this water was subsequently pumped back into South Pond. From October 1-2, wastewater from the Arcata oxidation pond was added to South Pond, and from October 3-4 to North Pond. Humboldt Bay seawater of about 32 o/oo salinity was then added to top off the ponds, resulting in a starting salinity near 15 o/oo.

During the experiment only one small addition of wastewater occurred (9 October), while several inches of pond water was discharged on several days to reduce pond levels raised by heavy rainfalls.

The major physical modification made to the pond for this experiment was an addition of 81 artificial reefs (Table 2). North Pond differed from South Pond by having had most of its edges lined with a vertical board wall. South Pond had unmodified earthen pond banks that allowed easy access to the pond edge by fish-eating birds. An aeration system of forced air (Figure 5, Allen and Dennis 1974) was not employed for this experiment, with aeration by spray system (AIR-O-LATOR, Figure 4, Ibid).

Table 2. Number, description, and location of artificial reefs placed into North Pond for Experiment IX October 1974 - January 1975.

Number	General Description	Location in North Pond
50	Plastic clothes basket filled with oyster shell, and rimmed with brush	Around periphery of pond about 2-3 feet from bank.
18	As above, but two baskets in depth	In deeper water, west central portion of pond.
13	Pieces of buoyant Astroturf nailed to redwood frame and weighted at two corners for a mid-depth positioning.	In deeper water, east central portion of pond.

Physical-Chemical Conditions

Methods of studying pond-water properties are outlined in Table 3.

Water temperatures, similar for both ponds, were ideal for rearing, beginning at 15° C and slowly declining to 6-8° C (Figure 2, North Pond only).

Table 3. Summary of methods, equipment and sampling procedure[1/] employed in determining physical-chemical parameters of waters in Arcata wastewater aquaculture ponds.

Parameter	Unit	Equipment and Procedure[2/]
Temperature	$^oC \pm 0.5$	Hand thermometers
Salinity	parts per thousand total halides (ppt) $\pm$ 0.25	Hydrometer (Kahl)
Clarity	depth of disappearance in cm	20 cm diameter Secchi disc mounted on calibrated rod
Oxygen	mg/l $\pm$ 0.1	Azide modification of Winkler method using PAO titrant (0.0250 N).
Hydrogen ion	pH units $\pm$ 0.1	Photovolt electric meter
NH_3-nitrogen	mg/l Hach unit	Hach kit, model DR-EL/2 Engineer's Laboratories[3/]
NO_2-nitrogen	mg/l Hach unit	Hach kit, model DR-EL/2 Engineer's Laboratories
NO_3-nitrogen	mg/l Hach unit	Hach kit, model DR-EL/2 Engineer's Laboratories[4/]
Alkalinity	parts per million as $CaCO_3$ (ppm)	Taras 1971
Calcium - Magnesium	ppm	Taras 1971
Silicon Maganese Iron Copper Phosphorus	mg/l Hach unit	Hach kit, model DR-EL/2 Engineer's Laboratories

1/ As far as availability of personnel and class schedules would allow, sampling of pond waters was to be conducted during the morning, preferably between 8 and 10 A.M. Since strict morning sampling was not accomplished, minor variations in non-conservative properties should be regarded mainly as diurnal variations. Sampling was conducted from pond headgates, with samples drawn from mid-depth in the pond (0.5 meters below the surface).

2/ Procedures using DR-EL/2 Engineer's Laboratories Hach kit all according to Hach Water Analysis Handbook, 1973.

3/ 6 drops of Rochelle Salt Solution required in our pond waters.

4/ We have not attempted to correct for chloride levels, thus values represent only relative concentrations.

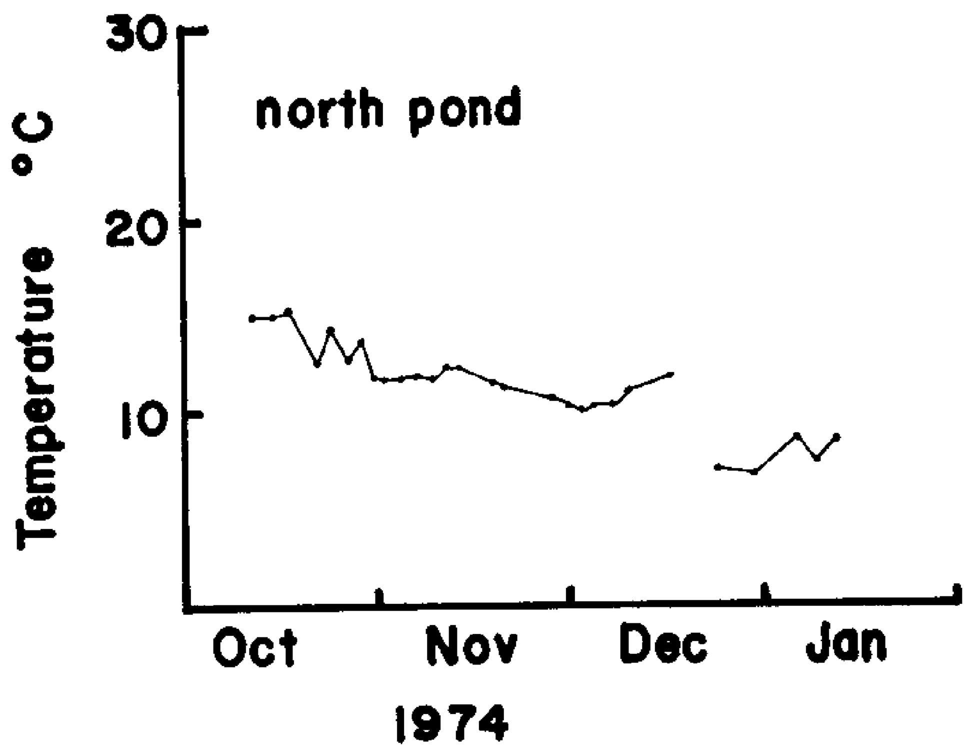


Figure 2. Temperature, surface water, North pond, October 1974 - January 1975 (Experiment IX).

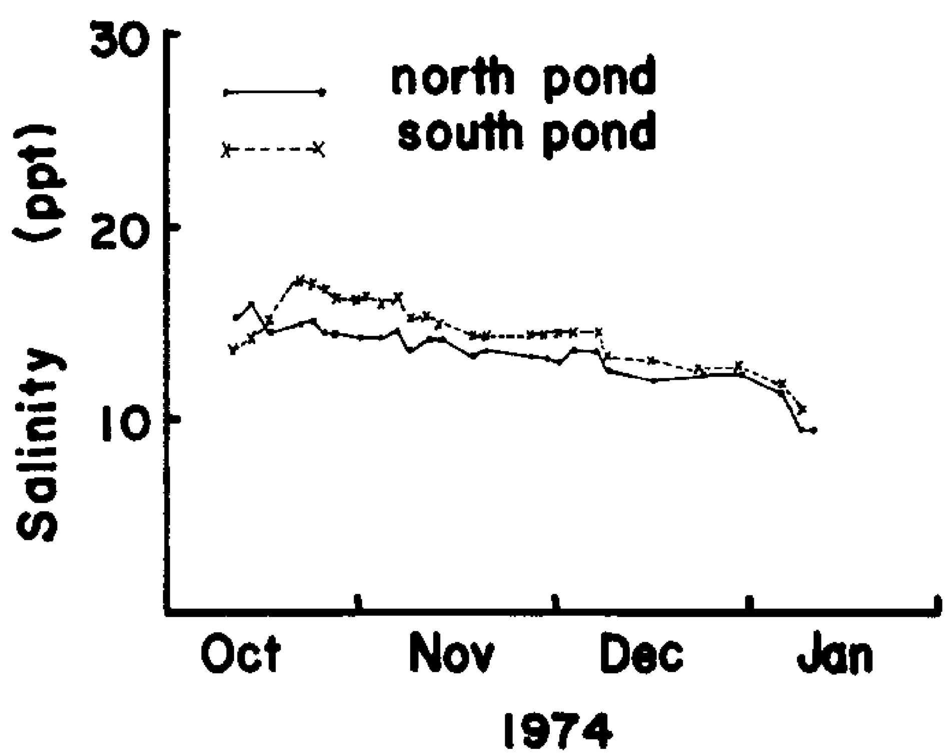


Figure 3. Salinity, surface water, North and South ponds, October 1974 - January 1975 (Experiment IX).

slight differences in salinity existed between the two ponds at beginning of the experiment, but slowly declined to final salinities near 10 o/oo (Figure 3). Dissolved oxygen began around 6 mg/l and rose steadily to over 10 mg/l by the end of the experiment (Figure 4). No periods of depressed oxygen were identified. Initially high pH values (near 9) in both ponds rapidly dropped to around values of 8 during most of the experiment, with a rise to over 8.5 near the end of rearing (Figure 5). A very sharp difference in clarity existed between the two ponds (Figure 6). North Pond turbidity was from a dense phytoplankton concentration which rapidly assimilated phosphorus introduced into the pond, whereas South Pond had a high macrophyte flora resulting in relatively clear water and a slowly declining phosphorus index (Figure 7).

Only scattered determinations of ammonia nitrogen, nitrite nitrogen and silicon were made. Four ammonia determinations each from North and South Ponds all fell within 0.0-0.6 Hach index units; similarly four determinations in each pond showed no values of nitrite over 1.0 Hach index units; while three determinations of silicon as SiO_2 Hach index units showed no values over 1.0 mg/l.

Survival Rates

On October 7, 1974, bioassay of pond waters was initiated by placing five coho in floating live cars in both ponds. There were no mortalities over a 2-week period. On 25 October 1974, 6,000 coho and 1,000 rainbow fingerlings were planted into each pond (Table 4) and 15 coho were planted into each of four 4-square meter pens fixed on various types of substrates (Table 5). These planting densities were four fish per square meter surface area. About 9,400 fingerling fish were recovered from the 14,000 total planted after 80 days of rearing. Rates of survival were between 55 and 85 percent depending on species and pond. South Pond showed a higher survival for both coho and rainbow than

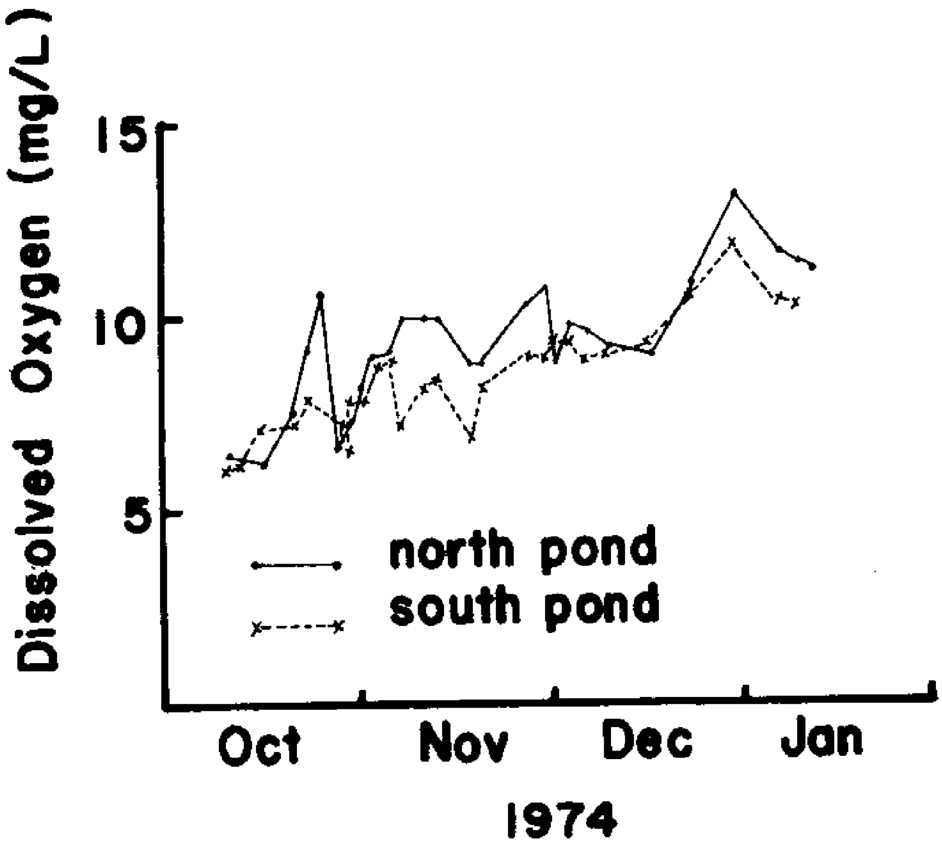


Figure 4. Dissolved oxygen, surface water, North and South ponds, October 1974 - January 1975 (Experiment IX).

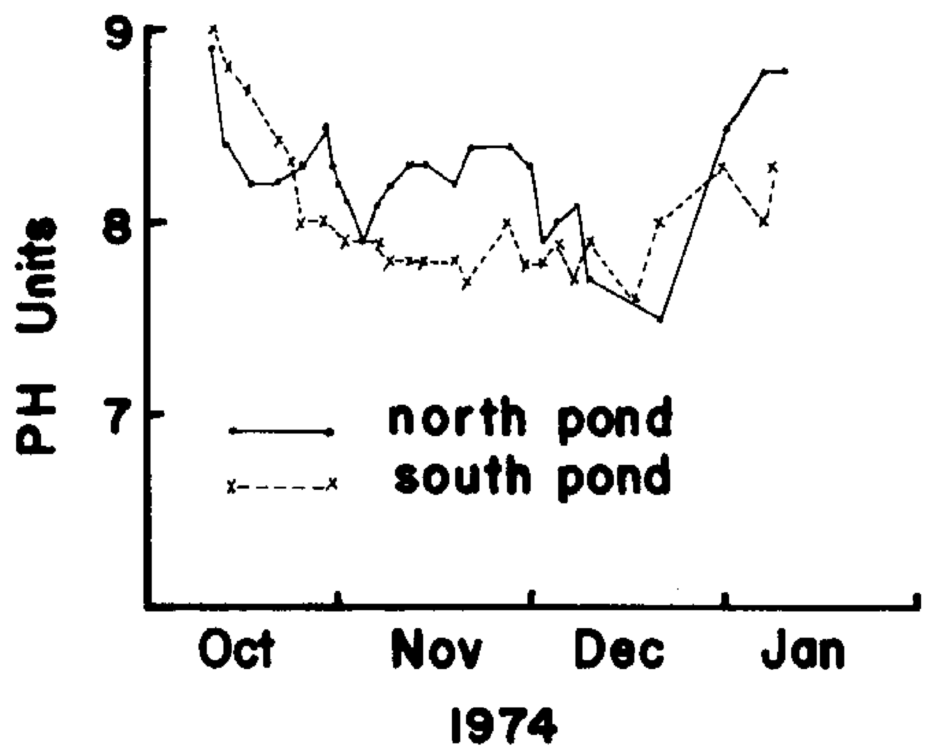


Figure 5. Hydrogen ion concentration, surface water, North and South ponds, October 1974 - January 1975 (Experiment IX).

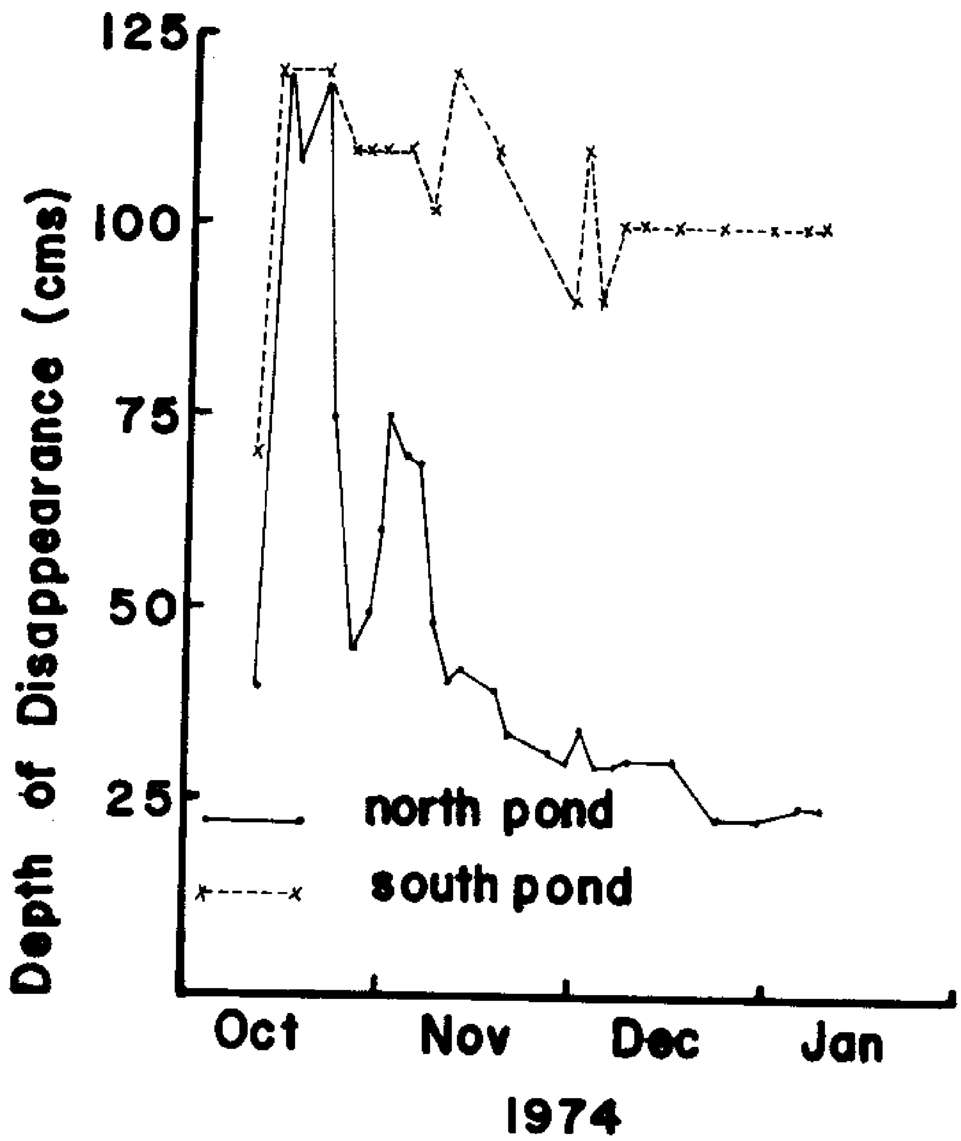


Figure 6. Clarity, North and South ponds, October 1974 – January 1975 (Experiment IX).

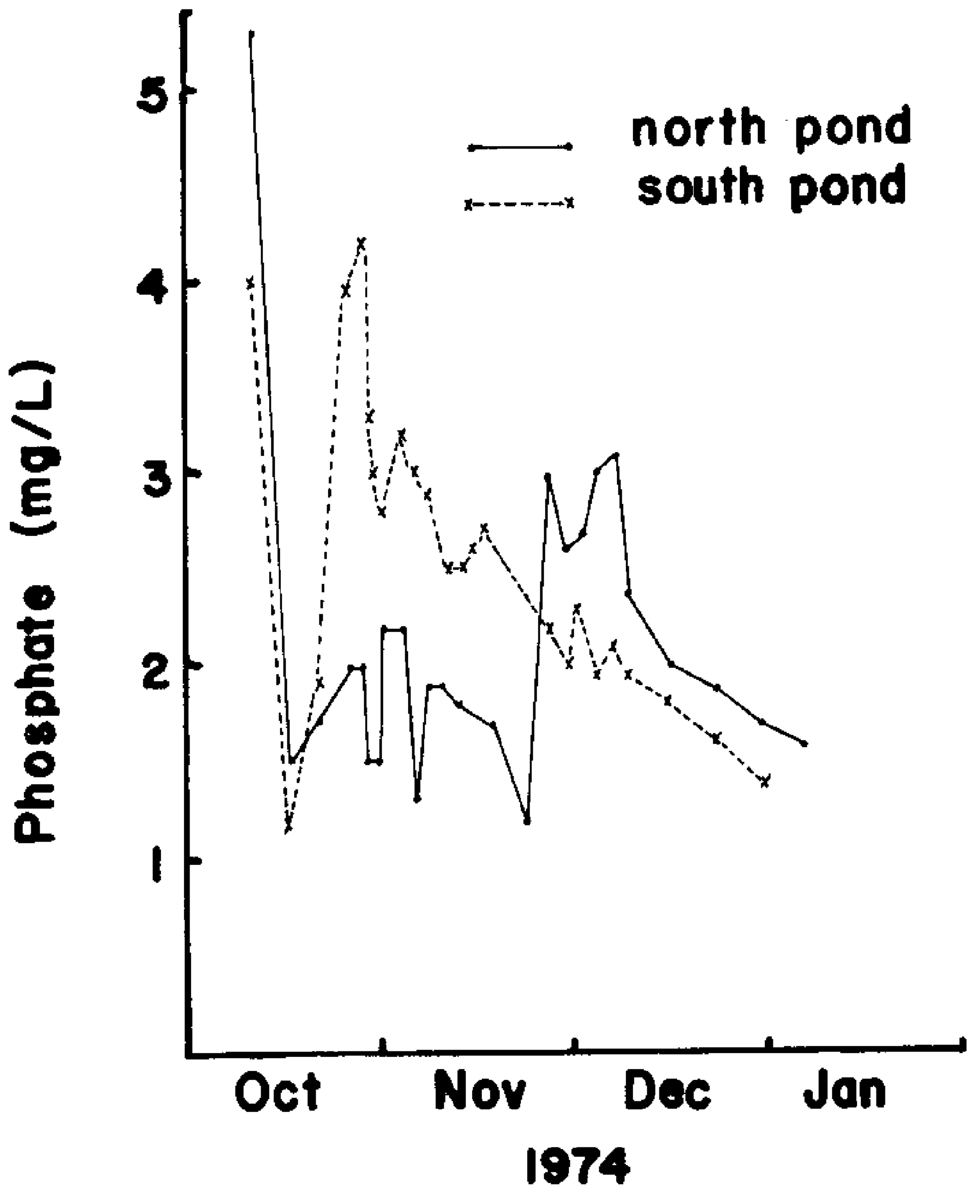


Figure 7. Phosphate phosphorus, North and South ponds, October 1974 - January 1975 (Experiment IX).

North Pond. Fish reared in pens showed very little mortality, with 3 of 7 pens having 100 percent survival (Table 5). Fish reared in pens in North Pond showed slightly less survival than South Pond, which is consistent with the results from fish reared in the open pond. Fish reared in small floating live cars also showed high survival rates (Table 6), with higher survival in South Pond than North Pond, which was consistent with the results for pond-reared fish and fish reared in fixed pens.

Table 4. Number of coho salmon and steelhead rainbow trout planted and recovered in North and South Ponds, 25 October 1974 - 12 January 1975 (Experiment IX).

Species	Number Planted[1/]		Number Recovered[1/]		Percent Survival	
	North Pond	South Pond	North Pond	South Pond	North Pond	South Pond
Coho[2/]	6,000	6,000	3,334	5,096	56	85
Rainbow	1,000	1,000	545	632	55	63

1/ Hand counted.

2/ Marked by excision of left ventral (LV) fin.

Growth Rates

Rainbow trout, which were longer but lighter than coho on planting, grew faster than the coho in both ponds, and showed greater growth especially in weight, which more than doubled in the 80 day growing season (Table 7). Not only was average rainbow growth greater than the coho, but in both ponds the largest fish appearing in the samples taken at the end of the experiment were rainbow, despite the fact that six times more coho had been planted. Pen-reared

Table 5. Growth and survival of 15 coho salmon planted 7 October 1974 into 4-square meter pens, North and South Ponds (Experiment IX).

Pen and Substrate	North Pond								South Pond							
	No. end	% Surv	Length			Weight			No. end	% Surv	Length			Weight		
			Min	Mean	Max	Min	Mean	Max			Min	Mean	Max	Min	Mean	Max
Gravel	12	80	83	92	105	7.1	9.1	13.1	14	93	67	94	105	6.7	10.1	14.7
Hookton soil	15	100	94	101	110	5.1	11.6	15.8	15	100	76	89	100	5.7	9.1	12.2
Oyster shell	13	87	83	95	104	7.9	10.0	12.2	14	93	80	89	99	7.1	8.7	11.5
Mud[1/]	-	-	-	-	-	-	-	-	15	100	81	98	109	6.0	10.5	15.9

1/ Hole located in bottom of pen. Only one fish recovered.

coho salmon (Table 5) grew at the same rate as pond-reared fish, with differences between pens not obviously correlated with any factor.

Table 6. Growth and survival of coho salmon in floating pens, North and South Ponds, October 1974 - January 1975 (Experiment IX).

Size of pen	Location	Start		End		% Surv	Size at end of experiment (fork length)		
		Date	No.	Date	No.		Min	Mean	Max
1-meter	North Pond	7 Oct	5	10 Jan	3	60 1/	86	95	112
1-meter	South Pond	7 Oct	5	10 Jan	5	100	65	82	104
½-meter	North Pond	25 Oct	8 1/	10 Jan	4	50	82	88	103
							(70)	(80)	(90) 2/

1/ North Pond 1-meter live car mortalities occurred between November 20-25, and between 9-17 December.

2/ Size at beginning.

Cause of Mortality

From 60 hours of observation made on 45 different days, Wagner (1974) observed black-crowned night herons (*Nycticorax nycticorax*) and belted kingfishers (*Megaceryle alcyon*) taking salmon from both ponds. Observations were made mainly in the early morning, and late in the evening. Rate of success in taking salmon was low, and extrapolation of observed bird predation only indicated about a one percent loss. Accuracy of observation on night-feeding by black-crowned night herons remains difficult to assess. Adequate infra-red spotting scopes for night work were not available.

Fish reared in fixed pens may have been liable to bird predation because their tops are not covered (see Figure 3, Allen and Dennis 1974). Small floating live cars, however, were all fitted with lids, and thus not susceptible to

Table 7. Growth in mean fork length and mean weight of coho salmon and steelhead rainbow trout in North and South Ponds, 25 October 1974-12 January 1975 (Experiment IX).

Species	Length				Weight				Range in size at end	
	Start	End	Gain	Percent	Start	End	Gain	Percent	Length	Weight
A. North Pond (N=25 Coho; 50 Rainbow)										
Coho[1/]										
"Large"	77	98	21	27	6.6	11.8	5.2	79	90-112	6.9-16.6
"Small"	77	85	8	10	6.6	7.7	1.1	17	70-98	4.9-11.6
Rainbow	81	106	25	31	6.1	14.7	8.6	141	75-149	5.0-39.4
B. South Pond (N=50 Coho and Rainbow)										
Coho[1/]										
"Large"	77	97	20	25	6.6	9.7	3.1	47	91-108	8.0-12.5
"Small"	77	87	10	13	6.6	7.7	1.1	17	70-99	3.6-9.9
Rainbow	81	108	27	33	6.1	14.3	8.2	134	79-134	5.9-26.2

1/ Coho were sorted into two groups (smaller or larger than 100 mm fork length) visually as fish were removed from the ponds for planting purposes. Actual size of fish in these groups was determined by measuring 24-hour formalin-preserved random samples from each group.

bird predation. Survival rates between these two rearing devices were about the same, but higher than pond-reared fish. As there was no obvious combination of water quality parameters that might indicate a cause for mortality, rates observed in these studies may represent a normal rate of decrease by loss of weaker, less-competitive fish.

If undiagnosed diseases were responsible for observed mortalities, pen-reared fish were able to resist them better than fish moving freely in the ponds.

Fish Production

The production rate for salmon reared in pens was similar to that obtained for unfertilized wastewater ponds rearing carp in Germany (500 kg/ha/year for a 6-month summer rearing period) (Table 8). The fish production of pond-reared fish, however, was low and in North Pond actually was negative (biomass of fish dying less than that gained by surviving fish, or weight of standing crop (biomass) at end of experiment less than the weight of fish planted). Thus, an 85 percent survival of coho in South Pond coupled with about a 50 percent increase in weight produced a production rate of 100 kg/ha/year, and a 63 percent survival of rainbow with a 134 percent increase in weight produced a production rate of 94 kg/ha/year. Combining salmon and trout, South Pond produced at about 200 kg/ha/year.

In contrast, 100 percent survival with a 75 percent increase in weight produced a production rate of 850-879 kg/ha/year (Hookton Pen, North Pond, Table 8). These results support our empirical approach of modifying both ponds to produce similar survival advantages to pond-reared salmon as produced by pen-rearing by providing artificial underwater reefs.

Table 8. Production of fish in ponds and pens, 25 October 1974 - 12 January 1975 (Experiment IX), (kilograms per hectare per year).

A. Pen-reared coho

Rearing Substrate	Method of Calculation			
	Surviving Fish		Biomass	
	North Pond	South Pond	North Pond	South Pond
Gravel	342	559	114	491
Hookton Soil	856 1/	434	879 1/	434
Oyster Shell	502	331	354	262
Mud	-	662	-	662

1/ Where survival is 100 percent, values calculated by the two methods should be equal (Hookton Soil, South Pond, and Mud, South Pond). Reason for slight discrepancy in figures not determined).

B. Pond-reared coho and rainbow

Rearing area	Species	
	Coho	Rainbow
North Pond	-311	63
South Pond	100	94

Food Habits

During the experiment, stomachs from 10 rainbow trout and 12 coho were examined for occurrence of food items (Table 9). Location of fish samples were not recorded, therefore results represent a pooled sample of fish from both ponds. Two amphipods (*Anisogammarus* and *Corophium*) dominated the stomach contents. Copepods, which bloomed in North Pond but not in South Pond, appeared in the salmon's diet. The gammarid amphipod (*Anisogammarus*) was found as whole bodies, while only the large antennae of the tube-dwelling form (*Corophium*) occurred in these stomach samples.

Table 9. Frequency of occurrence of food items consumed by rainbow and coho fingerlings reared in wastewater ponds, October 74 - January 75 (Experiment IX).

Food Item	Species	
	Rainbow (N=10)	Coho (N=12)
Anisogamarus	7	10
Corophium	3	2
Copepod	8	0
Isopod	0	4
Macro-algae	1	2
Gravel	2	1

Fish Behavior

Distribution and movements of rainbow and coho fingerlings was studied during this experiment using five types of small single-funnel traps (Collins

1976). The full results of this work will be reported elsewhere, however, there are a few results that appear important to pond management.

The traps reflected the relative abundance of coho and rainbow fingerlings much more accurately in the turbid waters of North Pond than did the catch in South Pond where apparently the coho actively avoided entering the trap (Table 10). A species-specific behavior, possibly schooling or territoriality, was indicated by the repeated occurrence of only coho or rainbow in the traps (Table 11). Trapping results also indicated that fish tended to cruise along the edge of the ponds. Future studies may be able to ascertain whether these are local movements or wide-ranging around the pond periphery. If the pond periphery is preferred by the fish, areas in the pond center must be made attractive to the fish before full utilization of pond food can be obtained.

Table 10. Comparison of ratio of coho to rainbow trout fingerlings caught in single-funnel wire traps to actual ratios of the two species, North and South Ponds (Experiment IX).

Comparison	North Pond	South Pond
Planted	6:1	6:1
Trapped	4.3:1	0.4:1
Recovered	6.1:1	8.1:1

Curios depressions were found around the bases of the double-basket artificial reefs placed in the center of the pond. Although the mud in the central part of the pond is quite soft, some of the baskets were placed in areas where gravel had been spread to help stabilize the bottom. Depressions also occurred around the base of baskets placed on these gravel-mud substrates. It is possible that territorial behavior may account for this such as the excavated home areas constructed by channel catfish in culture ponds (Randolph 1975). This again suggests that the placement of artificial reefs of proper design may be extremely important to maximizing pond productivity.

Table 11. Comparison of occurrence by species in individual trap catches (Experiment IX).

Single species only appearing in trap		Coho and rainbow appearing in trap[1/]	No. fish caught
Coho	Rainbow		
20	12	8	29

1/ Frequency of occurrence of various coho;rainbow ratios with number of coho and number of rainbow shown in parentheses: 2(1:1); 2(2:1); 1(1:5); 1(3:4); 1(7:2); 1(17:1).

Non-target Species

The number and variety of non-target species in the system was so small that no specific collections were made. Only two species of fish and one invertebrate came to our attention (Table 12). Significantly, no staghorn sculpin (*Leptocottus armatus*), a major predator, were recovered.

Water Quality

As part of a study to mass culture Dungeness crab larvae by Thorson (1976) at the Trinidad Marine Laboratory, a small experiment was conducted involving water from North fish pond. On January 7, 1975, five gallons of North Pond water was taken to Trinidad, and its salinity raised to 24 o/oo by a 50 percent dilution with 20-micro filtered water with the Trinidad laboratories recirculating seawater system. This served as the test water. Control water was recirculating seawater from the Trinidad system (20 micron filter seawater) and recirculating seawater filtered to 4.5 micron. Tests were run in 500 ml Erlenmeyer flasks. Fifty larvae, previously held for two days, were used in the bioassay. Replicate flasks were used for each solution tested. Water in the flasks was initially changed every two days, and then was changed every three days when the tests had run 20 days. Freshly hatched *Artemia salina* nauplii were used for larval food. The experiment was run for 33 days when the pond water supply was exhausted. The larvae molted twice going from the first zoeal stage to the third zoeal stage at the end of experiment. Molting was essentially the same in all flasks. Control water showed about twice the

Table 12. Recovery of non-salmonid fishes in North and South Ponds, January 11-12, 1975 (Experiment IX).

Species	North Pond	South Pond	Remarks
Stickleback	200-300	200-300	Not counted; visual estimation.
Gobiidae	25	50	Not counted; slightly more abundant in South Pond.
Shrimp (*Crago*)	few	few	Several specimens were weighed: 3-3.5 gm range.

rate of survival as compared to North Pond water and normal Trinidad laboratory water (Table 13). Reed (1969) found slightly better survival at 25 o/oo salinity than at 30 o/oo at temperatures similar to those in this study. Thus pond water mortality was not related to lower salinity. It is more probable that bacterial infections caused the lower survival in both pond water and Trinidad laboratory water. Aged North Pond water diluted 50 percent was no more harmful to Dungeness crab larvae than normal Trinidad marine laboratory water filtered to remove all particles larger than 20 microns.

Table 13. Survival over 33 day rearing of Dungeness crab larvae in aged wastewater-seawater fish pond waters January-February 1975 (50 larvae per 500 ml) (Experiment IX).

Factor	Solution	Percent survival (Average of 2 tests)
Control	Trinidad marine laboratory recirculated water; filtered to 4.5 microns.	75
Control	Trinidad marine laboratory recirculated water (filtered to 20 microns by system).	37
Test	North Fish Pond water diluted 50% with Trinidad marine laboratory recirculated water (filtered to 20 microns by system).	43

EXPERIMENT X

(February - May 1975)

Objectives

Success in rearing fall chinook salmon had steadily improved over the past three years, with the highest survival rate achieved of 27 percent from 15,000 fry planted in 1974 in South Pond (Allen and Carpenter, In press). Since the 4,000 smolts harvested averaged 4.3 grams in weight, and were growing rapidly at the end of the experiment it was obvious that the natural productive capacity had not been attained in 1974. Experiment X (February - May 1975), therefore, was the first in a program of exploring the maximum smolt production that the system could sustain without supplemental feeding. Continuing the use of conditioned wastewaters from previous rearings was also an objective of the experiment. Methods of selectively trapping of smolts were studied during this experiment for the first time.

As in past experiments, North Pond contained a number of physical features different from South Pond. North Pond had vertical pond banks with an associated forced-air bubble stream at the base of the bank and assorted underwater reefs as installed during Experiment IX (Table 2). Aeration was extended to South Pond by a single perforated pipe placed through the center of the pond and terminating in the fish collecting sump in front of the pond headgate. This produced a bubble field through the center of the pond. AIR-O-LATORS were available for each pond. Stocking level (30,000) was set at double that of Experiment VII. Salinity levels were to be maintained as close to 15 o/oo as conditions would permit.

Pond Operation

Following pond draining on January 11-12, water remaining was equalized between the two ponds so that each pond contained between 1/3-1/2 its volume with aged water. The ponds remained partially filled until January 21-22 when oxidation pond water was added to each pond, followed by seawater from Humboldt Bay on January 24. South Pond salinities remained slightly higher than North Pond until mid-February when both ponds were brought to about 12 o/oo. Considerable additions of Humboldt Bay water, plus drainings to compensate for heavy rainfalls, caused salinity variations both between ponds and during the course of the experiment. Several days of flushing in late February to improve water quality also occurred. During the last week in April and first week of May, several major additions of oxidation pond water and of Humboldt Bay water were made in order to raise and lower the salinity around a 10 o/oo level to test empirically the influence of salinity on movement of chinook salmon smolts into a newly constructed smolt trap (Hume 1976).

Considerable problems occurred with failure of air pumps operating the forced-air aeration system. In addition, joints in the forced-air system broke loose and had to be resealed. Thus an erratic switching between forced-air and spray aeration (AIR-O-LATOR) systems occurred during the rearing experiment.

Physical-Chemical Conditions

Methods for studying pond water properties were the same as for Experiment IX (Table 3). Water temperatures were optimum for salmonid growth during Experiment X starting at 10° C, and slowly increasing to around 13° C, except for a short period of cooler weather in late January (Figure 8). Water temperature in South Pond and North Pond were similar. Salinities at the start of the experiment were from 18-22 o/oo range (Figure 9). In early March, pond salinities were equalized in both ponds at around 16 o/oo, dropping slowly to around 9 0/oo.

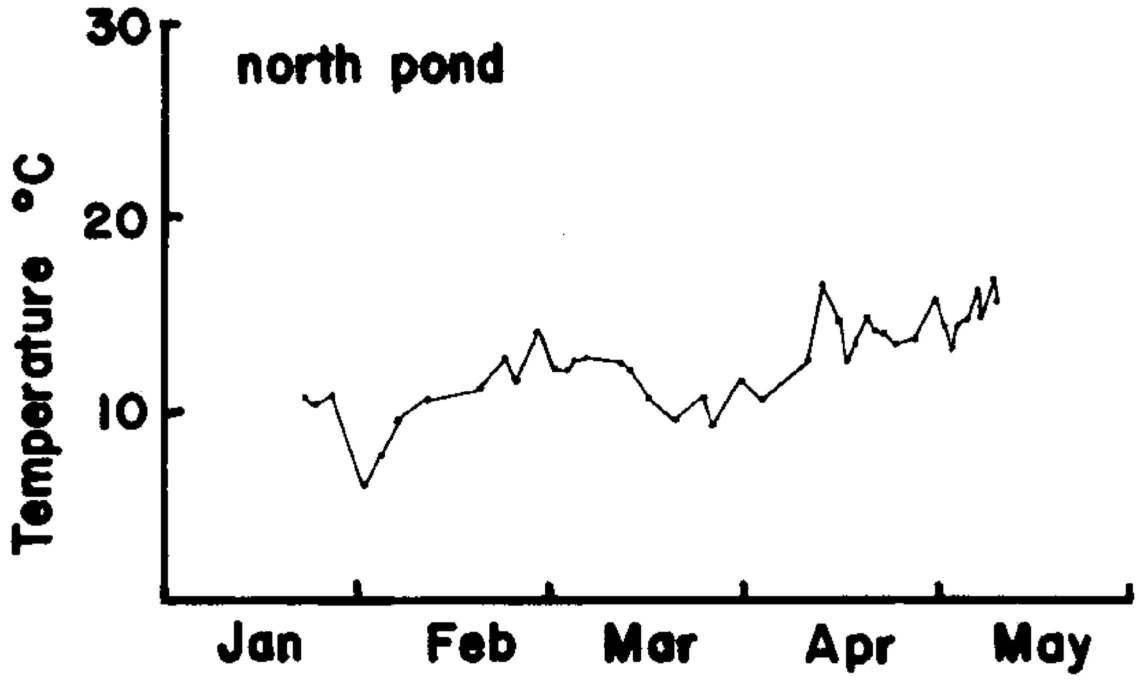
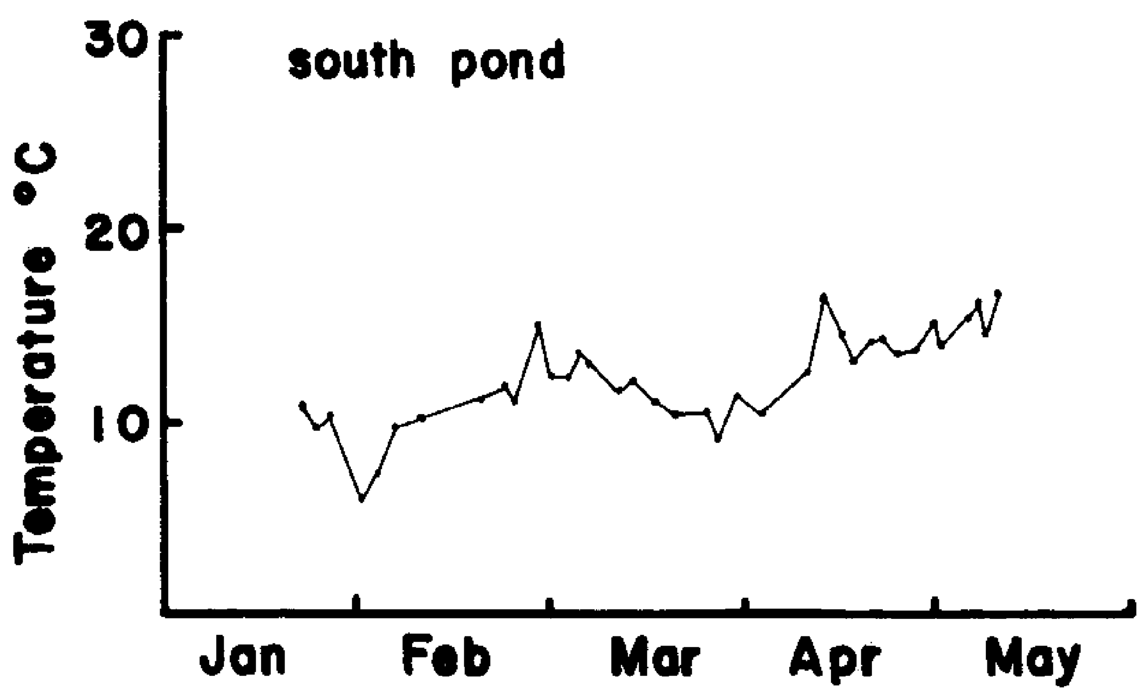


Figure 8. Temperature, surface water, North pond (above), South pond (below), January-May 1975 (Experiment X).



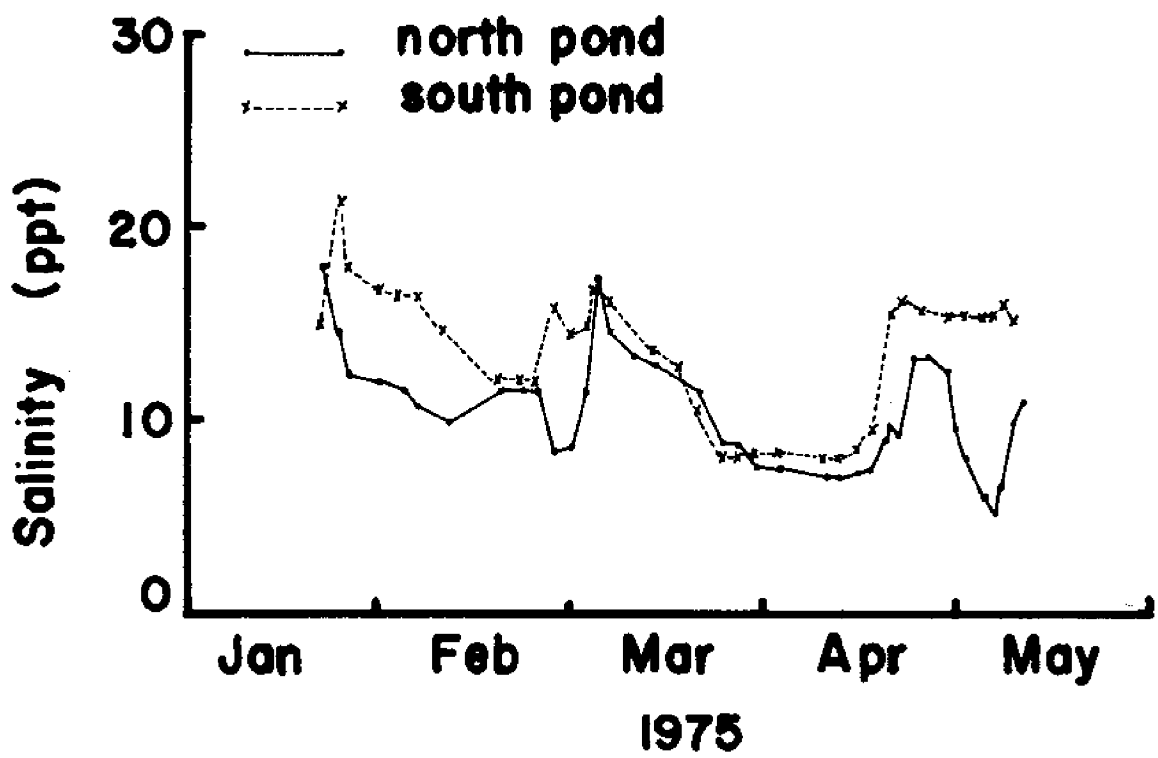


Figure 9. Salinity, surface water, North and South ponds, January - May 1975 (Experiment X).

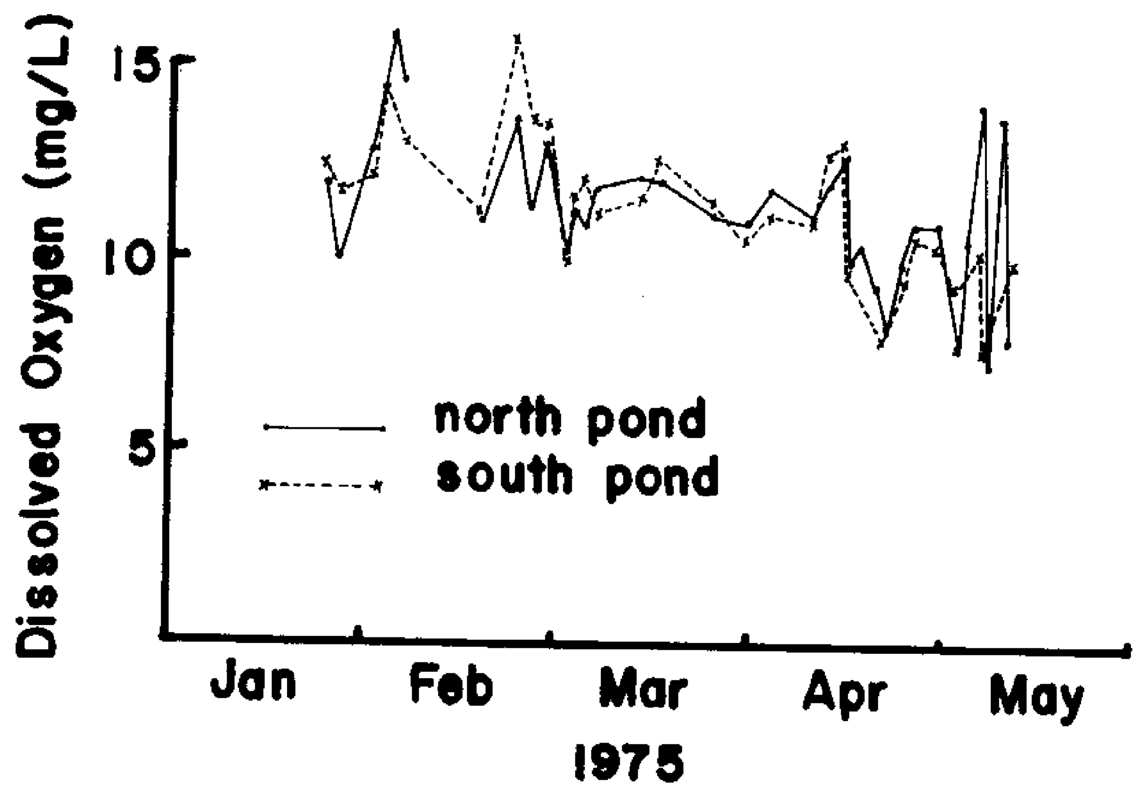


Figure 10. Dissolved oxygen, surface water, North and South ponds, January - May 1975 (Experiment X).

Salinities were then adjusted to 15 o/oo in South Pond, whereas it was varied in North Pond between 5-11 o/oo to test trapping of smolts under different salinity regimes. Dissolved oxygen was high and stable in both ponds (Figure 10), except in North Pond in the early May period when major additions of seawater and oxidation pond effluent were made over short periods of time. Oxygen levels were related to similar phytoplankton densities in both ponds as measured by transparency (Figure 11). Hydrogen ion levels fluctuated between near 7 and 10 pH units (Figure 12), with the highest level occurring in North Pond in late February, but with consistently high levels (over 9) occurring in South Pond. North Pond pH levels rose to 9.6 in early May with additions of oxidation pond effluent. Ammonia nitrogen was measured sporadically (Figure 13), and tended to remain high during the latter portion of the experiment.

Nitrate nitrogen index levels in both ponds, showed no values over 50 index units, with most below 5 (N = 11-12). During the last week of May, values in the 500-600 range occurred in North Pond with the addition of large amounts of oxidation pond water. Nitrite nitrogen was also low, with only one reading showing more than 2 mg/l (N = 12-14).

Samples of pond water were taken to the HSU botany department for species identification (Dr. William Vinyard) on 8 May 1975). South Pond phytoplankton population was mainly Chlorella, in a very pale and generally poor condition. Some Skeletonema was also present. In contrast, North Pond was totally dominated by Chlorella, which had abundant chlorophyll and was in good condition. These conditions reflected the fresh injections of seawater and oxidation pond water into North Pond during early May, and the resulting rapidly changing dissolved oxygen, pH, and nitrate values recorded.

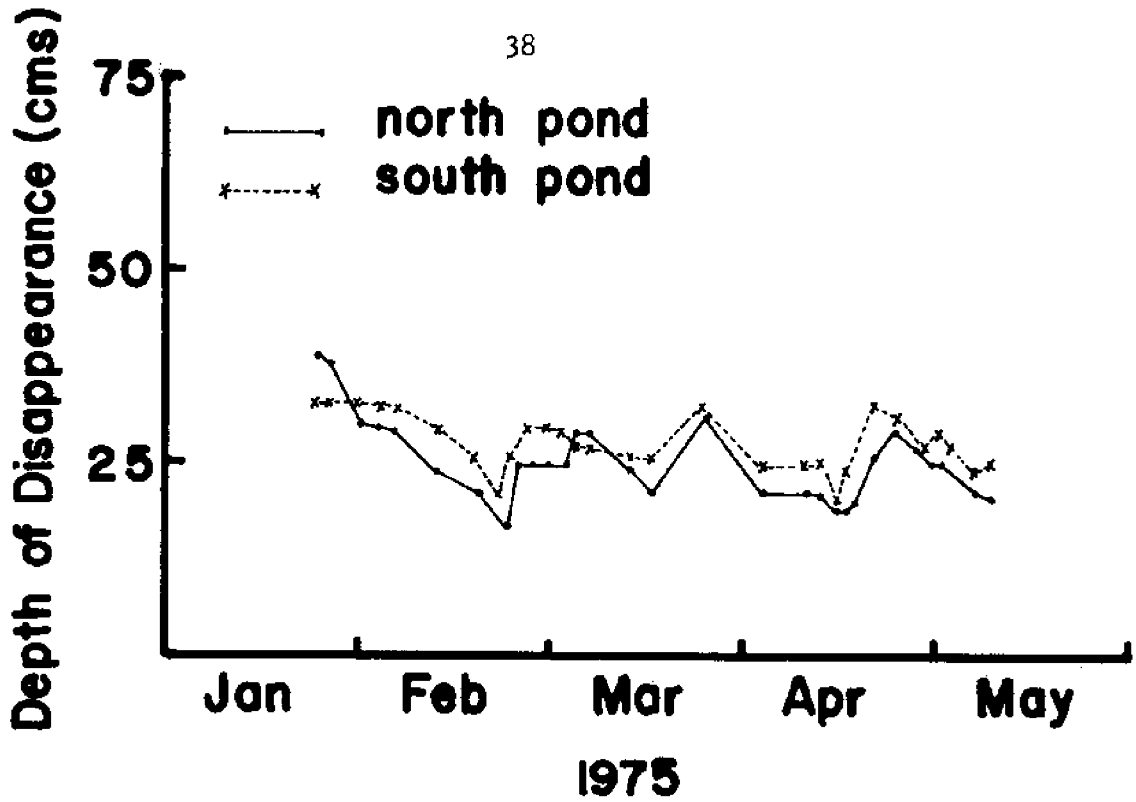


Figure 11. Clarity, North and South ponds, January-May 1975 (Experiment X).

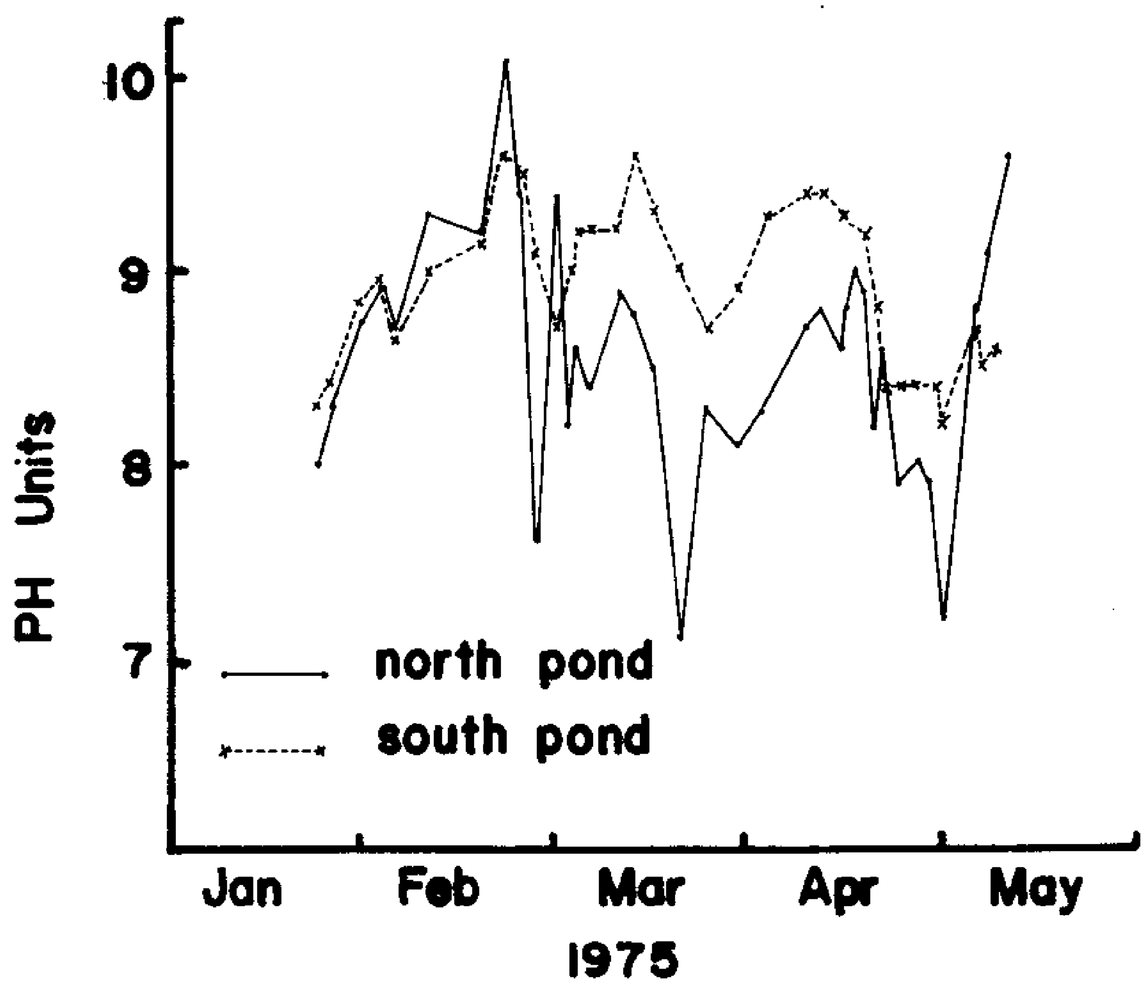


Figure 12. Hydrogen ion concentration, North and South ponds, January - May 1975 (Experiment X).

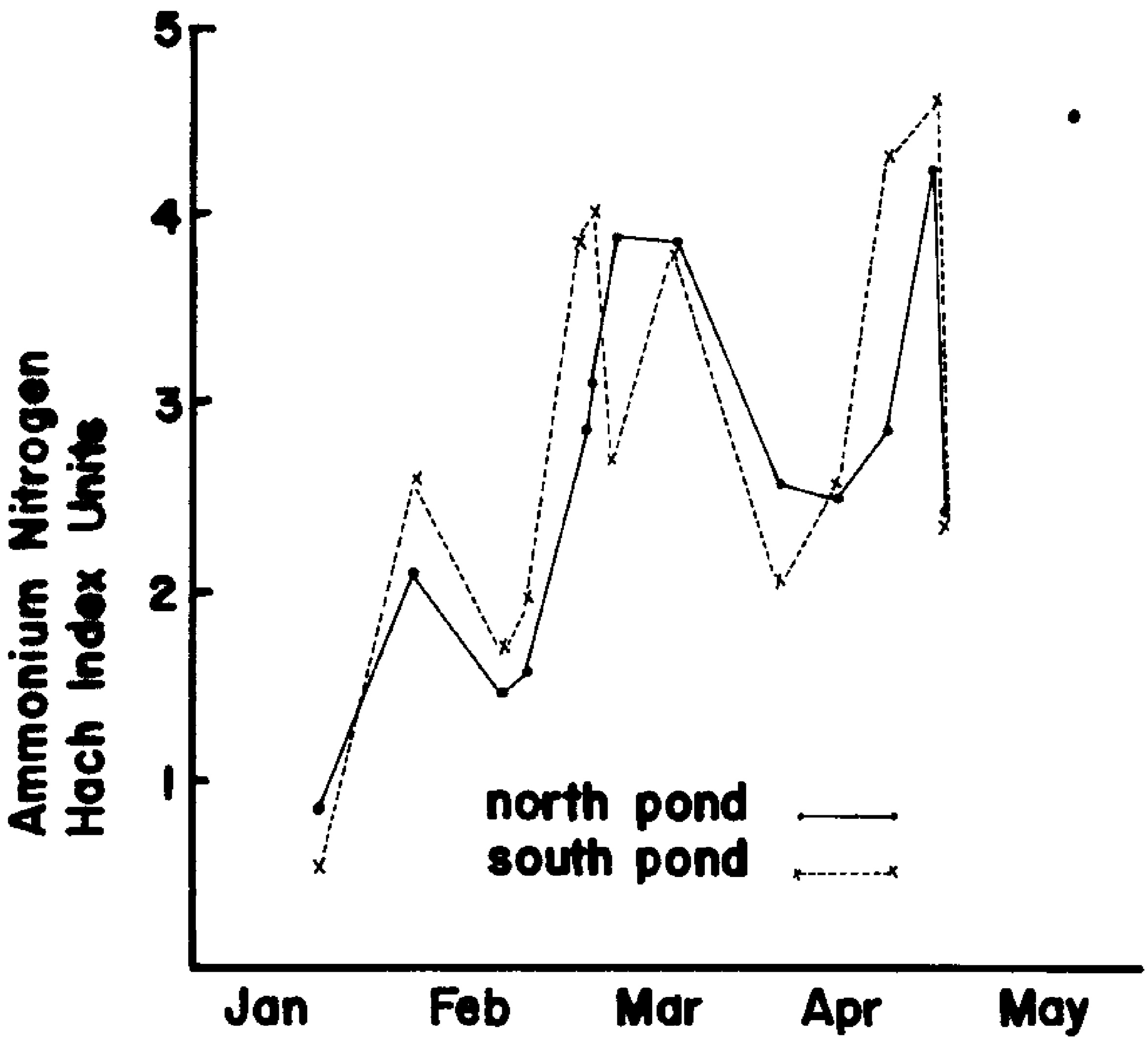


Figure 13. Relative ammonia nitrogen, surface water, North and South ponds, January - May 1975 (Experiment X).

Survival Rates

On January 22, chinook fry were placed in floating pens in both North and South Pond, and monitored until 4 February. No mortalities occurred over this period. Chinook fry were planted into North and South Ponds on 4 February 1975, and in a series of fixed and floating pens (Table 14).

On February 21 personnel began reporting the presence of great blue herons and egrets around the ponds during working hours indicating the presence of easily-caught or moribund fish. On 26 February, small chinook trapped behind pond inlet screens were seen near the surface showing signs of stress. On 28 February chinook salmon being reared in 1-square meter floating pens were showing stress, as well as salmon living freely in the pond (Table 15). Subsequently, a heavy mortality was recorded in the 1-square meter floating pen in North Pond in late February (Figure 14), and at a somewhat later date (time uncertain) in the 1-square meter pen in South Pond. No further mortalities occurred amongst the remaining salmon in the floating pen in North Pond until all remaining fish died on 6 May. When the ponds were drained on May 7, 1975, only 31 chinook salmon were recovered from South Pond and no salmon from North Pond. Salmon, however, were recovered by Hume (1976) in a specially-designed smolt trap fished in a slot designed into the headgate of North Pond as late as May 5, while Gray (1975) consistently caught salmon in 1-meter cylindrical single-funnel traps fished throughout the pond, including catches on May 5.

The catch-per-unit effort in single funnel traps in North Pond is shown in Figure 15. No catches were made in any traps fished in South Pond after the first week in March. These trap catches reflect the history of mortalities as correlated with physical-chemical conditions in the pond. Initially there was a high density of fish with a high catch in the traps, followed by a drastic drop in catch in the period in late February and early March due to salmon

Table 14. Number and location of fall chinook salmon fry planted 4 February 1975 (Experiment X). (38 mm mean fork length and 0.5 gm mean wt).

Planting Location	Total Units	Number planted per unit	Area/Unit (Hectares)
North and South Ponds	2	30,000	1,500
Fixed pens on four substrates North and South Ponds	8	80	4.0
Fixed pens on three substrates NW corner of North Pond	6	50	4.0
Movable pens, South Pond on gravel	3	30	1.5
Floating pen, North and South Ponds	2	25	1.0

Table 15. Observations on chinook fry during period of mortalities, North Pond, February 27 - 2 March 1975 (Experiment X).

Date	Observation
27 Feb	Small, thin fry noted at surface behind headgate screen.
28 Feb	Chinook fry in floating-pen were showing obvious signs of distress. Five fry taken from pen and placed in a 1:1 mixture of pond water and Humboldt Bay water for transportation to fish pathology laboratory. Three additional fry dip-netting from pond surface added to sample. As fish pathology laboratory was closed (late Friday afternoon), sample transported to home residence for observation: Fry swam in circles, or with a cork-screw path. Several of the fry showed active hemorraghing through gills and jaws. Two fry had very evident gas bubbles under the skin of the jaws and head, and were unable to close jaws. One fish showed serious exopthalamia. A late-afternoon sample of North Pond showed a pH value of 9.85.
1 Mar	All fish lying on sides on bottom of container, ventilating rapidly (0800). Two fish on surface still ventilating; three fish on bottom slowly ventilating; three fish dead (1530). Four fish only ventilating (1600).
2 Mar	All fish dead (0800). Range in size (fork length mm): 35 - 40.

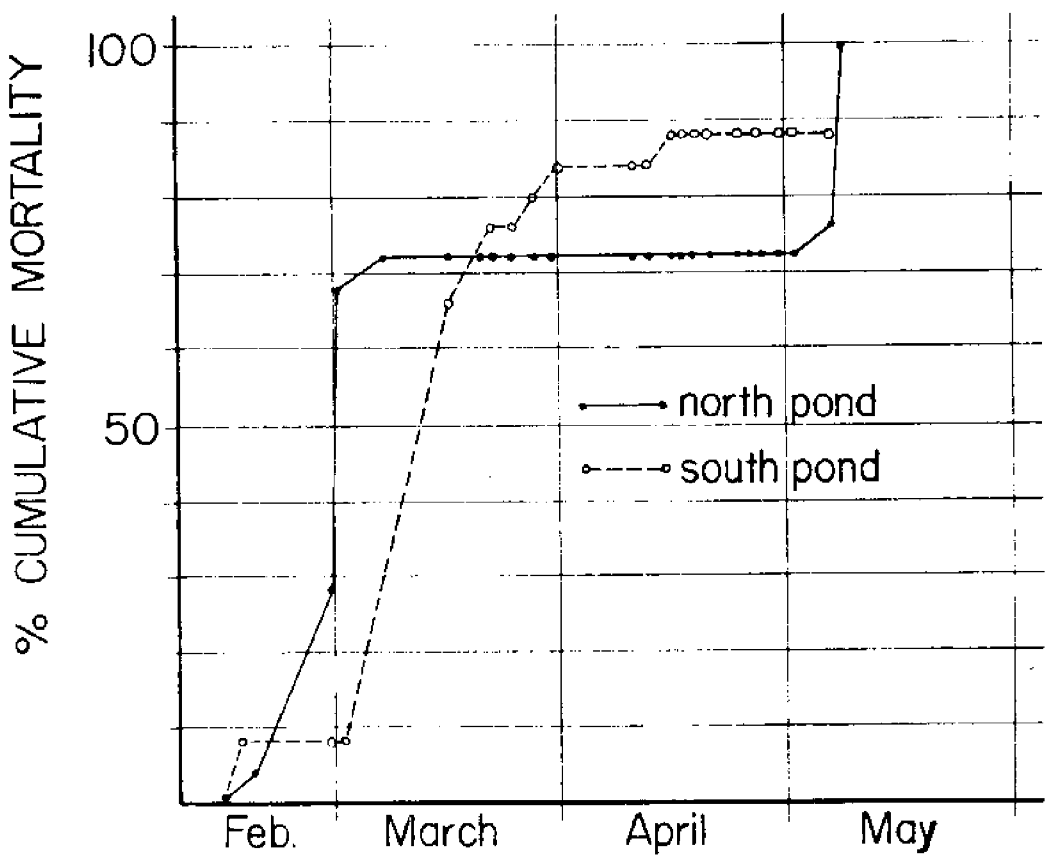


Figure 14. Cumulative mortality of chinook salmon reared in 1-square meter floating pens near headgate, North and South ponds, February - May 1975 (Experiment X) (from Allen and Carpenter, In press).

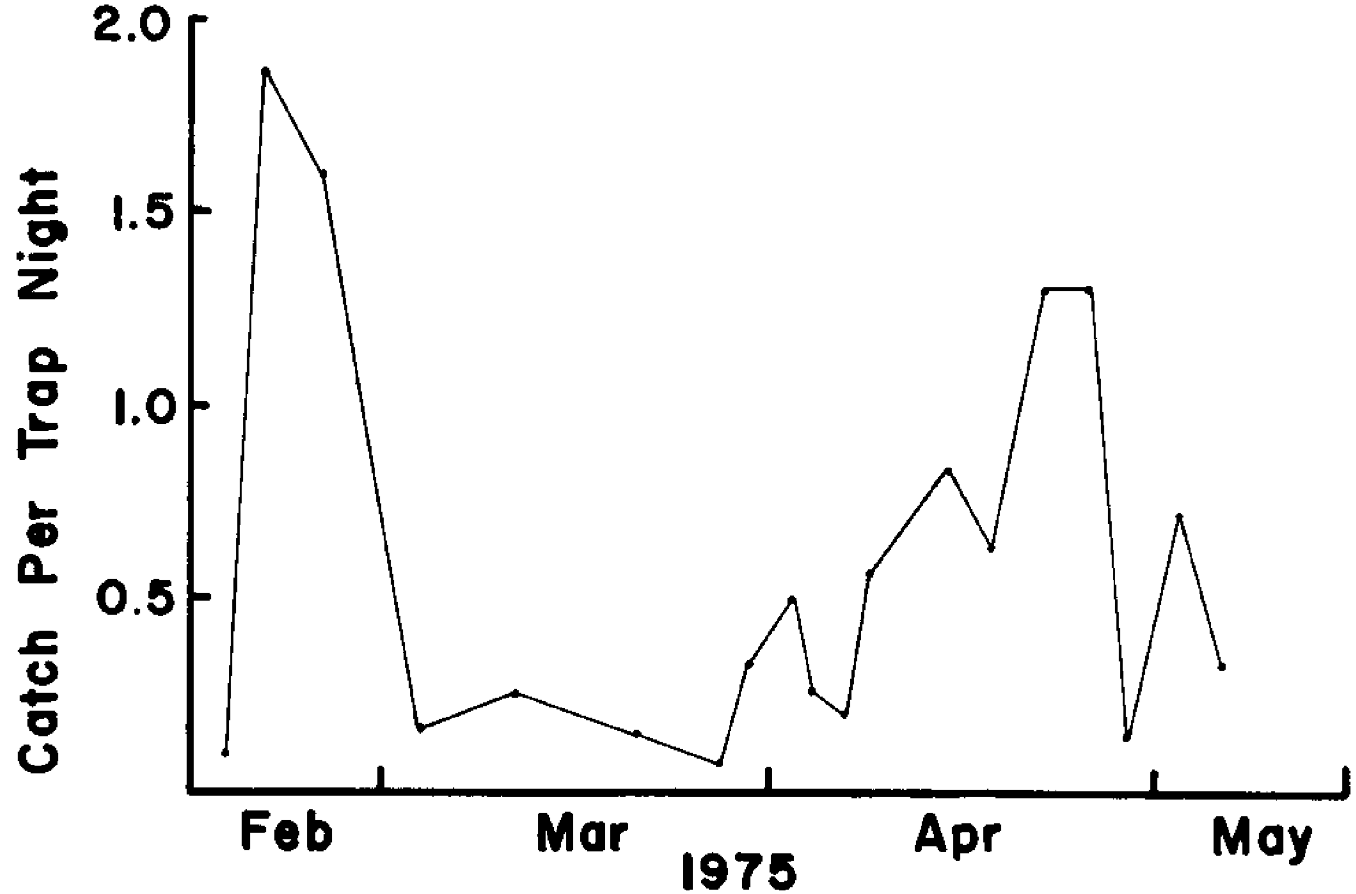


Figure 15. Catch-per-unit effort in 3-6, 1-meter cylindrical single-funnel traps located near pond edge, North pond, February - May 1975 (Experiment X) (from Gray 1975).

mortalities in the pond. Following a period of recovery from stressful water quality conditions, surviving fish in North Pond became more active with smolting in early April. Reduced catches in late April and early May then occurred from at least three factors: smolts could migrate to Humboldt Bay through a broken screen during pond salinity manipulations in late April and early May; mortalities could have been induced from addition of excessive amounts of oxidation pond waters; and reduced activity of chinook from residualization (Collins 1976).

Since salmon had survived in North Pond until May 6, it was of interest to obtain some general idea of the size of this population at that time. Four indirect estimates of the number of salmon in North Pond in late April 1974 are described in Table 16. Catch-per-unit effort data used in these estimates are listed in Table 17. A wide range of population values resulted from these calculations (600 to 8,400 salmon) (Table 16).

The most straight-forward technique (Method A) unfortunately greatly overestimated the population for two reasons. First, survival rates of salmon in floating live cars are consistently higher than for rates for pond-reared fish. Second, salmon were able to escape from the pond when water was either being discharged to or added from Humboldt Bay through the lower portion of the headgate screen which had come loose from its frame.

The remaining three estimates (Methods B, C, D) utilized catch-per-unit effort data made with 1-meter cylindrical single-funnel traps fished in the ponds during 1974 and 1975 (Table 17). The size of the population in North and South Ponds in 1974 on 7 May was known since all fish were recovered when the pond was drained. Thus estimates of the size of the population in North Pond in 1975 could be made by use of simple proportions (Table 16). Major assumption in the valid use of this technique is that similar sampling gear fished in

Table 16. Method and results of estimating the number of fall chinook salmon in North Pond in late April 1975 (Experiment X).

Method	Description	Calculation[1/]	Estimate of number of salmon in North Pond
A	Application of survival rate of fish in 1-square meter floating pens to total number of fry planted into North Pond.	(30,000)(0.28)	8,400
B	Ratio of maximum catch-per-unit effort recorded in a single 1-meter cylindrical single-funnel trap in South Pond in 1974 to that in North Pond in 1975.	(4,000)(0.10)/(0.10)	4,000
C	Ratio of catch-per-unit effort April 4-6, 8-10, North Pond in 1974 to that in period April 19-24 in North Pond in 1975	(2,400)(0.08)/(0.29)	662
D	Ratio of maximum catch-per-unit effort recorded in a single 1-meter cylindrical single-funnel trap in North Pond in 1974 to that in North Pond in 1975.	(2,400)(0.10)/(0.42)	571

1/ Total salmon recovered May 7, 1974: North Pond, 2,400; South Pond, 4,00; catch-per-unit effort data from Table 17.

Estimates using methods B, C, and D by ratio:

$$X \text{ (estimated population in 1975)} = \frac{\text{(known population in 1974)} \times \text{(catch-per-unit effort in 1975)}}{\text{(catch-per-unit effort in 1974)}}$$

Table 17. Comparison of catch-per-unit effort in 1-meter cylindrical, single-funnel traps, in North and South ponds in 1974, and North Pond in 1975.[1/]

Year	Date	Location	Number of traps	Total trap hours	Salmon caught	Catch-per-unit of effort (salmon per hour)	Remarks
1974	4-5 Apr	North Pond headgate	1	24	10	0.42	Peak catch for single trap.
	5-6 Apr	North Pond headgate	1	24	0	0.0	
	6-8 Apr[1/]	North Pond headgate	1	48	106	2.21	Headgate open during fishing period.
	8-10 Apr	North Pond headgate	1	48	18	0.38	
1974	19-24 Apr	South Pond headgate	1	120	12	0.10	Peak catch for single trap.
1975	18-21 Apr	North Pond periphery	4	288	24	0.08	
	18-21 Apr	North Pond periphery	1	72	8	0.01	Peak catch for single trap.

1/ Data provided by Collins 1974, Personal communication.

approximately the same manner is a measure of the relative abundance of salmon at the time of sampling. Sampling of chinook salmon in South Pond in 1974 with the same type of trap as fished in 1975 in North Pond produced an estimate of 4,000 fish in North Pond in 1975 (Table 16, Method B). Water in South Pond in 1974 was much clearer (65-95 cm Secchi disc reading) than the water in North Pond in 1975 (20 cm reading). Since salmon tend to avoid the traps in clearer water (see discussion on subject in results of Experiment IX) the catch-per-unit effort for South Pond in 1974 would be lower than North Pond for the same population level. This would lead to overestimating the North Pond population in 1974.

Estimates using trap catch data from North Pond in 1974 and 1975 are probably the most accurate (about 600 salmon, Methods C and D, Table 16) for two reasons. First, water clarity was about the same in both years (25 cm Secchi disc reading). Second, maximum catch of salmon in stationary traps would tend to occur at the time when the downstream migrational urge is at its highest within the salmon population. Active fish would be easily caught by the stationary traps. The population estimate using the highest catch-per-unit effort available for the two years (Method D) was in good agreement with the estimate using combined data over a longer period of time covering the presumed peak of downstream migrational movement in the Pond (Method C). This correspondence would support the reasonableness of these estimates of the North Pond population in 1975.

In summary, the survival of chinook salmon reared in North and South Ponds in 1975 was very low (Table 18). Practically no fish survived the stress period in late February-early March in South Pond; however, about two percent of the salmon survived until May 6 in North Pond. As presumably many chinook salmon in North Pond escaped unmarked into Humboldt Bay during the experiment, returning adult fish perhaps can be identified by scale analysis.

Table 18. Number and estimated size of chinook salmon recovered from North and South Pond 6-7 May, 1975 (Experiment X).

	Number planted	Number recovered	Percent survival
North Pond	30,000[1/]	0	2.0-2.3[2/]
South Pond	30,000	31	0.001

1/ Headgate screen found loose from lower-right hand side of frame on draining pond, thus fish had direct access to the ocean for an unknown length of time when any water either wasted to or added from Humboldt Bay.

2/ Calculations of estimated population in late April in Table 16.

Although pond-reared salmon suffered high mortalities during the experiment, pen-reared fish showed a wide range in survival rates. In 4-square meter fixed pens on four different pond substrates, there was only a single salmon recovered from North Pond as compared to survival ranging from 1-20 percent in South Pond (Table 19). Combining all recoveries from 4-square meter pens in South Pond, a minimal survival of 13 percent was recorded, in contrast to less than 0.001 percent for salmon reared throughout the pond. An even greater difference in survival rates in South Pond was found for chinook salmon reared in 1.5-square meter movable pens located over a gravel substrate (13-67 percent survival) (Table 20). The pen with the highest survival had been fitted with six small brick-and-pine cone artificial reefs that covered the bottom of the pen. In North Pond salmon reared in fixed pens in the open portion of the pond showed apparent total mortality, whereas salmon reared in six, 4.0-square meter pens recessed into the northwest corner of North Pond produced survivals ranging from 14-40 percent (Table 21). These pens had been completed during the summer of 1975, and were designed for experiments requiring replicate tests. Substrates utilized in these pens during Experiment X were oyster shell, river run gravel,

Table 19. Number, length, and weight of chinook salmon recovered from 4-square meter pens over four substrates, North and South Ponds, 10-11 May, 1975 (Experiment X).

Substrate	North Pond				South Pond							
	Number	Survival (Percent)	Length	Weight	Number	Survival (Percent)	Length			Weight		
							Min	Mean	Max	Min	Mean	Max
Gravel	1	1	66	3.0	13	16	40	52	63	0.9	1.9	3.5
Hookton Soil	0	0	-	-	1 1/	1		56			2.2	
Oyster Shell	0	0	-	-	16 2/	20	38	48	58	0.7	1.6	2.0
Mud	0	0	-	-	2 3/	1	44	47	49	1.0	1.3	1.5

1/ Pen exposed during period of low water level in pond.

2/ Pen covered with netting to exclude possibility of bird predation.

3/ Hole in pen webbing.

Table 20. Number, length, and weight of chinook salmon reared in 1.5-square meter movable pens located over gravel substrate, South Pond, (Experiment X).

Pen	Number	Percent Survival	Length			Weight		
			Min	Mean	Max	Min	Mean	Max
Pen[1/] covered with plywood; no reefs	7	23	41	45	48	0.5	0.9	1.2
Uncovered; 6 reefs	20	67	36	46	56	0.6	1.3	2.9
Uncovered; no reefs	4	13	44	47	51	1.2	1.4	1.9

1/ Small holes in bottom mesh may have allowed fish to escape during removal of pen and recovery of fish.

and pond mud. The outer row of pens (Numbers 2, 4, and 6) were subject to ambient water conditions of the pond. Survival rates were highest over the mud substrate, intermediate over gravel, and lowest over shell. The combined survival rate from these six 4.0-square meter pens was 26 percent in comparison to no recoveries in the pond. The lack of recoveries of chinook salmon from North Pond, however, was spurious for reasons as previously discussed.

Growth

Growth was monitored by samples of fish taken in traps. Gray (1975) fished from 3-6, 1-meter long, cylindrical single-funnel traps throughout North Pond, while Hume (1975) fished at the headgate to North Pond a trap designed to catch smolts by directing a flow of water through the trap. Both fork length (mm) and weight (gm) were obtained on trapped salmon. By late April, a mean weight of around 3 grams (65 mm fork length) per fish was attained with range in weight from about 1.4-5.0 grams (Figure 16). Range in weight attained in late April corresponded to fork lengths of 50-55 mm and 70-75 mm. Growth in length is included in Figure 17. The larger fish were approaching the minimum size of 70 mm found for fall chinook migrating to the Mad River estuary (Taniguchi 1969). Fish recovered from North Pond pens (Table 21) were smaller than trap-caught fish from the pond, but were larger than any of the salmon recovered from pens in South Pond (Tables 19 and 20). This result is congruent with the much more severe mortality suffered by South Pond fish than fish in North Pond.

Table 21. Number, length, and weight of chinook salmon recovered from six, 4-square meter pens recessed into northwest corner of North Pond, 10 May 1975, Experiment X.

Number, Location, and Pen Substrate			Number	Percent Survival	Length			Weight		
Pen No.	Location	Substrate			Min	Mean	Max	Min	Mean	Max
1	Inside	Shell	10	20	43	48	60	0.8	1.2	2.3
2	Outside	Shell	7	14	49	57	67	1.4	2.3	3.6
3	Inside	Gravel	11	22	47	55	62	1.1	1.8	2.7
4	Outside	Gravel	14	28	43	57	70	0.6	2.1	4.0
5	Inside	Mud	20	40	45	56	72	1.0	2.1	4.4
6	Outside	Mud	15	30	38	55	64	1.1	1.9	2.8

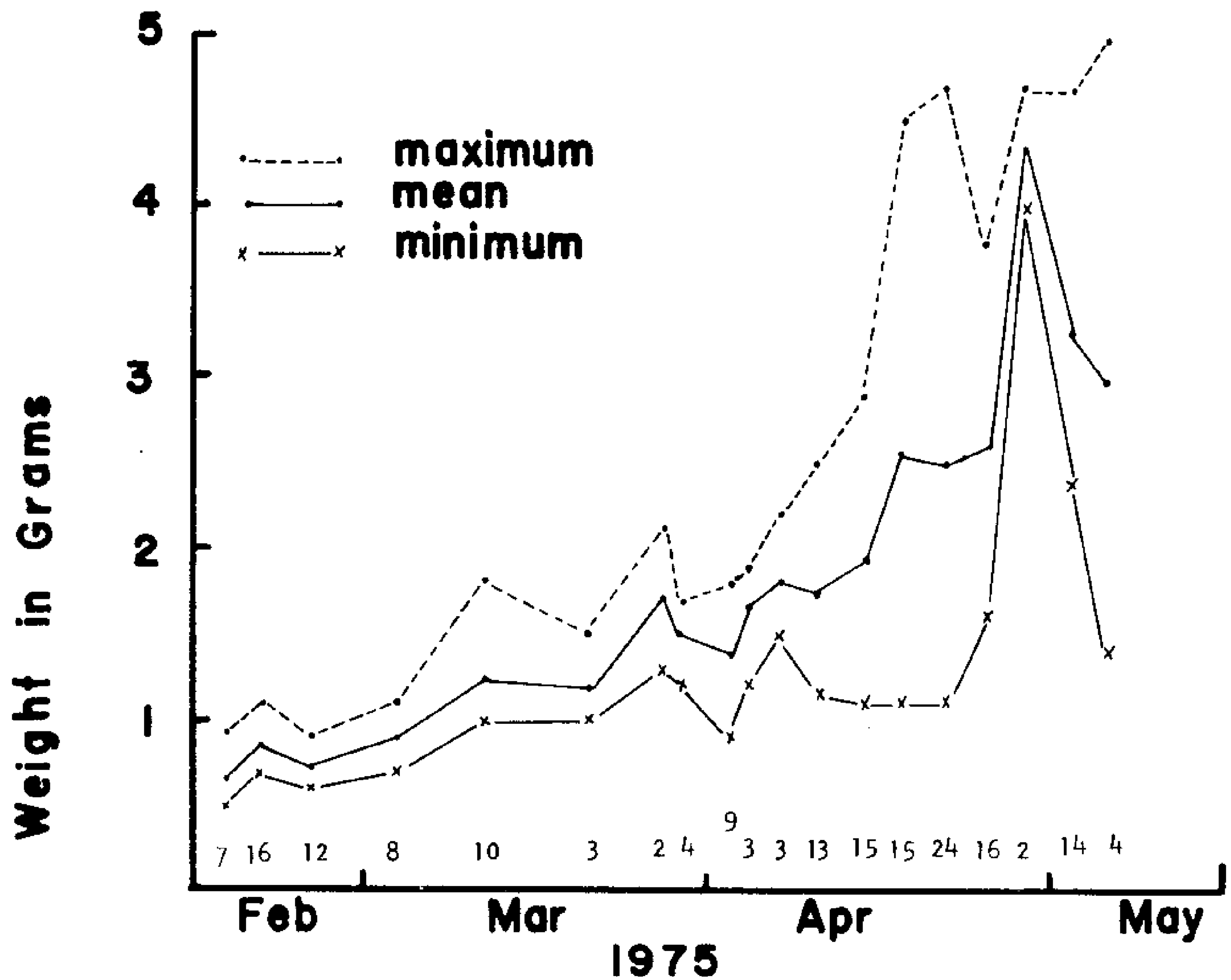


Figure 16. Weight in grams of fall chinook salmon captured in 1-meter long cylindrical single-funnel traps, February - May 1975 (Experiment X) (from Gray 1975).

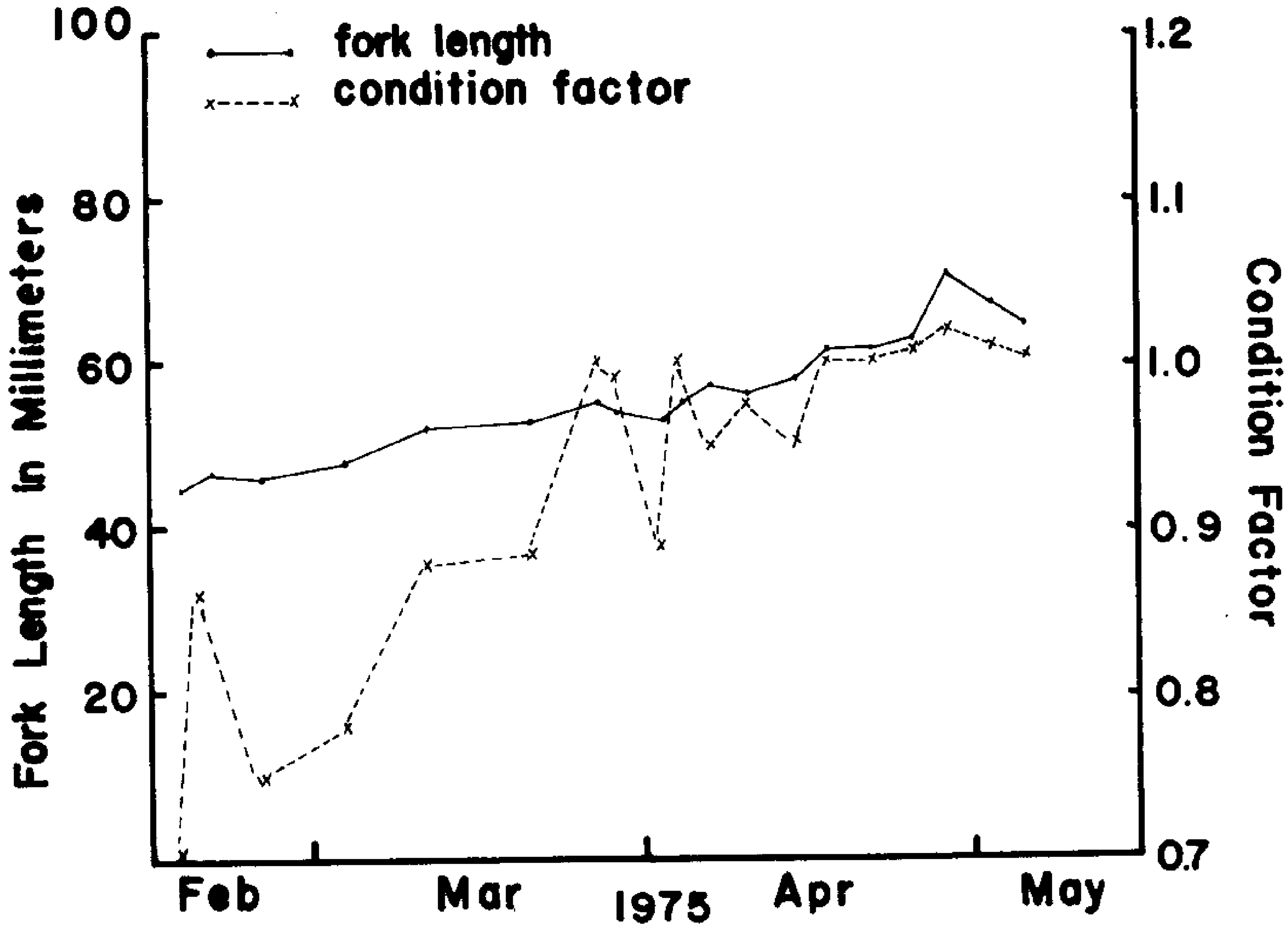


Figure 17. Condition factor and mean fork length of fall chinook salmon captured in 1-meter long cylindrical single-funnel traps, February - May 1975 (Experiment X) (from Gray 1975).

Fish Production

The most valid estimates of fish production were those based on recoveries of salmon reared in pens. Production estimates would be minimal for North Pond. Unfavorable water chemistry occurred in the last week of the experiment which would have produced mortalities in the pen-reared fish during the last 7-10 days of rearing. Although computations were made for each pen, only the production figure for the pen with the highest survival rate in either North or South Pond is presented here (Table 22). South Pond showed the highest extrapolated production rates (300-400 kg/ha/yr) as compared to North Pond (150-300 kg/ha/yr minimal). Pen-reared fish produced rates of survival and fish production required for commercial operations. This production rate resulted from survival rates over a 95-day growing period of 40 and 67 percent, with fairly low average increments in growth (1.6 and 0.8 grams).

Table 22. Fish production rates from pen-reared salmon showing highest production rate, North and South Pond, for 95 day rearing period, Experiment X.

Method	North Pond 1/	South Pond 2/
Based on survivors	307	410
Change in biomass	167	302

1/ 4-square meter pen, inside position, over mud substrate.

2/ 1.5-square meter pen, uncovered, over gravel, with 6 artificial reefs.

Smolting

In the spring of 1974 (chinook salmon, Experiment VII) Collins (1976) undertook the first studies of the behavior and physiology of smolting for salmon reared in our wastewater aquaculture ponds. Salmon behavior was studied in North and South Ponds by trapping using a variety of trap designs. The results of these studies are not present here. Smolting was studied by determining the level of Na+, K^+-ATPase specific activity in the gill microsomes. Mean enzyme levels of fish reared in North and South Ponds rose to about 1.0 micromoles of inorganic phosphate per milligram of protein per hour in late April. Mean gill enzyme levels in chinook salmon in both freshwater and brackish water prior to mid-April were about a third of this value. A sharp increase in catch of salmon in stationary 1-meter cylindrical single-funnel traps was recorded in late March and early April. Collins considered this result functionally equivalent to the first downstream migratory movements of fall chinook salmon moving to an estuary. Thus downstream migration (DSM) presumably precedes smolting, since peak gill enzyme activity followed peak trap catches.

Based on Collin's work in 1974, Hume (1976) designed a system which caught chinook salmon smolts by directing a stream of water through a special trap fitted into a slot designed into the headgate. The concept was to simulate a downstream flow to which downstream migrants approaching pre-smolt or smolt condition would be attracted. Trapped fish were to be held in tanks in our fish barn for marking, and for release following a maturation cycle similar to that found in nature.

Details of Hume's successful smolt trapping studies will not be reported here. There is, however, some additional information which was not included in Hume's thesis which is pertinent to a fuller understanding of future smolt collecting work. During smolting the salmonids are reported to become much slimmer, a condition which should be capable of measurement through a "condition factor" (CF). Gray (1975) calculated a mean condition factor for trapped chinook salmon in North Pond in 1975 (Figure 17). The CF rose steadily during February and March, then stabilized during April and May. Thus no loss of condition was shown by trap-caught salmon during their period of presumed smolting. Hume tested chinook salmon caught in his smolt trap at the North Pond headgate by bioassay using a wide range of salinities (Hume 1976, Table 3). Independently of this study, Mr. Al Merritt, HSU Fish Hatchery Superintendent, tested fall chinook of the same stock being held in freshwater in the HSU hatchery (Table 23). Hume showed that in 31 o/oo salinity water after 96 hours there was a 64 percent survival, which was reduced to 8 percent at 34 o/oo. Fresh-water reared chinook salmon were also adapted up to salinities approaching 32 o/oo (Table 23). Such adaptation would be in conformity with estuarine behavior of fall chinook salmon in Sixes River, Oregon reported by Reimers (1973), where the salmon took up estuarine residence during the summer, and not venturing into high salinity ocean waters until late fall.

Of most significance to future pond management was Hume's findings that chinook salmon movements into the actively fished smolt trap (and also into stationary traps) decreased when water salinities were less than 9.5 o/oo. It seems appropriate to state that this was an empirical finding resulting from an assumed need to acclimatize chinook salmon to high salinities prior to pond draining. When seawater was introduced into North Pond to raise salinity levels, trap catches stopped. It was this event which made us decide to test the idea further by introducing oxidation pond effluent to reduce salinities. To carry out this smolt-trapping experiment, we eventually sacrificed most of our North Pond salmon production. This was an empirical finding, and is characteristic of empirical research where experiments in progress are redesigned based on

Table 23. Salinity tolerance studies on fall chinook salmon, 25 March - 19 May 1975. (5 fish per 20 gallon aquaria aerated with forced air through air-stones).

Salinity Level	Number of mortalities	96-Hour percent survival	Time of recorded mortalities
18	0	100	
22	0	100	
26	2	80	March 26; May 3
32	2	60	March 26, March 28

day-to-day results. It will be most interesting to monitor the return of chinook salmon to Jolly Giant Creek in 1977 and 1978, since there appears a good likelihood that many unmarked salmon escaped the pond through the broken screen as noted previously.

Food of Pond-Reared Salmon

Extensive studies were made on feeding habits of chinook salmon reared in North and South Ponds during Experiment X. Following the loss of fish in 1.0-meter floating pens, indicating major loss of salmon in the ponds, a sample of nine fish from North Pond was collected by dip netting along the edges of the pond. All fish examined were feeding on small copepods (10-40 copepods per stomach minimum (Table 24). Four fish had a major portion of their diet of single food item (gammarid amphipod, *Corophium*, insect pupae, or plant seeds).

Two fish had very full stomachs. Externally, all fish appeared in good condition, although the smaller fish tended to be thin, and the smallest was definitely a "pin-head".

'able 24. Frequency of occurrence[1/] of food items in chinook salmon gut from fish sampled by dip net, North Pond, March 3, 1975 (Experiment X).

lo. of fish	Size						Copepods	Amphipods		Insect Pupae	Plant Seed
	Length			Weight				Aniso-gammarus	Corophium		
	min	mean	max	min	mean	max					
9	36	42	46	0.5	1.0	1.9	9 (100)	3 (33)	8 (87)	2 (22)	2 (22)

1/ Percent frequency of occurrence shown in parentheses.

Gray (1975) analyzed the stomach contents of trap-caught chinook salmon from North Pond (Table 25). Only the stomach content was examined. This study showed over 50 percent without stomach contents. As the fish grew larger, copepods were less important in the diet, with the dominant benthic forms in the pond being consumed (Anisogammarus and Corophium). A fairly large occurrence of the isopod (Rocinela) was recorded. About 21 percent of the salmon stomachs with Corophium had parts of the animal, while about 40 percent has whole animals (Table 26). As Corophium is a tube-dweller, it is obvious that it must leave its burrow at times, presumably at night. Undoubtedly any technique which would cause these forms to leave their burrows, or at least make them more available, would increase the productive capacity of the ponds. Anisogammarus as adults are too large for small chinook salmon and thus are consumed as juvenile forms (Powers 1973). Methods of managing Anisogammarus suggested by Powers by use of

Table 25. Occurrence of food items in chinook salmon with stomach contents obtained from fish caught in stationary traps throughout length of rearing period (Experiment X).

	Amphipods		Rocinela	Copepods	Insects
	Aniso-gammarus	Corophium			
Number of occurrences	98	95	45	16	9

Table 26. Frequency of occurrence of whole Corophium or parts in 95 chinook salmon stomachs found with this food item as obtained from fish caught in stationary traps (Experiment X).

	Whole animal	Part of animal	Both whole animal and parts
Number of stomachs	38	20	37
Percentage	40	21	39

early high salinities, then reduced salinities to favor production of young amphipods is compatible with having reduced salinities at the end of a rearing period to favor smolt trapping.

Food in the gut of all surviving chinook salmon obtained from pen studies was also recorded. Contents of the intestine as well as that of the stomach were included in the analysis. A high survival of chinook salmon in a pen fitted with underwater reefs appeared correlated with both a qualitatively and quantitatively improved diet (Table 27). In 4-square meter pens in both North and South Ponds, an overall higher occurrence of whole Corophium appeared in the diet (Table 28). As the only difference between the environment of pond-reared fish and pen-reared fish was the mesh surrounding the pen, it would appear that the Corophium living on this webbing is more available to fish than the same form living in burrows in the pond bottom. Thus any technique, such as underwater reefs, which increases the utilization by the fish of highly important food items to salmon will lead to increased growth and survival. This further supports additional installation and study of underwater reefs.

The isopod, Rocinela, appeared in greater numbers in the food of South Pond-reared salmon than North Pond (Tables 27 and 28). Aquaria observations have shown juvenile salmon preferring other food items over Rocinela, probably due to its hard shell. The animal forms a ball just before being seized by a salmon, but is usually extruded, similar to behavior of salmon on seizing and rejecting a pebble. A large consumption of these isopods in South Pond fish probably indicated a lack of other preferred food. During Experiment X, one large trap was lost in South Pond. The trap was located when the pond was drained. It contained 14 staghorn sculpin, Leptocottus armatus. Stomachs of six of these fish were examined, and contents was dominated by Rocinela. One fish weighing 20.7 grams had 1.9 grams of Rocinela in its stomach. Possibly the sculpins have a

Table 27. Percentage of occurrence of food items in digestive tract of chinook salmon in 1.5-square meter movable pens on gravel substrate, South Pond, 10 May 1975 (Experiment X).

Food Item	No reef plywood cover	No reef mesh cover	Six reefs mesh cover
Anisogammerus	29	25	40
Corophium - Whole	0	25	10
- Part	29	100	30
Rocinela	57	50	65
Copepod	0	0	35
Insect	15	0	5
Empty tract	15	0	0
Number fish	7	4	20

preference for isopods, but it is more likely that the isopods were the only available food source for the sculpin. Isopods are commonly found in large numbers on trap surfaces in our ponds.

Table 28. Percentage of occurrence of food items in digestive tract of chinook salmon in 4-square meter pens, North and South Ponds, 10-11 May 1975 (Experiment X).

Food Item	Pen description							
	South Pond		North Pond					
	Oyster shell bottom; mesh cover	River-run gravel bottom; no cover	Oyster shell bottom; inside position	Oyster shell bottom; outside position	Gravel bottom; inside position	Gravel bottom; outside position	Mud bottom; inside position	Mud bottom outside position
<u>Anisogammerus</u>	62	100	70	67	82	92	70	74
<u>Corophium</u> -								
Whole	50	100	0	100	64	50	65	80
Part	100	54	10	100	18	21	10	20
<u>Rocinela</u>	69	23	0	0	9	0	15	0
Copepod	0	0	0	50	9	21	10	0
Insect	31	0	0	0	0	0	5	0
Empty tract	0	0	20	0	9	7	10	7
Number of fish	16	13	10	6	11	14	20	15

Water Quality

Bacteriological studies on pond waters during Experiment X have been reported elsewhere (Allen, Busch and Morton 1976) and will not be repeated here. One small study was undertaken during Experiment X, however, that adds information on the toxic levels of oxidation and fish pond waters.

As part of the experiment involving large additions of oxidation pond effluent into North Pond during early May, bioassay of oxidation pond water was conducted on 27 April and 30 April using juvenile coho salmon and threespine stickleback. On April 27, five coho salmon were placed into two 0.5-square meter floating live car located in the oxidation pond off a small dock adjacent to the fish ponds. Salmon were obtained from the HSU fish hatchery. Water temperatures at the hatchery and the oxidation pond were 12° C and 13° C respectively. All fish died within 48 hours. As oxygen content of the oxidation pond was not determined, the test was repeated under laboratory conditions. Ten gallons of oxidation pond water was placed in a ten-gallon aquarium under forced-air aeration. Five coho salmon from the HSU hatchery (13° C water temperature) were placed in the aquarium on 2 May. No mortalities occurred for either species after a 96 hour test period.

Miscellaneous Observations

The number and weight of non-target species recovered from South Pond showed only six species, mainly of small size and low in number (Table 29). Incidental fish catch was even less in North Pond and was not recorded. Of interest was the total of 8 staghorn sculpin recovered from South Pond, because 14 staghorn sculpin were found in a lost trap recovered during draining of South Pond. Thus 70 percent of all the sculpin in the pond had entered a single trap. Thus it appears that constantly fishing a simple trap is a successful method for controlling this predator.

In addition to non-salmonid species of fish found in South Pond, there were 15 extremely well-conditioned rainbow trout recovered averaging 16 cm in fork length, with one fish reaching 21.5 cm (Table 29). These fish escaped into the pond during initial stages of pond filling when samples of these fish probably jumped out because personnel were late in covering the pens with nets due to oversight. These fish grew about 6 cm over the 95-day rearing period.

One hundred rainbow steelhead trout reared in Experiment IX were retained in two fixed pens ("crab pens") located in the northwest corner of South Pond as a source of trout for planned crab-trout polyculture studies. During the course of Experiment X, 30 of these fish were removed. Of the 170 trout left, 85 were recovered on 11 May 1975 (Table 30). In addition, 13 coho salmon were also recovered which may have been misidentified as rainbow trout. It is possible that the 15 rainbow trout recovered from the ponds escaped from the crab pens. Thus, survival of rainbow trout in the pens ranged somewhere between 50 and 61 percent. No systematic feeding of these fish occurred, and consequently they only maintained their initial weight over the rearing period. The rainbow loose in the pond, however, increased from 11 cm mean size to 16 cm, with one fish reaching 21 cm as noted previously (Table 29). These data indicated a relatively greater sensitivity of juvenile fall chinook salmon to water quality parameters than the yearling coho and rainbow trout.

During draining of South Pond, a large number of crustacea about 10-15 mm total length were observed on dip nets being used to collect fish. Identification (Dr. George Crandell, HSU Oceanography Department) indicated they were *Neomysis awatschensis* (?). Chinook salmon in bioassay tanks fed voraciously on aliquots of these mysids. These forms have appeared sporadically in our ponds but never in such numbers. Mysids were not nearly as abundant in North Pond, drained on 11 May. This would be an expected result since a population of chinook salmon had existed in North Pond just prior to draining.

Table 29. Number, length, and weight of non-target species of fish recovered from South Pond, 11 May 1975 (Experiment X).

Common Name	Scientific Name	Number Recovered	Mean Weight (mm)	Total Weight (gr)	Remarks
English sole	*Parophrys vetulus*	2	-	-	Small
Stickleback	*Gasterosteus aculeatus*	ca 700	2.3	1,646	
Staghorn sculpin	*Leptocottus armatus*	8	7.5	60	41-111 mm T.L.
Surf smelt	*Hypomesus pretiosus*	40	2.7	109	
Goby	*Gobiidae*	10	1.8	18	
Herring	*Clupea harengus pallasi*	ca 250	0.9	236	40-75 mm F.L.
Total Weight				2,069	
Rainbow steelhead trout	*Salmo gairdneri*	15			120-215 mm F.L. (159 mean)
Staghorn sculpin (from lost trap)		14	11.0	154	61-113 mm T.L.

Table 30. Number, size, and survival of two lots of rainbow trout reared in two fixed pens (crab pens), 11 May 1975, South Pond, Experiment X.

Species	East Pen					West Pen				
	Number		Fork Length (mm)			Number		Fork Length (mm)		
	Start	End	Min	Mean	Max	Start	End	Min	Mean	Max
Rainbow	100	56	80	105	137	100	29	86	104	136
Coho 1/	0	7	75	95	111	0 1/	6	92	108	135
Total 2/	100	63				100	35			

1/ Coho probably misidentified and planted as rainbow trout.

2/ 15 rainbow recovered during draining of the pond (Table 29).

EXPERIMENT XI

(May - November, 1975)

Objectives

As noted previously, the Arcata wastewater aquaculture system has always been considered marginal for summer rearing due to periods of water temperatures considered too warm for successful salmonid culture (Allen 1975). Small lots of fall chinook salmon, coho salmon, and Humboldt State University stock rainbow trout, were available to continue testing the potential of the ponds to rear salmonids during warm summer months. Late in the experiment (November) a small lot of kokanee salmon from Trinity Reservoir was also made available for rearing.

We continued testing the concept that the use of previously conditioned water would increase the rate of stabilization of newly introduced oxidation pond water and sea water. Only North Pond was available for 1974 summer rearing experiments as South Pond was allowed to dry during the summer for installation of pens designed for future crab rearing studies.

During this experiment, studies on different types of underwater reefs were continued in six 4-square meter pens located in the NW corner of North Pond.

Pond Operation

On May 11, 1974, about 1/3 of the pond was filled with aged South Pond water. The remainder of the pond was filled with oxidation pond water and Humboldt Bay sea water on May 12. The experimental level of 15 o/oo salinity for fish rearing was slowly attained by the end of May by small additions of fresh water from domestic water supply. During mid-August (August 8-19) a series of minor additions were made of freshwater, oxidation pond water, and sea water to reduce salinities to the 15 o/oo level. Water from North Pond was not released to the bay at the end of the experiments but pumped into South Pond.

Aeration was primarily with a forced-air system, with AIR-O-LATORS turned on during early September during a period of low dissolved oxygen.

Recovery of fish on pond draining was particularly difficult in this experiment because curious depressions around the base of basket-oyster shell reefs (see previous discussion) had enlarged. Many rainbow were trapped here and suffocated before they could be recovered and placed in freshwater. An estimated 5 percent of the total production was lost in the mud in attempts to rescue stranded fish.

Physical-Chemical Conditions

Methods for determining pond water properties are summarized in Table 3. Water temperatures during the summer of 1975 were warm, with periods in May, June, July and late August all showing temperatures near 25^{o} C. As these mainly represented morning readings, the normal diurnal increase probably produced periods of water temperature in the 26-27^{o} C range by late afternoon. Water temperatures steadily declined from around 20 C in early September until pond draining in early November (Figure 18).

A pond salinity slightly above 15 o/oo occurred during the experiment (Figure 19). Salinities decreased to 10 o/oo by early November due to dilution by late fall rains.

The clarity of pond water reflected density of phytoplankton populations (Figure 20). A very heavy bloom existed during June and July, and was interrupted slightly by pond water manipulations in mid-August. With the dilution of salinities and general winter conditions, the phytoplankton decreased markedly and the water became relatively clear by early November at the end of the experiment.

Dissolved oxygen levels generally remained about 5 mg/l during the experiment, but periods of low oxygen were experienced in late August and September (Figure 21). Following additions of oxidation pond effluent in mid-August, some

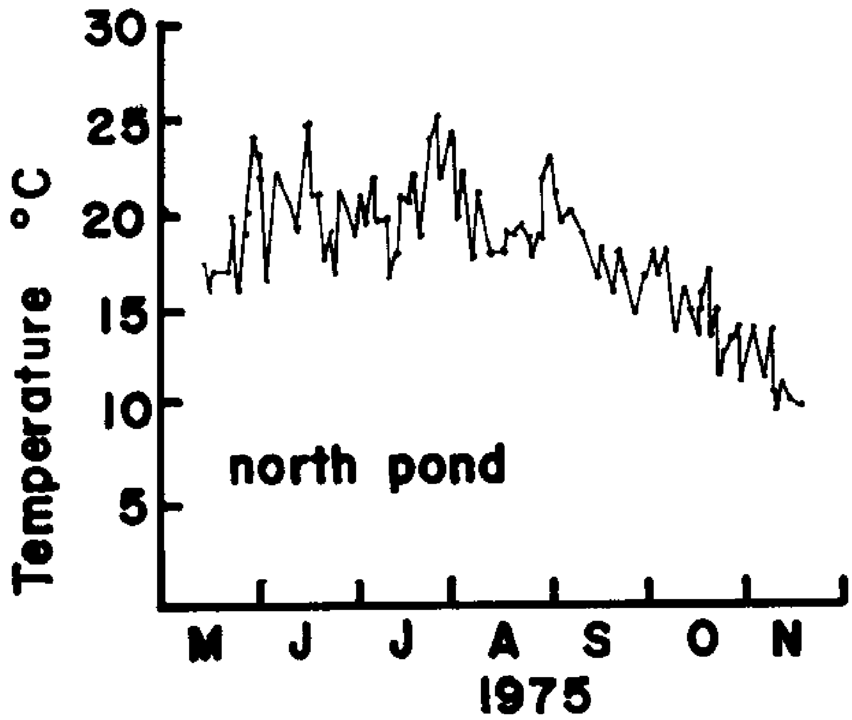


Figure 18. Temperature, surface water, North pond, May - November 1975 (Experiment XI).

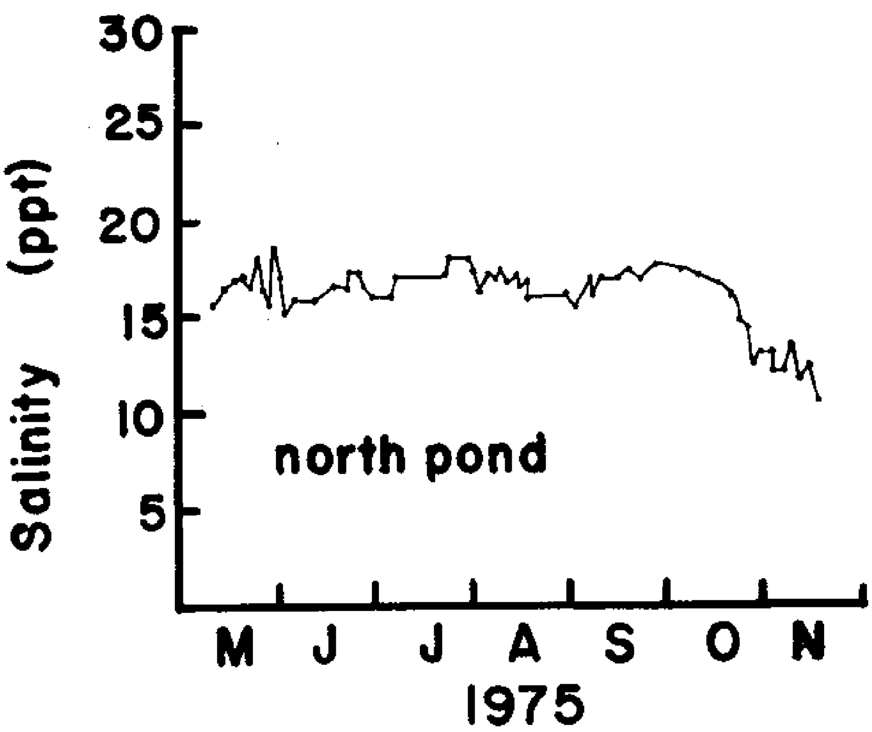


Figure 19. Salinity, surface water, North pond, May - November 1975 (Experiment XI).

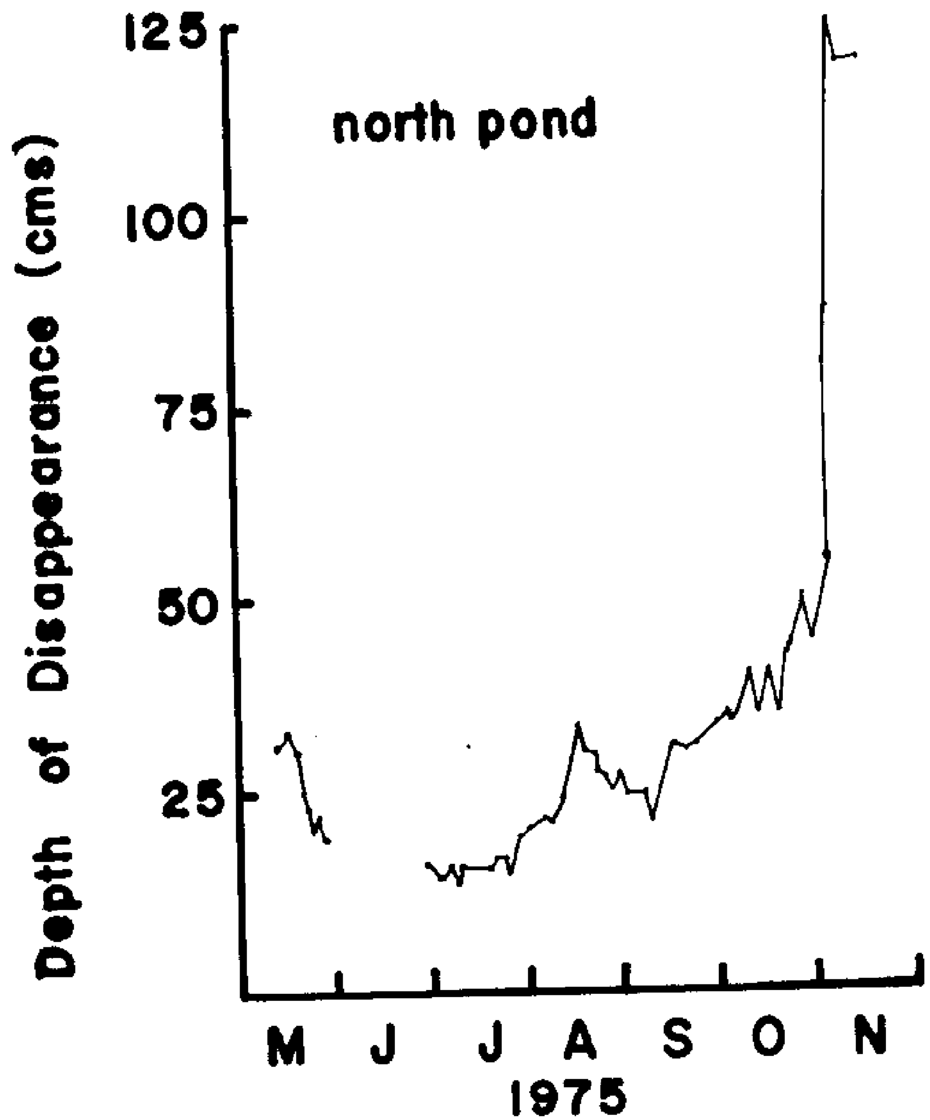


Figure 20. Clarity, North pond, May - November 1975 (Experiment XI).

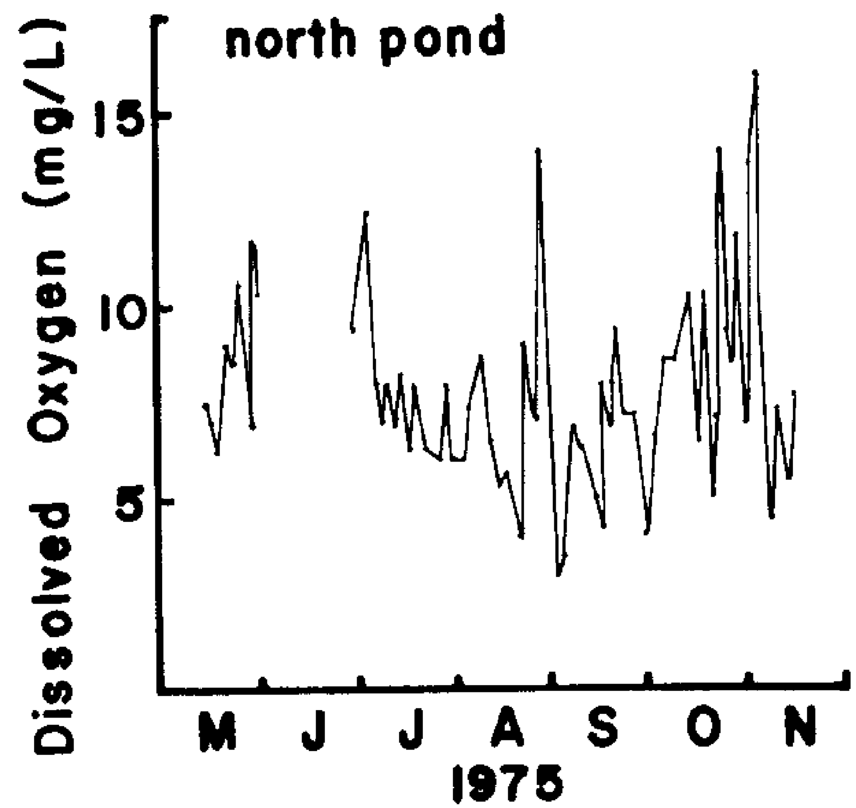


Figure 21. Dissolved oxygen, surface water, North pond, May - November 1975 (Experiment XI).

high DO values were recorded. High values and wide fluctuations occurred in late October and early November. Some of the high values were from determinations made late in the afternoon (5 June and 23 October), however, they also occurred in the morning (4 November). No intensive studies of diurnal or spatial variations in oxygen levels throughout the pond were conducted during this experiment, and the few conducted showed different rates of oxygen increase during the day (Table 31). On 19 July dissolved oxygen was 7.2 in the deepest portion of the pond (fish collecting sump in front of headgate) as compared to 10.2 at the bottom in the middle of the pond. On 15 September, water in the fish collecting sump showed 4.4 mg/l and on the bottom in the middle of the pond 3.8 mg/l as compared with 8.2 mg/l at the surface.

Table 31. Diurnal dissolved oxygen, November 1975, (Experiment XI).

Date	Time	South Pond	North Pond
Nov 3	0800	8.0	8.4
	1700	8.4	8.7
Percent Increase		5	4
Nov 7	0900	-	4.4
	1800	-	9.4
Percent Increase			113

Hydrogen ion content generally varied around pH values of 8.0, but two periods of high values (around 9.0) occurred in late May and late August, and were associated with periods of addition of oxidation pond effluent (Figure 22). These additions undoubtedly stimulated increased phytoplankton respiration which utilizes CO_2, thus raising the hydrogen ion content of the water.

Considerable effort was made to obtain measurement of the various nitrogen components during this experiment (ammonia, nitrite, and nitrate nitrogen). Nitrogen as ammonia, is the most critical as far as survival of salmonids because alkaline conditions turn ammonium ions into free ammonia which is highly toxic to salmonids[1/]. Values generally were around 1.0 (± 0.5) Hach units (Figure 23), except for late May, when values reached 3-4 units. This had disastrous consequences for early fish plantings as to be discussed later. The only other high value for ammonia occurred in mid-August (2.0 units) associated with water additions from the oxidation pond. High nitrogen nitrate (700 units) occurred on 15 May, quickly dropping to near zero (Figure 24). Nitrogen as nitrate remained low except for mid-August when oxidation pond effluent was introduced into the ponds. It is possible, however, that the mid-August increase could have arisen from releases of nitrate from a senescent phytoplankton population. Most nitrogen-nitrite values were less than 0.1 Hach index units (Table 32), with the highest recorded values of 8.25 occurring on 15 May. Values dropped to zero in four days, with the only other value greater than 1.0 units occurring on 18 August (2.8 units).

Alkalinity values ranged between 161-240 mg/l for 17 determinations, while 4 determinations of Calcium (Ca^{++}) as $CaCO_3$ ranged between 200 and 264 mg/l.

Single determinations using Hach kit procedures produced no detectable amounts of iron or manganese, and 0.09 mg/l Hach units for copper.

1/ (mg/l ammonia nitrogen (N)) X (1.22) = mg/l ammonia (NH_3).

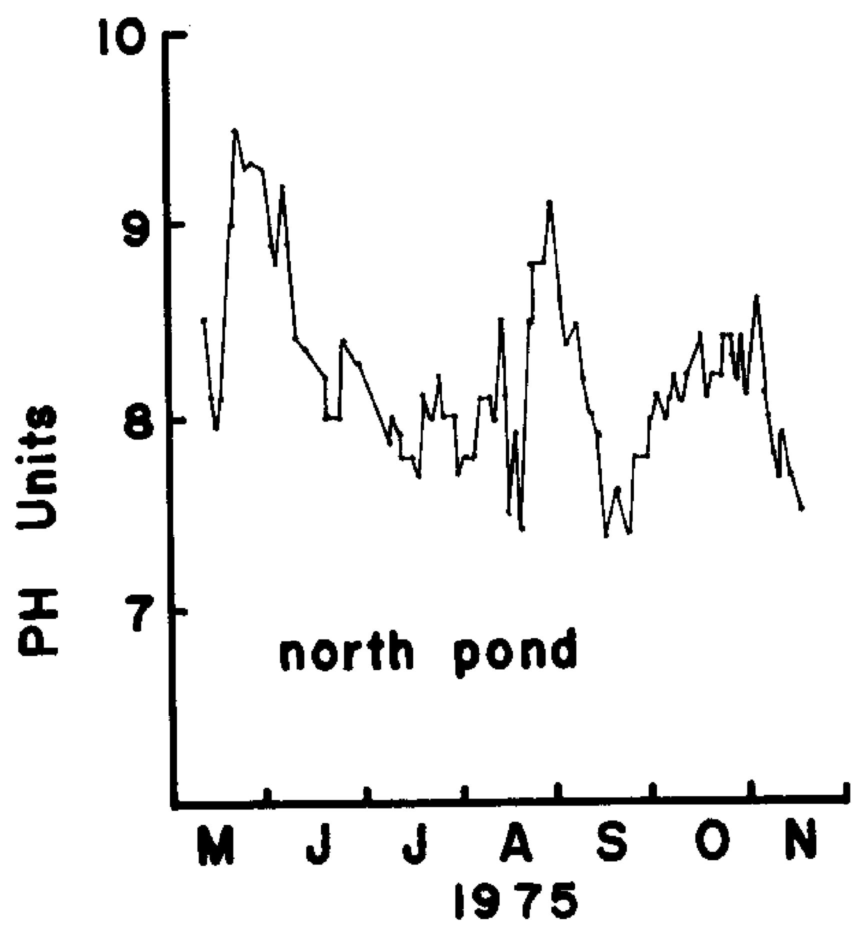


Figure 22. Hydrogen ion concentration, surface water, North pond, May - November 1975 (Experiment XI).

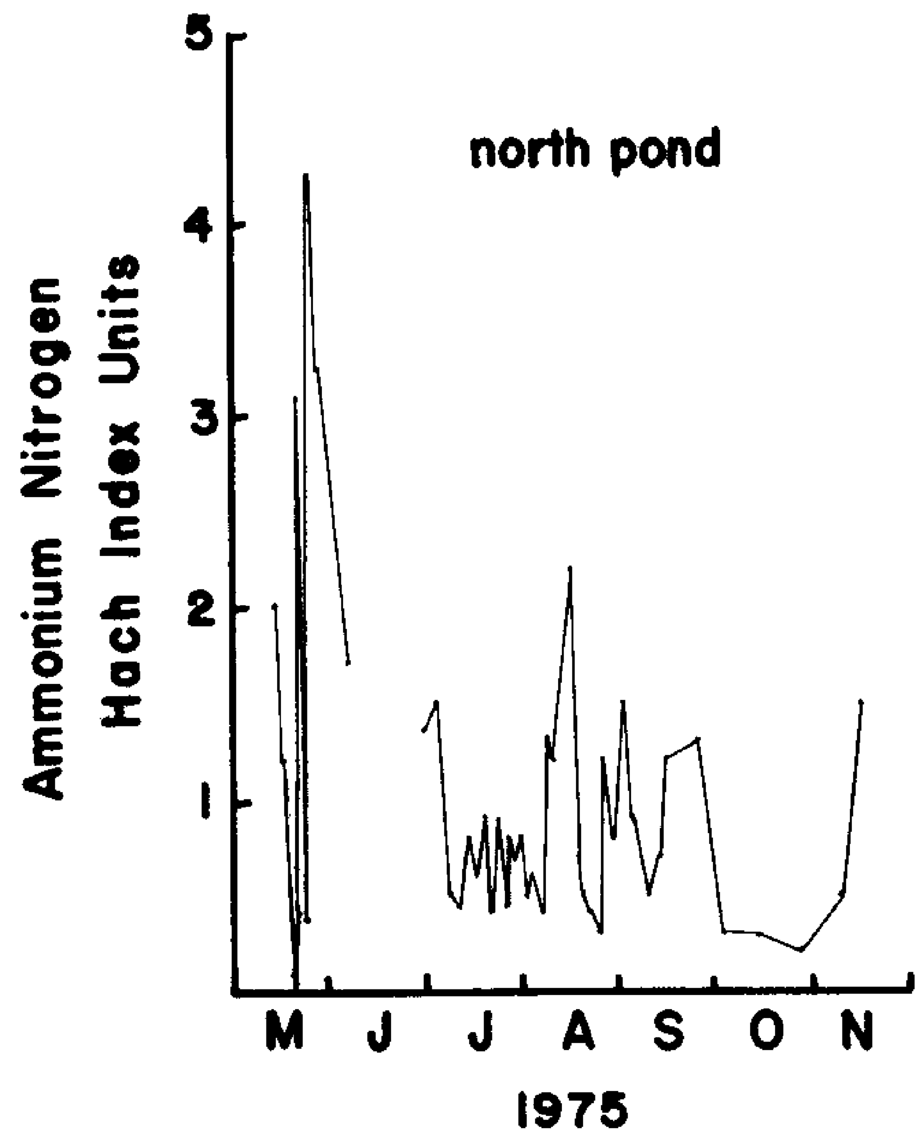


Figure 23. Relative ammonia nitrogen, surface water, North pond, May - November 1975 (Experiment XI).

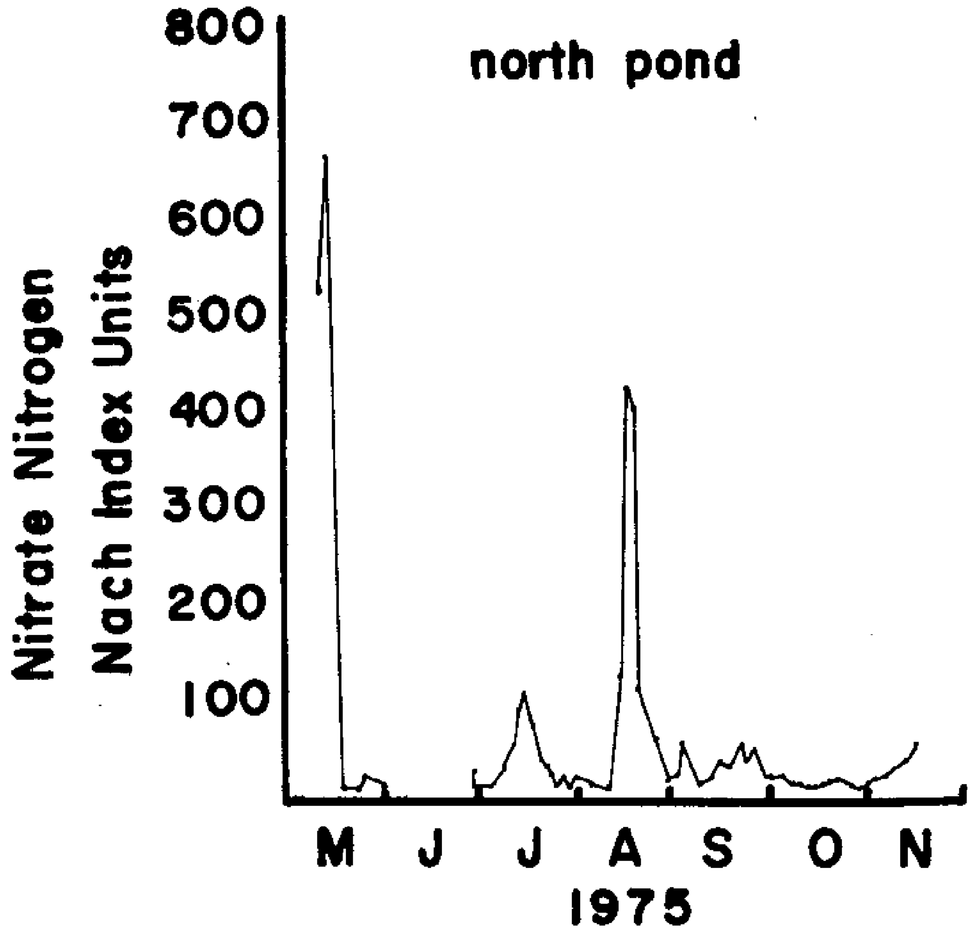


Figure 24. Relative nitrate nitrogen, surface water, North pond, May - November 1975 (Experiment XI).

Table 32. Distribution of nitrogen as nitrite (Hach kit index units) in South Pond, May-November 1975 (Experiment XI).

Interval	Number of readings
0-trace	19
0.0-0.09	26
0.1-0.9	6
1.0-4.9	3
5.0	1

Pond Survival Rates

As bioassay with coho salmon between 13 May and 22 May using 25 salmon in a floating pen showed no mortalities, we planted 2,000 chinook salmon fingerlings on 23 May (Table 33). To monitor the survival of these fish, 25 chinook were placed in a floating live car on 27 May. 80 percent died the first day (20 fish). Of the remaining 5 fish, 3 were alive (60, 78, 100 mm fk len) by 12 June 1975 when the bioassay was ended. Based on visual observation of salmon planted on 23 May (erratic swimming), we assumed that most pond-reared fish died, and that survivors taken from the pond on 17 November came from chinook planted on 12 June. Chinook salmon planted on 23 May acted stressed immediately on being placed in the pond, whereas those planted 12 June behaved normally. The few chinook salmon recovered (Table 34) were extremely healthy, vigorous fish, and of an average size probably needed for good smolt quality (13 cm and 27 grams). No study of gill Na^{+}-K+ ATPase activity was undertaken on these fish as qualified personnel were not available for this work in the fall of 1975.

Table 33. Summary of releases of salmonids into North Pond, June-October, 1975 (Experiment XI).

Species	Date Planted	Number Planted	Mark	Average size Fork Length (mm)	Weight (grams)
Fall chinook	23 May	1000	none	85	7.6
		1000	none	53	2.3
Fall chinook	12 Jun	1500	none	81	7.7
Rainbow	12 Jun	2000	none	55	2.4
Rainbow	17 Sep	2000	LV	75	6.0
Rainbow 1/	26 Sep	800	RV	95	13.0
Kokanee	23 Oct	1940	none	75	4.2

1/ 1,000 rainbow were placed into holding tank on 22 September (89 mm; 11.2 grams) for acclimation - 16° C; 7.0 pH; 6.6 D.O.; 17.5 o/oo sal.).

Rainbow trout fry were placed into floating live-cars on 27 May, and suffered 100 percent mortality in one day. In contrast, the 25 coho showed a 100 percent survival from 13 May to 8 June as shown by an actual hand count of remaining salmon. It is obvious, that bioassay of pond waters in May should have been conducted initially with chinook salmon, rather than coho which are much harder than chinooks.

Survival of rainbow trout (20-81 percent) varied directly with size and time of planting (Table 34). The later in the summer the fish were planted, and thus of larger size, the greater the survival. Acclimated rainbow trout (RV) survived at twice the rate than fish planted directly into the ponds (LV), but the true difference is less since the unacclimated fish were smaller at planting.

Table 34. Summary of recovery of salmonids from North Pond, 17 November 1975 (Experiment XI).

Species	Mark	Number Recovered	Percent Survival	Days Reared	Size on Recovery					
					Length			Weight		
					Min	Mean	Max	Min	Mean	Max
Fall chinook	none	20	0.01 1/	158-(177)	92	134	159	9.0	27.4	44.7
Rainbow	none	394	20	158	75	111	138	4.2	19.0	36.0
Rainbow	LV	755	40	75	70	93	129	4.7	10.8	26.5
Rainbow	RV	646	81	52	79	107	131	6.7 2/	16.2	27.7
Kokanee	none	522	37	25	68	75	82	-	4.1	-

1/ Based on assumption that all chinook salmon planted on 23 May died - see text discussion on cause of mortalities.

2/ Smallest fish not weighed, next smallest 8.6 mm weighed 6.7.

Kokanee suffered from Vibriosis almost as soon as they were planted into the pond as confirmed by pathology studies on stressed fish recovered by dip netting. Significance of this result has been discussed elsewhere (Allen, Busch, and Morton 1976).

Pen Survival Rates

A total of ten 4-square meter pens were available for polyculture experiments utilizing a combination of coho and rainbow (Tables 35 and 36). Although rainbow fry planted into Exclusion Pens on 27 May were all assumed dead, we did recover 2 percent (4 out of 300). Of coho planted 16 June into these pens, overall survival in 3 pens ranged from 19-39 percent (Table 34). A minimum of 19 unmarked coho were recovered during pond draining on 17 November 1975, which had escaped into the pond through a tear in the webbing of one pen (Hookton). In the hectic operation in recovering fish, we probably misidentified some coho as unmarked rainbow. The error would be great in coho statistics but minor as far as rainbow data. Of special interest, was the pen with the lowest coho survival (mud, 19 percent). This pen contained 4 rainbow, three of which were over 100 mm and one of which was 167 mm and 83 gm in weight. It is likely these rainbow had dominated the coho, since the mean weight of coho in this pen was much lower than either the shell or gravel pens (Table 36). The single rainbow in the gravel pen had grown to 172 mm in length and 91 grams in weight.

On 12 June, 25 coho and 25 rainbow were placed into each of six contiguous pens located in the NW corner of North Pond (Table 35). Four of the pens were modified with four different types of artificial reefs. Three of the pens directly against the pond bank are subject to slight seeps of oxidation pond water (Pens Nos. 1, 3, 5 - inside). In contrast, the pens fronting onto the pond, actually jut out into the ponds and are subject to ambient water conditions (Pens Nos. 2, 4, 5 - outside). Inside pens showed 20-28 percent survival of coho,

Table 35. Percent survival and size of coho salmon recovered from 25 coho fingerlings planted on 16 June into 4-square meter pens over three substrates and fitted with underwater reefs, northwest corner of North Pond, 17 November 1975 (Experiment XI).

Pen No.	Location	Type of Reef	Percent Survival[2/]	Size: Fork Length (mm) Min	Mean	Max	Weight (gm) Min	Mean	Max	Other fish[1/] Stickle-back	Gobie
1	Inside	Brick-pine cones	20	66	74	87	3.6	5.7	9.5	6	2
3	Inside	Plastic mesh socks filled with burlap	20	60	73	82	2.4	5.5	7.8	7	3
5	Inside	Plastic grain sacks weighted with brick	28	58	74	92	2.7	6.2	10.2	7	1
2	Outside	New Zealand flax bundles	40	60	76	90	2.7	6.4	10.0	27	7
4	Outside	None	48	63	80	91	3.0	7.5	10.9	4	3
6	Outside	None	40	70	82	100	5.1	8.2	12.8	2	0

1/ Pen 5 - 1 sculpin; Pen 6 - 2 top smelt.

2/ Subject to 10% error, see text.

Table 36. Percent survival and size of coho salmon recovered from 100 fingerlings planted 16 June into 4-square meter pens over four substrate , North Pond, 17 November 1975 (Experiment XI).

Pen Substrate	Percent Recovered	Size						Other fish[1/] recovered (rainbow)
		Fork Length (mm)			Weight (gm)			
		Min	Mean	Max	Min	Mean	Max	
Shell	37	59	79	93	2.0	7.1	10.2	0
Mud	19	56	71	93	3.0	5.4	10.7	4
Gravel	39	56	77	95	2.4	6.8	11.9	1
Hookton[2/]	(19)	(71)	(86)	(96)	(4.6)	(7.7)	(10.5)	-

1/ 100 rainbow fry planted into each pen on 27 May. Sizes: Mud Pen - 75, 115, 110, 167 mm fk len; Gravel Pen - 172 mm fk len.

2/ Hole in pen. Fish were recovered from pond.

and outside pens 40-48 percent survival. No rainbow trout were recovered, a fact we are unable to explain unless 50 coho alone were planted in error. All survival values would be reduced in this case by one half. Fish reared in the outside pens were consistently larger than fish reared in inside pens. Low dissolved oxygen levels occurred in the inside pens, indicating that water quality was probably the controlling factor (Table 37). Underwater reefs had no apparent influence on survival, or growth as measured in this study.

Table 37. Dissolved oxygen in water of middle units of six 4-square meter pens, northwest corner of North Pond (Experiment XI).

Date	Time	Pen No. 3 (Inside Position)		Pen No. 4 (Outside Position)	North Pond (headgate)
		Bottom	Off Bottom	Mid Depth	Surface
Nov 3	0930	0.0	6.1	12.2	13.6
Nov 17	0930	0.0	8.6	8.6	7.6

Kokanee

The fortuitous availability of kokanee salmon for rearing in our pond system was due to personnel of the California Department of Fish and Game at Trinity River hatchery offering the last of a small lot of experimental fish at the hatchery. These kokanee were from kokanee stock introduced into Trinity River Reservoir. The majority of the kokanee were planted into North Pond, while groups of 50 were placed into 4-square meter pens and into 3 movable pens of 1.5 square meters. Following previous results with other salmonid species, fish reared in pens had consistently higher survival rates (2 to 3 times higher) than fish released into the open pond (Table 38). Moribund fish dip-netted from the pond were taken to the fisheries pathology laboratory, where positive identification of *Vibrio* bacterial infection was made. The lack of any recoveries from two of the movable pens cannot be explained. Careful examination of the pens revealed no holes. It is possible animal predators were responsible. Land otters were positively identified on several days during November in and around the ponds, while several small floating pens had screened lids ripped open and all fish removed.

Table 38. Summary of survival over 25-day rearing periods of kokanee salmon planted into three different rearing conditions and differing densities 23 October-17 November 1975 (Experiment XI).

Rearing condition	Size (sq meter)	Number planted	Number per sq meter	Percent survival	Remarks
North Pond	1,500	1,940	1.2	37	Mortalities *Vibrio* infested
Fixed pens	4				
Mud		50	12.5	78	
Shell		50	"	88	
Gravel		50	"	94	
Movable pens	1.5				
Not covered		50	33.3	0	5 plastic sack-brick reefs
Not covered		50	"	0	5 plastic sack-brick reefs
Plywood cover		50	"	62	No reefs

Miscellaneous Observations

Six species of common Humboldt Bay fishes, and 1 species of crab, were recovered during pond draining (Table 39). No salmon predators, such as the staghorn sculpin, were found, although a single specimen was taken during fishing of 1-meter single-funnel fish traps. Very few non-target species were reared in the experiment.

The two largest rainbow trout recovered from the 4-square meter fixed pens (Table 36) were used for taste tests on November 18, 1975. Four panel members,

Table 39. Non-salmonid fish taken from North Pond, 17 November 1975 (Experiment XI)

Common Name	Scientific Name	Number Recovered	Range in Size	
			Length (mm)	Weight (gm)
Pacific herring	Clupea harrengus	6	84-100	7.9-15.3
Bay pipefish	Syngnathus leptorhynchus (griseolineatus)	2	215-220	-
Topsmelt	Atherinops affinis	7	110-121	10.0-15.4
Prickly sculpin	Cottus asper	3	70-85	4.5-9.0
Arrow gobies	Clevelandia ios	12	49-60	-
Crab	Hemigrapsis oregonensis	3	-	-
Stickleback	Gasterosteus aculeatus	ca 1,000[1/]	small	

1/ Not collected but a relatively small number and mainly of very small individuals.

all members of the project director's family, were told where the fish were reared, and were asked to taste the fish before any other part of the meal and report on their taste experience. All members indicated that the taste was milder (less fishy) than wild trout, and that the flesh was attractive because of its bright pink coloration. Undoubtedly there was some favorable pre-conditioning amongst these panel members to a favorable attitude toward wastewater-grown fish. Also, the fish were very silvery, highly colored, and deep-bodied, all of which would impart additional positive attitudes toward the fish by the panel members.

Water Quality

Results of bacteriological studies undertaken on salmon and culture water of North Pond (Experiment XI) and South Pond (Experiment X) during the summer and fall 1975 have been reported in Allen, Busch and Norton (In Press). Considerable evidence suggested that "green water", especially that produced by *Chlorella*, had therapeutic properties for cultured salmonids, presumably by inhibiting fish pathogens. It is possible that inhibition of pathogens may have produced the unexplained therapeutic effects recorded for fall chinook salmon reared for two-week periods in oxidation pond-saltwater mixtures (Allen and O'Brien 1967).

SUMMARY

Experiment IX

An 80-day rearing of coho and steelhead yearlings in late fall - early winter period yielded relatively high survival rates (55-85 percent) in two 0.15 ha ponds using conditioned wastewater-seawater mixtures. Coho reared in 4-square meter pens at the same planting density as pond-reared salmon showed survivals of 80-100 percent. Phytoplankton dominated one pond and macrophytes the other, resulting in dramatic differences in some physical-chemical characteristics between the two ponds, however, temperature, salinity, pH, and dissolved oxygen regimes were similar in the two ponds. Fish growth was good, the ponds produced fish at about 200 kg/ha/yr, at a planting density of about 5 fish per square meter. Pond water was of good quality as determined by bioassay using the zoeal stages of the commercial crab (*Cancer magister*).

Experiment X

The overall survival of fall chinook salmon fry reared in North and South ponds during a late winter - early spring rearing period in 1975 was very low due to an anomalous period of poor water quality occurring in late February. In contrast to the heavy mortalities suffered by salmon which ranged over the pond, salmon reared in both fixed and floating pens showed a wide range of survivals (0-67 percent). Successful trapping of fall chinook salmon smolts (or perhaps more accurately, downstream migrants) was undertaken for the first time in the system by directing a flow of water through a stationary trap. Catch of salmon ceased in the trap when salinities were higher than 9.5 ppt. No drop in the condition factor of fall chinook salmon reared in the ponds from February

through May was recorded. The rate of growth of fall chinook salmon was greatest during mid-April. Fall chinook salmon reared either in freshwater or brackish water could all adapt successfully to abrupt immersion in salinities of about 25 ppt or less, but with about 60 percent surviving in salinities up to about 31-32 ppt, indicating that the fish were not adapted to open ocean salinities. Two species of amphipods were the major food items of fall chinook salmon. Although water quality caused heavy mortalities of chinook salmon in South Pond, both rainbow trout and coho salmon reared in pens showed high survival. Yearling rainbow trout introduced by accident to the pond showed an average increase of 6 cm in length during a 95-day of rearing. Other than a short late February period when high dissolved oxygen and pH were produced by an unseasonal period of warm, cloudless weather, water quality appeared good for salmonid rearing. A broken headgate screen allowed an unknown number of salmon in North Pond to escape into Humboldt Bay unmarked.

Experiment XI

Small groups of fall chinook salmon fingerlings, rainbow trout fry and yearlings, coho fingerlings, and kokanee salmon fingerlings were reared in North Pond during the summer of 1975. Chinook salmon and rainbow trout fry were introduced into the ponds in May before pond waters had become stabilized, resulting in heavy mortalities. Rainbow fingerlings introduced after pondwater stabilization had survival rates from 20-81 percent, over 158-52 days of rearing. Coho fingerlings reared in pens had survival rates of from 20 to 48 percent in one set of pens, and from 19-39 percent in another set of pens. Kokanee introduced into the ponds in late October suffered mortalities immediately from Vibrio infections. Survival of kokanee planted into the pond was 37 percent, whereas kokanee reared in pens showed survivals of from 62-94 percent over the same period of time. Growth of fall chinook was good, with an average fork length of 13 cm and average weight of 27 grams attained by mid-November. High levels of nitrogen as ammonia, nitrite and nitrate quickly disappeared on introduction into stabilized fish pond waters.

Therapeutic effects on salmonids apparently resulted from "green water" produced by high levels of phytoplankton, especially *Chlorella*.

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