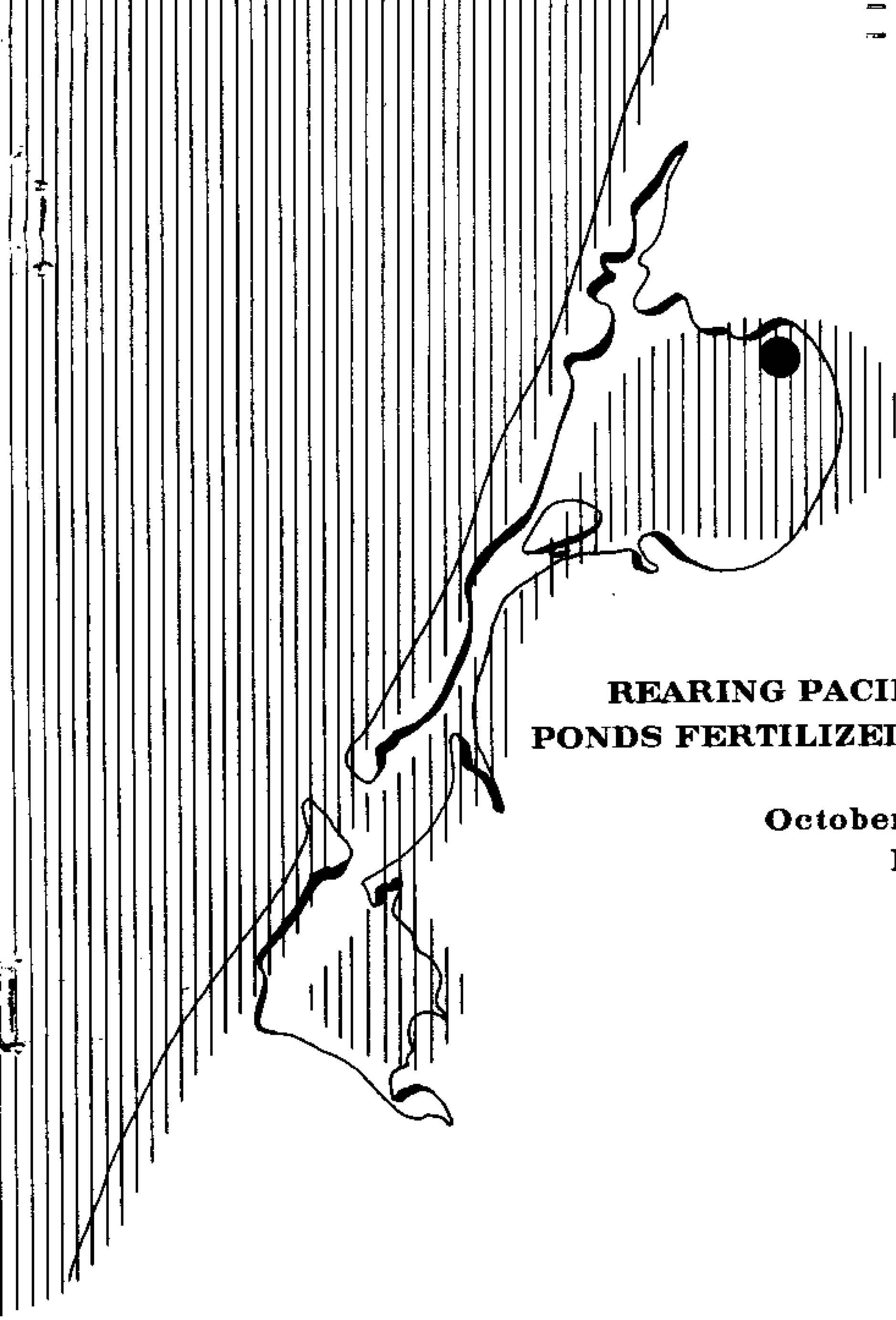


REARING PACIFIC SALMON IN SALTWATER PONDS FERTILIZED WITH DOMESTIC WASTEWATER

October 1975-August 1976
Data Report

HSU-SG-11

SEA GRANT PROGRAM
HUMBOLDT STATE UNIVERSITY

REARING PACIFIC SALMON IN SALTWATER PONDS FERTILIZED WITH DOMESTIC WASTEWATER

October 1975 - August 1976

by

George H. Allen, Professor of Fisheries

Humboldt State University

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

Data Report

December, 1976

HSU-SG-11

ABSTRACT

Rearing juvenile salmonid fishes in brackish-waters fertilized with treated domestic wastewater during 1975-76 season achieved levels of growth and survival envisioned for the system at the beginning of field testing in 1971. Coho salmon fingerlings showed a 45 percent survival in South Pond from October 1975 to May 1976. Supplemental feeding of materials obtained free or at low cost (live *Daphnia*; ground fresh and frozen fish carcasses) was initiated during coho rearing to insure all fish had the opportunity to reach minimum size for smolting before onset of higher summer water temperatures. About 16,000 coho were produced with most of the survivors being smolts of excellent quality. Selective trapping of smolts from the pond occurred from about mid-April to early May, with over 6,000 smolts being removed from the pond by this technique. Smolts are collected by directing a flow of water through a trap located in an existing slot in the headgate of the pond. Other smolts were removed by seining, and by draining of the pond in early May when reversion to parr was detected with rising water temperatures. Coho reared in pens showed survivals of 100 percent over the rearing period. No evidence of vibriosis was detected in the coho population.

Spring chinook salmon fry reared in North Pond from February to mid-June 1976 showed the highest survival for any chinook salmon rearing experiment. In order to continue studies on rearing chinook salmon through the summer for late fall releases, only a portion of the salmon in the pond by late spring were removed for planting into Jolly Giant Creek. The remaining fish suffered almost total mortality when stressed from a combination of very high water temperatures (over 25 C in late June) and smolting. These two factors induced vibriosis in the population. Resistance to vibriosis by the salmon was

evidenced by an estimated 15 percent of the salmon population remaining in the pond by mid-July. Yearling rainbow trout, however, were not affected by either the high water temperatures or vibriosis, and grew at a rate of about 2 grams per day per fish.

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)

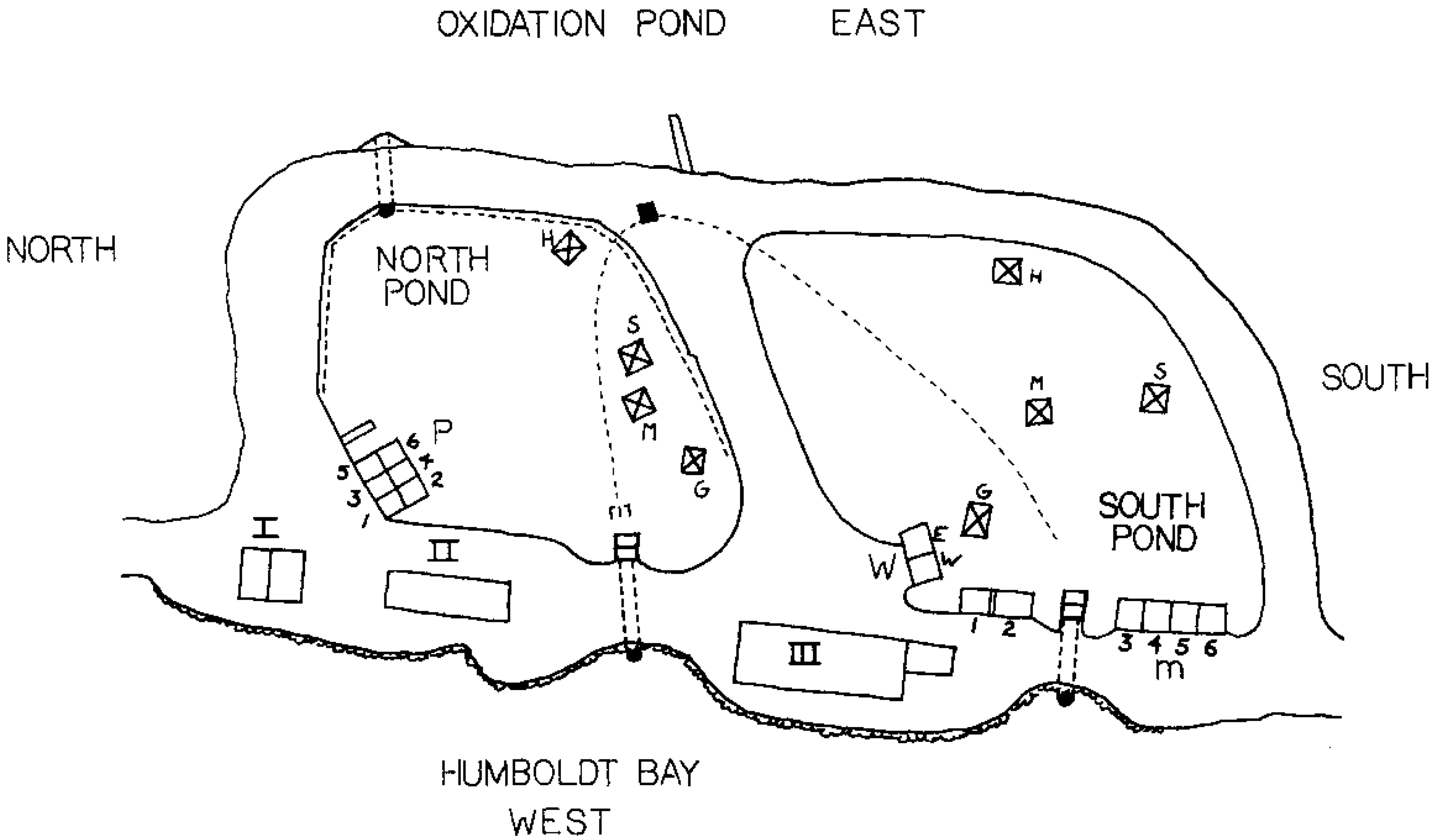
BACKGROUND

This is the final data report on the freshwater rearing of salmonids in two 0-15 hectare wastewater aquaculture ponds constructed by the Wildlife Conservation Board, California Department of Fish and Game (Allen, Conversano and Colwell 1972), and operated, in part, under the National Sea Grant Program, HSU Coherent Area Program, from 1969-1975. Details of the location, physical facilities, methods of operation, and photographs of the ponds have been published previously (Allen and Dennis 1974; Allen and Carpenter, In press; Allen 1973, 1975, 1976). A synopsis of rearing experiments numbered I-XI is given in Allen (1976, Table 1). The rearing experiments conducted October 1975-September 1976 (XII-XIV), are summarized in Table 1. Due to mechanical error, Experiment XIV was prematurely terminated. Results have not been included in this report. The format of this report will be that outlined for reporting the results of Experiments IX-XI (Allen 1976).

Figure 1 provides a sketch of the ponds, showing major features and location of rearing pens mentioned in the text.

Table 1. Species, size of fish, and location of juvenile salmonids reared in Experiments XII-XIV in Arcata wastewater aquaculture system, November 1975 through August 1976.

Experiment Number	Species	Size at planting	Pond	Major areas of study in experiments
XII	Coho	Fingerling	South	First completed experiment involving rearing, trapping of smolts, holding, marking, and release into potential "home-stream". Intensive study of smolting, down-stream-migration, and residualization.
XIII	Spring Chinook	Fry	North	High-density chinook planting to repeat basic design of Experiment X. Highest chinook salmon survival rates to date. Studies of smolting, down-stream migration and residualization.
XIV	Coho	Yearlings	South	Major study of summer-rearing potential of system for rainbow trout, plus holding fin-marked lots of coho reared in Experiment XII. Improperly shut valve-gate drained pond. Partial results only. Data not included in this report.
	Rainbow	Fry		



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).

EXPERIMENT XII

(October 1975 - September 1976)

Background

Experiment XII marked our first attempt to rear coho salmon to smolting, selectively trapping the smolts from the pond, holding and marking the fish, and releasing the smolts in small groups in selected planting sites (home stream). Prior to Experiment X (coho salmon, October 74 - January 1975 rearing period), fish were released unmarked directly into Humboldt Bay. With Experiment X, holding tanks allowed coho salmon to be planted into other locations. By the summer of 1975, four 1,000-gallon tanks were installed in our fish barn. Each tank is fitted with a false bottom, a foot of dolomite rock, and two air-lift water recirculating units. Each tank has a minimum capacity of holding 10,000 fingerling salmonids over an extended period of time (Dennis 1975). In addition, a water table was completed for marking salmon. These facilities will allow identification of all future project fish released from the wastewater aquaculture ponds.

For salmon reared in Experiment XII, freshwater planting sites were selected to test where future adult salmon trapping facilities could be most conveniently located. Two "home stream" sites receiving juvenile salmon were: Jolly Giant Creek which enters Humboldt Bay immediately west of the aquaculture ponds, and a small tidal slough fitted with a flap gate, lying immediately east of the Arcata oxidation pond.

As the release of smolts of proper size and at the proper time is necessary to avoid "residualization" of planted fish (Royal 1972), an intensive study of smolting of coho salmon and chinook salmon (Experiment XII) was completed by Del Sarto (1976). Our initial investigations of smolting of fall chinook salmon in the spring of 1974 familiarized our personnel with the biochemical procedures for determining Na^+ and K^+ -ATPase (Collins 1976). Del Sarto (op. cit.) combined gill enzyme analysis, selective trapping of pond smolts and monitoring of the DSM salmon planted into Jolly Giant Creek, during Experiment XII (and Experiment XII), in order to understand as fully as possible coho and chinook salmon smolting process in the pond system.

Supplemental feeding, with natural foods available in the Arcata oxidation pond (*Daphnia* - water fleas) and other free or inexpensive organic materials from a variety of sources, was instituted about mid-way through the experiment. This had not been part of our original planning for this experiment.

Polyculture studies using pen-rearing of sublegal *Cancer magister* and coho salmon also had been planned. The study was to rear crabs under different densities and types of substrates to supplement work previously undertaken by Welsh (1974). Knowledge of optimum density for growth and survival of sublegal crabs is needed to plan any major crab-salmon polyculture experiments in the future. Unfortunately, sublegal male crabs were extremely difficult to secure in the fall of 1975. Commercial crab pots were catching only legal crabs due to an extremely successful year-class of adult crabs in the fishery. The crab-salmon rearing study was not carried out although all necessary facilities were constructed for the work which will be eventually undertaken.

Pond Operation

On August 6, 1975, Humboldt Bay water of 34 o/oo salinity was added to South Pond. From August 8 to August 30, North Pond water was added to South Pond, along with small additions of Humboldt Bay water and freshwater, attaining a salinity of 21.5 o/oo on August 30. A salinity regime of between 21 and 23 o/oo was maintained for the first three months of the experiment to provide a salinity regime not too high for coho salmon juveniles but not too low for *Cancer magister*. When it became apparent that crabs would not be available for this study, no attempt was made to keep the salinity at this level. Pond level was maintained by discharging small lots of water after heavy rains which slowly reduced salinities during the winter. When the rains ceased, pond salinity varied between 8-11 o/oo during the last three months of rearing.

One major change in pond conditions occurred on November 17, 1975, when the pond was lowered 18" in order to place a small-meshed netting around our crab pens to prevent interchange of salmon between pond and pen rearing areas. The pond was refilled to operating level with Humboldt Bay water, which was at about the same salinity level as the fish ponds (23 o/oo).

On the day of fish planting our temporary forced-air pump finally wore out. As a result, during the first two weeks of coho salmon rearing (early October) aeration was either by an AIR-O-LATOR, or by short 2 to 3 hours of forced-air aeration using a gasoline driven air pump. Beginning in late October a new electrically-driven air-pump was installed and aeration was continuous using the forced-air aeration system.

Physical-Chemical Properties

Water properties were studied with methods previously outlined (Table 2). Although no 24-hour studies of physical-chemical properties were undertaken, on six days dissolved oxygen was studied during morning and afternoon periods. When the pond waters were well stabilized, only moderate increases in diurnal oxygen values were recorded (Table 3).

At the time of planting coho, the salinity was near 23 o/oo, which is near the upper limit that fingerling coho can tolerate without prior acclimation. The salinity slowly dropped during the experiment, finally reaching

Table 2. 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	$^{o}C \pm 0.5$	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 (D.O.)	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.

Table 3. Measurements of increase in oxygen levels during daylight hours, South Pond, September-October 1975 (Experiment XII).

Day	Morning Sample		Afternoon Sample		Percent Increase	Rate of Increase (mg/hour)
	Time	D.O.	Time	D.O.		
Sep 11	1100	7.6	1700	11.4	50	0.6
Oct 15	1200	4.0	1530	7.0	75	0.9
Nov 5	1000	11.8	1800	12.0	0.2	0.03
Nov 10	0830	9.6	1200	12.8	33	0.9
Nov 25 1/	0945	1.4	1530	10.0	610	1.5

1/ North Pond during initial filling of pond with wastewater from Arcata oxidation pond (Experiment XIII).

8 o/oo in early May 1976 (Figure 2). Temperatures were within optimum growing ranges for salmon, starting near 17^{o} C, dropping to around 10^{o} C in late November, remaining around this level until February, before slowly climbing to around 17^{o} C by the end of April (Figure 3). Hydrogen ion concentration was low (high pH values) in August shortly after pond filling. During September it ranged around 8.5, dropping to below 8.0 in October, finally reaching a low of 7.2 in late November (Figure 4). pH values fluctuated around 7.5 until mid-April when under heavy feeding, lengthening days, and increasing phytoplankton activity brought pH values up to near 8.5. Dissolved oxygen generally remained high. D.O. levels below 5 mg/l were recorded only during mid-late October (Figure 5). Although the plant community of the pond was changed from one of mainly phytoplankton to one mainly of macrophytes by pond level changes on November 17, there was no reflection in dissolved oxygen levels in the pond, which remained over 10 mg/l throughout the remainder of the experiment. Water clarity, which reflects mainly the plant community of the pond, was quite different before mid-November (low visibility), compared to after mid-November (pond bottom almost always visible) (Figure 6). This was due to water mixtures being altered on 17 November as noted previously. Relative nitrogen nitrate values were inversely correlated with phytoplankton, with relatively higher nitrate values occurring in the absence of high phytoplankton (Figure 7). An incipient phytoplankton bloom began appearing in late April, with nitrate showing a steady decline. Nitrogen as ammonia could be categorized into two periods - an early period (7 August - 2 October) with higher relative values and a later period (3 October - 7 May) with lower values. Peak value (3.6) during the early period occurred both on August 10 and September 26. In the later period, peak value was 1.4 on 17 November, with two values in the 0.5-0.6 range occurring in May. Nitrogen as nitrite was always low, with only one reading out of 27 determinations over 0.1 Hach units.

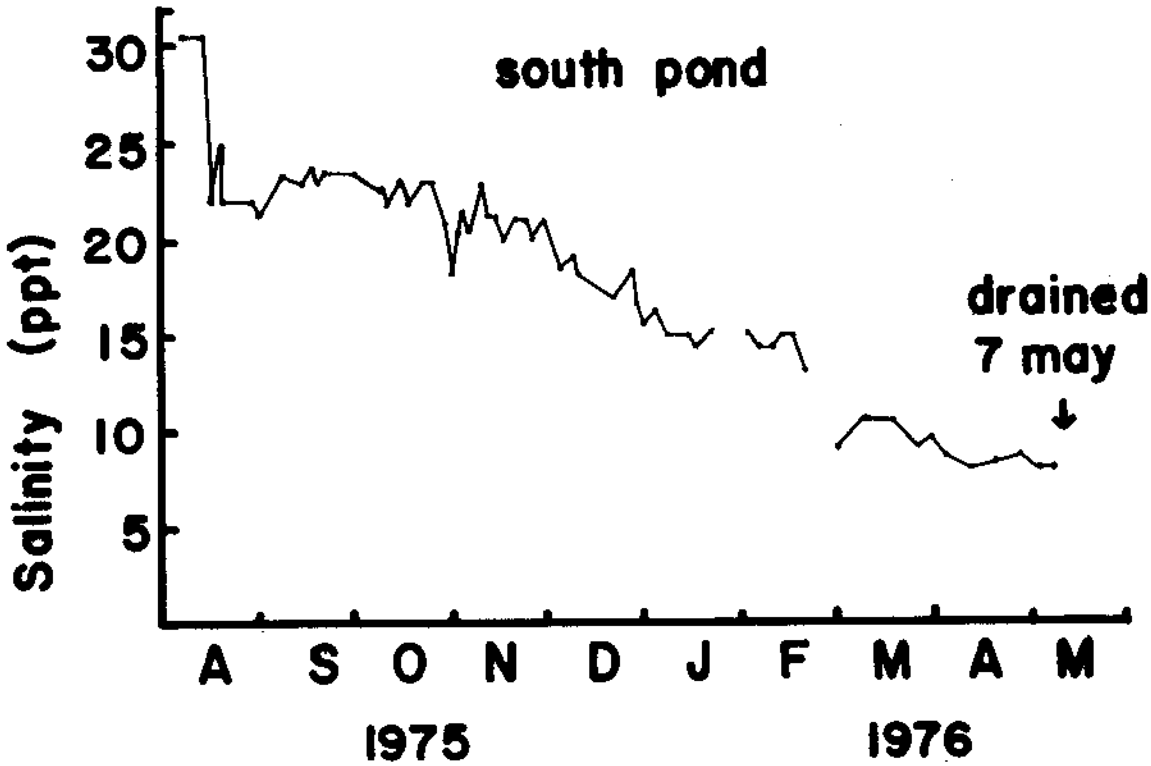


Figure 2. Salinity, surface water, South Pond, August 1975-May 1976 (Experiment XII).

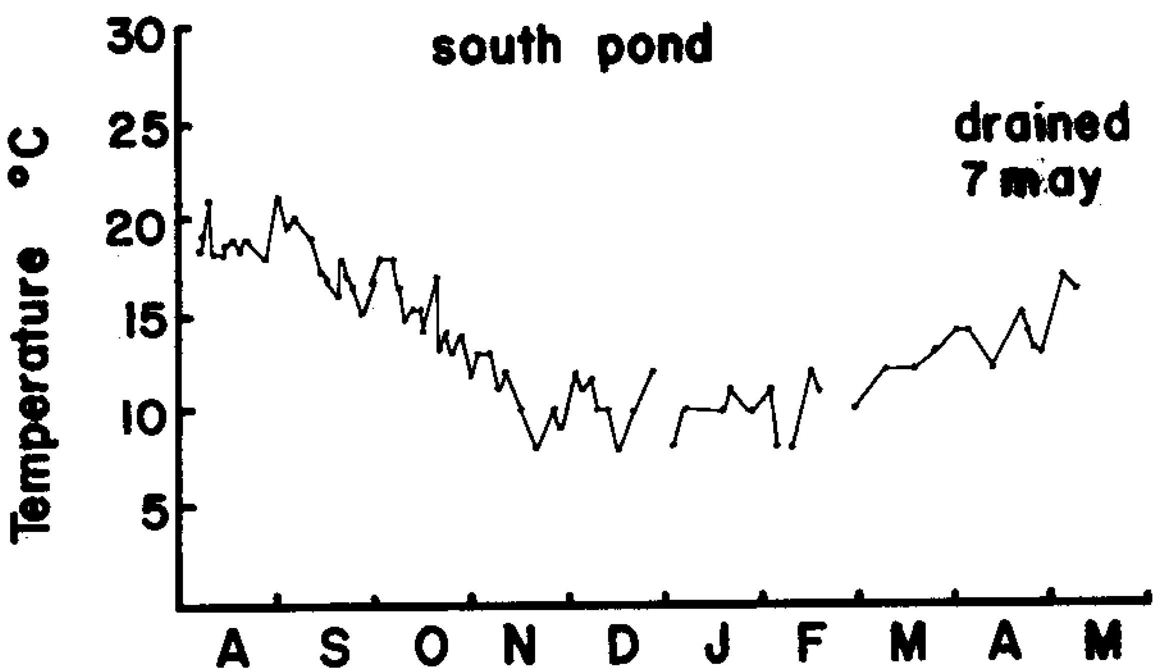


Figure 3. Temperature, surface water, South Pond, August 1975 - May 1976 (Experiment XII).

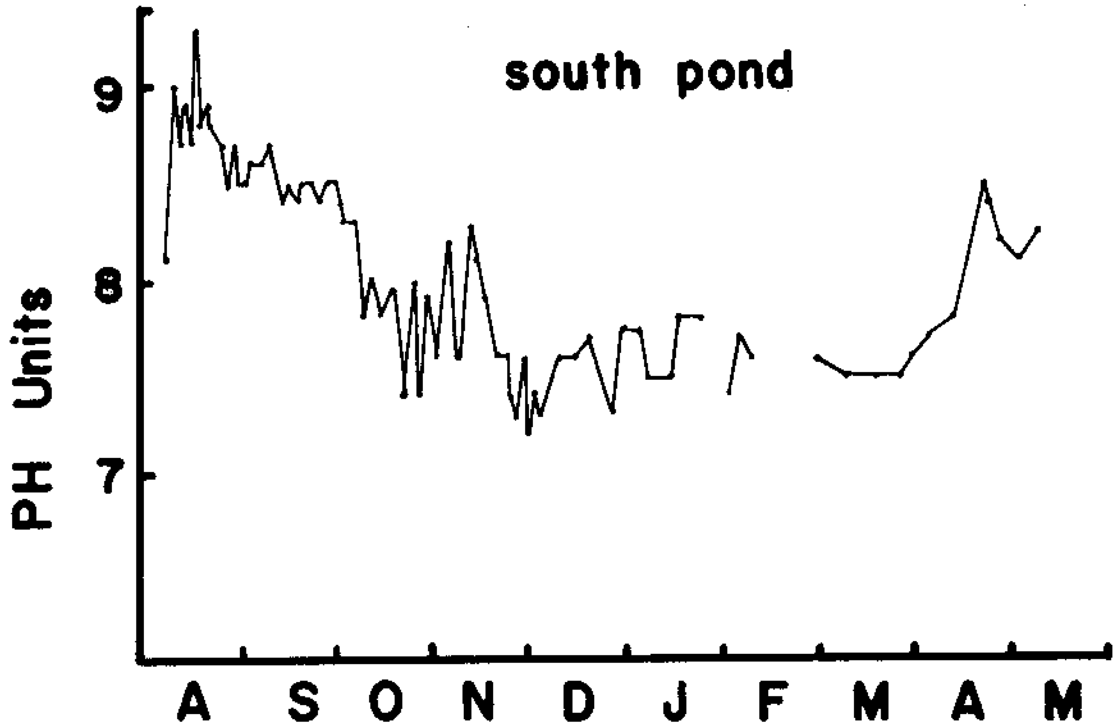


Figure 4. Hydrogen ion concentration, surface water, South Pond August 1975 - May 1976 (Experiment XII).

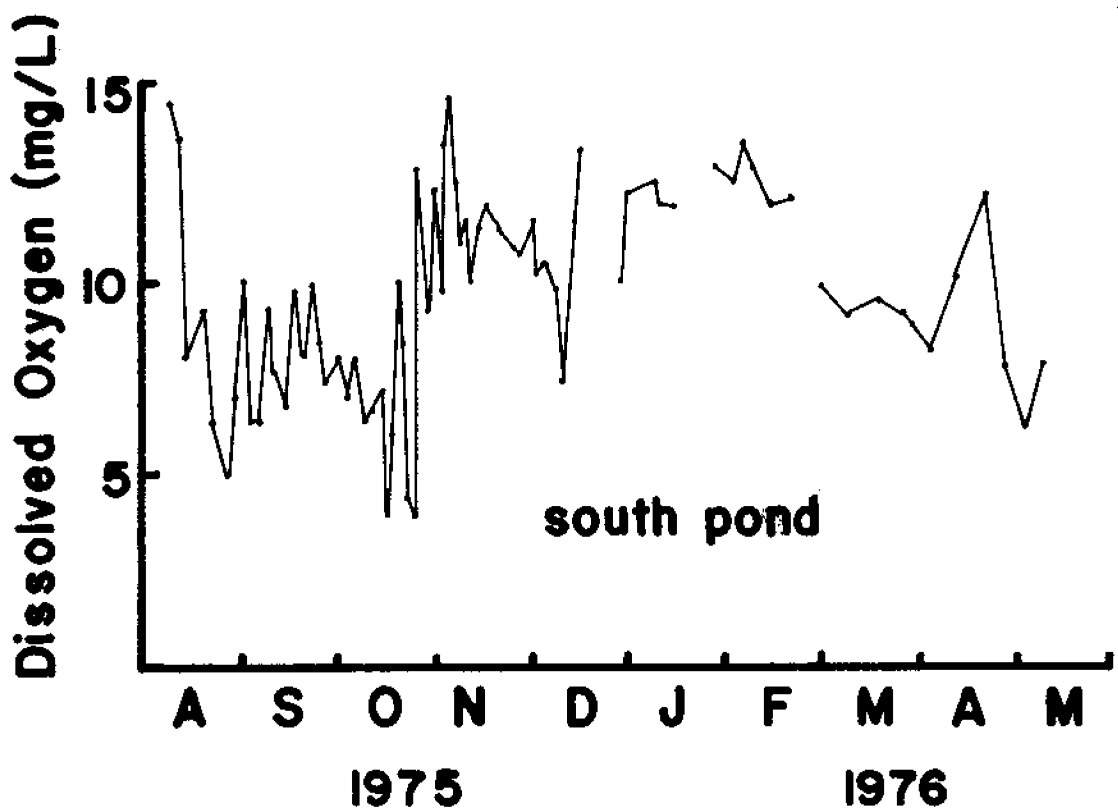


Figure 5. Dissolved oxygen, surface water, South Pond, August 1975 - May 1976 (Experiment XII).

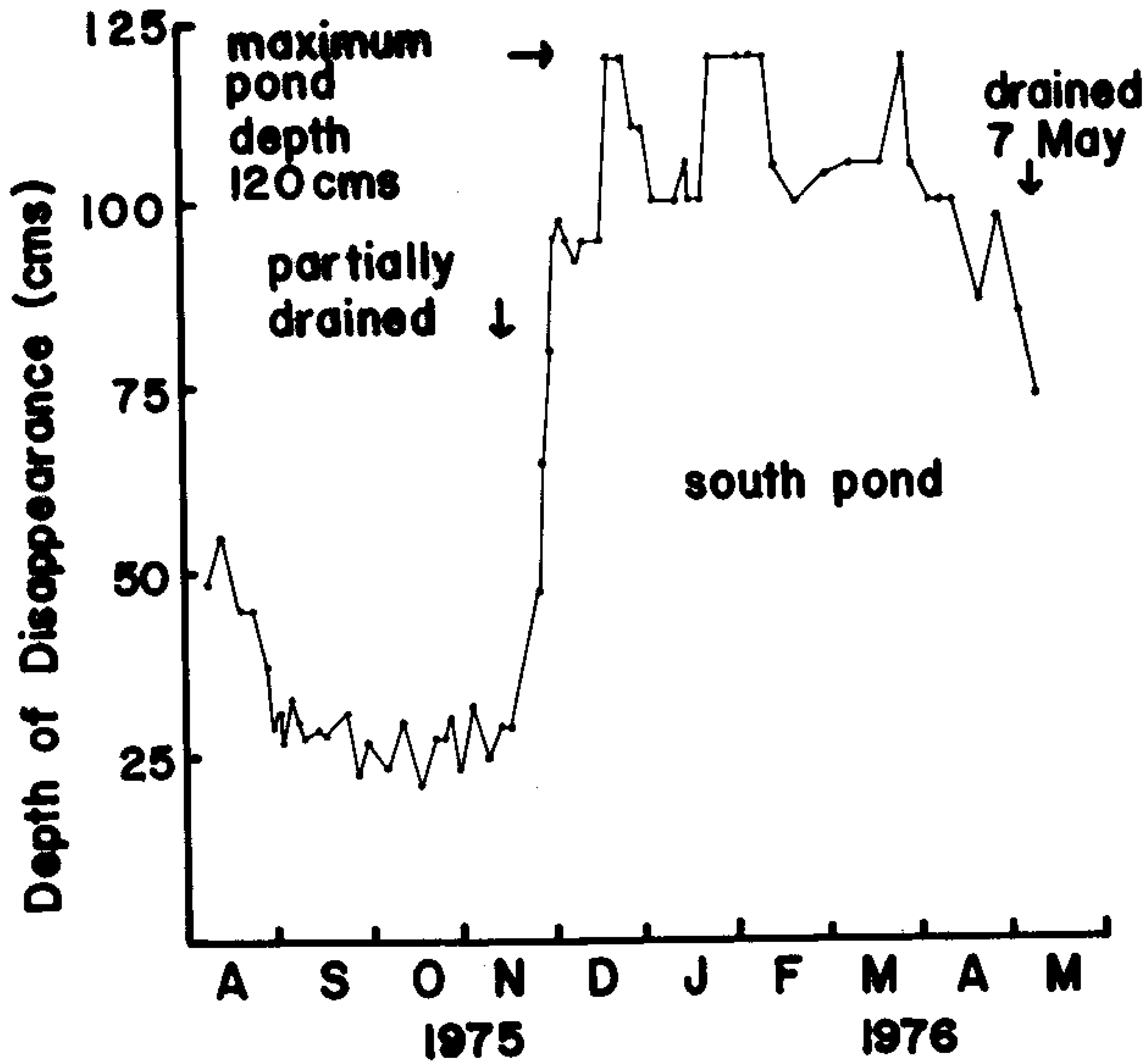


Figure 6. Clarity, South Pond, August 1975 - May 1976 (Experiment XII).

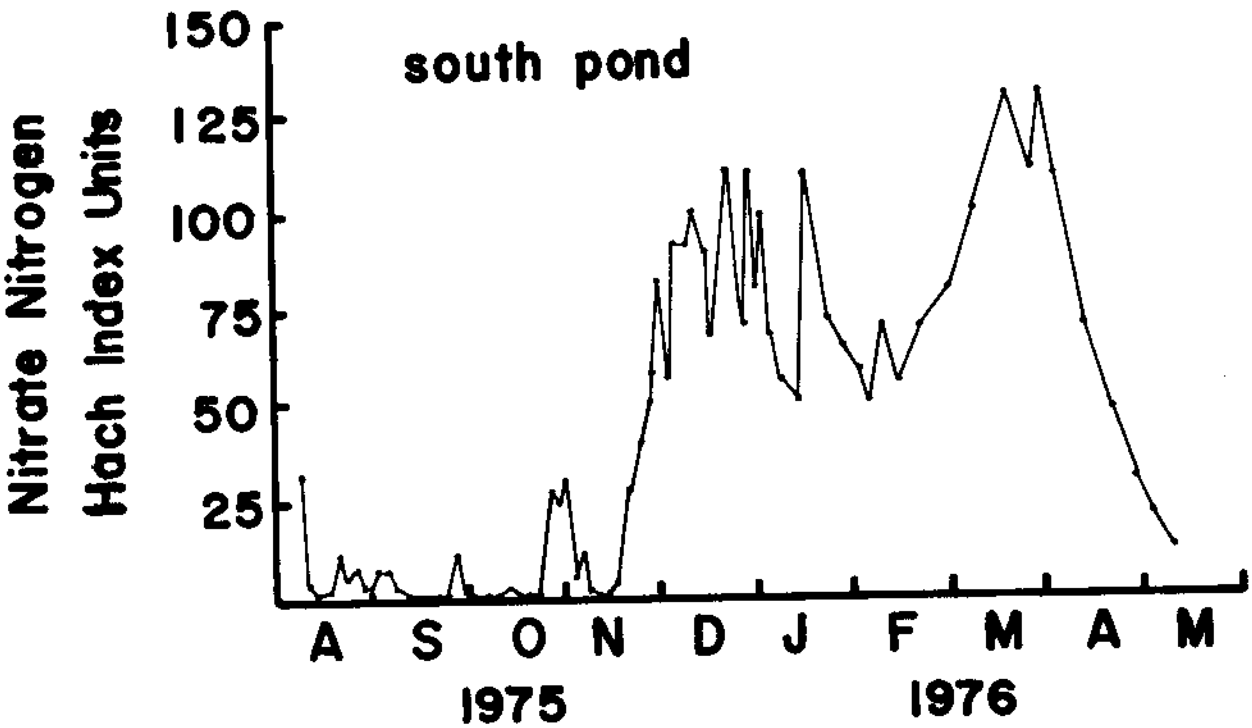


Figure 7. Relative nitrate nitrogen, South Pond, August 1975 - May 1976 (Experiment XII).

Supplemental Feeding

Six kinds of low-cost or waste food were fed to coho fingerlings in South Pond: live *Daphnia magna*; beef liver; ground frozen Dover sole fillet carcasses; ground frozen shrimp offal; fresh crab offal; and miscellaneous organic matter. A total of about 2,400 pounds wet weight of this material was fed (Table 4). The only material which was not available free was Dover sole carcasses purchased at 5 cents per pound. Dover sole and ground shrimp offal had been prepared for a crab feeding experiment. *Daphnia* was obtained by fishing a fyke-net in the outfall channel of the Arcata oxidation pond. Fresh crab offal and miscellaneous fish fillets were obtained from a local fresh fish market. Most of the supplemental feeding took place from mid-March until mid-April, although *Daphnia* feeding began on 5 December 1975. Material was hand-fed from the pond periphery, or from the middle of the pond from a boat. Crab offal was chopped into small chunks with a blunt shovel in an aluminum tub prior to feeding. Dover sole and shrimp offal had been ground and stored frozen until fed.

No supplemental feeding was given the coho reared in the 4-square meter fixed pens.

Survival Rates

A total of 34,900 coho fingerlings were planted into South Pond on three separate dates (Table 5). Most of the fish had been reared at the HSU hatchery, while 4,900 were from a rearing experiment to test the holding capacity and water quality of one unit of the four 1,000-gallon aquaria system for marking and holding smolts. Of the 30,000 fish from the HSU hatchery, 10 percent (3,000) were marked by removing the left ventral (LV) fin. The 4,900 fish planted from the 1,000-gallon aquaria had received a standard terramycin treatment (Allen, Busch and Morton 1976) which had been used to arrest

Table 4. Wet weight in pounds of supplemental feeds, coho salmon, South Pond. 5 December 1976 - 5 May 1976 (Experiment XII).

Feeding Period	Type of feed					
	Live Daphnia	Beef liver	Dover sole carcasses	Shrimp offal	Crab offal	Misc.
5 Dec 75 - 5 Feb 76	277					
11 Feb	53	18				
11 Feb - 17 Feb	118					
18 Feb - 5 May	1,026		645	120	137	6
Sub Totals	1,474	18	645	120	137	6
Grand Total	2,400					

Table 5. Number and average size of coho parr planted in South Pond September-October 1975 (Experiment XII).

Date	Number Planted	Average Size		Rearing Location
		Fork Length (mm)	Weight (gm)	
21 Sep	2,000	74	5.8	Tank 1, 1,000-gallon aquaria, fish barn.
26 Sep	2,900	74	5.3	As above
13 Oct	30,000*	86	7.9	HSU fish hatchery
Total	34,900			

* 3,000 marked LV.

mortalities from an epidemic of Vibrio. Total production was 15,800 fish (45 percent of the fingerlings planted). Most of these fish were smolts as shown by three criteria discussed later. Of smolted coho obtained from South Pond, 14,479 were planted in several locations for a variety of experimental purposes (Table 6).

On 13 October 1975, 100 coho were planted into each of four 4-square meter fixed pens. Salmon from one pen escaped into the pond during partial draining of the pond on 17 November 1975. In the other three pens a very high survival (84-89) percent were recovered on 7 May after 206 days of rearing (Table 7).

Smolting Studies

As noted previously, major attention was given by the project to studies on smolting since this was the first experiment where all the necessary facilities were available to carry a group of salmon through the entire catching, holding, marking, and planting process. This work was primarily carried out by Del Sarto (1976). A review of the smolting process and prior work done on our pond system by Collins (1976) and Hume (1976) will not be covered here. Major phases of smolt studies undertaken during the spring of 1976 on our pond system included:

1. Gill enzyme analysis following methods of Zaugg and McLain (1970) as modified by Collins and Kerstetter. Inorganic phosphates were determined by methods of Fiske and Subbarow (1925), and protein analysis following Lowery et al. (1951). Samples of fish for analysis were taken by seining, and from catches in a smolt trap described below.
2. Selective trapping of smolts from the pond by use of a single-entrance, stainless steel trap fitted into a slot originally designed into the

Table 6. Summary of coho smolts planted into local waters from fish taken from South Pond, April-May 1976 from South Pond (Experiment XII).

Fin Mark[1/]	Number	Place of Release	Time of Release	Study	Weight (No/lb)
RV	7,938	upper tidewater, Jolly Giant Creek	20 April - 12 May	Use of creek as point-of-return for adult salmon.	33
None	3,249	As above	10-12 May	Test differential loss from Vibrio from RV-fin clipping.	32
LV	1,018	tidal slough with flap-gate; immediately east of Arcata oxidation pond.	20 April - 12 May	Use of small slough as a point-of-return for adult salmon; test differential loss from Vibrio from RV-fin clipping.	35
RP-DCP	500	Mad River hatchery fishway	6 May	Marking technique study	33
DCP	738	Mad River hatchery fishway	6 May	Marking technique study	33
RV	1,036	Jolly Giant Creek 1 mile above tidewater	22 March - 6 May	7 lots of fish (20-213 fish per lot) to test DSM of smolts	-
Total	14,479				

1/ 3,000 LV-marked coho released on 13 October (See Table 5); RV mark was placed on unmarked smolts as they were removed from South Pond.

Table 7. Percent survival, and size of 100 coho salmon fingerlings in 4-square meter fixed pens, 13 October 1975 - 7 May 1976, South Pond (Experiment XII).

Parameter	Pen Substrate and Modification[1/]								
	Gravel: 7 stringers of 1-sq foot astro-turf material; no pen cover			Mud: no reefs no pen cover			Oyster Shell: no reefs pen cover		
Percent Survival	85			84			89		
	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
Fork Length (mm)	60	81	117	60	87	119	62	87	121
Weight (gm)	3.1	8.2	19.7	3.1	8.2	14.7	3.0	8.4	22.2

1/ Fish in pen over Hookton soil lost into pond through hole under pen baseboards during lowering of pond on 17 November 1975.

headgate structure of each pond. This collecting system (Hume and Allen, Under review) caught fish only when a current of water was directed through the trap. This current stimulated the outlet flow from a lake or pond. Salmon in moving downstream (downstream-migrant - DSM) prior to, or part of the process of smolting (Physiological changes leading to salt-water adaptation by the salmon) are presumably negatively rheotatic at this stage. Two year's preliminary work on the principle on fall chinook salmon by Hume (1976) indicated that sufficient water flow to attract fish could be produced through the trap by using a small electric outboard motor mounted in front of the trap.

3. Comparison of size and visual appearance of coho salmon reared in 4-square meter fixed pens to pond reared fish for degree of smolting.
4. Study of degree of smolting by visual appearance of the fish randomly sampled from the pond by seining.
5. Bioassays to ascertain degree of saltwater tolerance on fish classified as smolts by visual appearance.
6. Actual stream behavior of smolts and non-smolts by recovery of groups of coho planted into Jolly Giant Creek and recovered in a downstream migrant trap.

Results of studies 2-5 will be reported here, and studies 1 and 6 are under analysis.

During the present experiment, a classification of parr, presmolt, and smolt based upon external appearance was developed as follows:

Maturity	Description
parr	skin color yellowish, fins yellowish; strongly developed parr marks.
presmolt	skin color only faintly yellow; fins clear with slight touches of black along distal edges; parr marks present but not bold.
smolt	no yellow tinge to skin color; fins clear, with dorsal and anal fins with a very dark distal edge; parr marks faint to absent; scales with silvery sheen; dorsal portion of body often quite dark.

On March 16, a smolt was reportedly caught in a single-funnel stationary trap but physiological condition and external appearance of the specimen was not verified. On March 18, the smolt trap (Hume 1976) was fished from 2000 to 0100 but no fish were taken. On March 29, entries into official log for the experiment noted a definite schooling behavior of the fish was occurring in the pond. On April 2, the Hume trap was operated during the night with no catch. On 6 April, a smolt (125 mm in fork length and 19 grams in weight) was taken by seining, while 8 more were taken in the Hume trap during that same night (Table 8). The Hume smolt trap was then operated as often as personnel was available.

From April 6 to May 6, a total of 6,256 smolts were taken in the trap at an average rate of 27 smolts per hour (Table 8). Although the catch rate per hour was higher for daytime hours (30 smolts per hour) than for night (22 fish per hour), this difference was primarily due to the catch made on the mornings of 23 and 24 April when 34 percent of the total smolt catch in the Hume trap occurred. This catch was not due to a greater fishing effort but due to a very high rate of catch (Figure 8). The catch occurred just as a weather front passed through the local area. Personnel recorded a dramatic change in the coloration of the fish in the pond on April 19, signalling a rapid process of smolting was underway. A sharp elevation of gill enzyme levels occurred

Table 8. Rate of catch by day and night of coho in actively-fished Hume smolt trap, South Pond headgate slot, 18 March - May 6, 1976 (Experiment XII).

Date	Trapping Period				Combined		
	Light Period (0600-1800)		Dark Period (1800-0600)				
	Hours trap fished	Number coho caught	Hours trap fished	Number coho caught	Hours trap fished	Number coho caught	Number of coho caught per hour of trapping
April							
6			10	8	10	8	0.8
7	7	0	-	-	7	0	0.0
10	11	16	-	-	11	16	1.45
13	6.75	10	-	-	6.75	10	1.48
16	-	-	5.5	62	5.5	62	11.27
18	-	-	2.5	174	2.5	174	69.6
19	-	-	9.25	346	9.25	346	47.40
20	4.5	64	-	-	4.5	64	14.22
21/22	2	3	8	59	10	62	6.20
22	-	-	6.25	339	6.25	339	54.24
23/24	10	1,093	12	277	22	1,370	62.27
24/25	3	714	(12)	(1)	3	714	238.0
	(6)	(1)					
25	11	372	-	-	11	372	33.82
26/27	5.5	131	3.75	35	9.25	166	17.94
27	9.75	24	-	-	9.75	24	2.46
28/29	10.25	262	7.75	208	18.0	470	26.11
29/30	11	377	7.0	76	18.0	453	25.16
30/1	11.25	262	13	360	24.25	622	25.65
May							
2/3	6.0	8	2.0	7	8.0	15	1.87
3	7.5	459	-	-	7.5	459	61.20
4	7.5	381	-	-	7.5	381	50.80
5	7.75	114	-	-	7.75	114	14.71
6	7.75	15	-	-	7.75	15	1.9
Totals	139.5	4,241	91.5	2,015	231.0	6,256	
Days fished:	17		13			23	
Catch per hour	30.4		22.0			27.1	

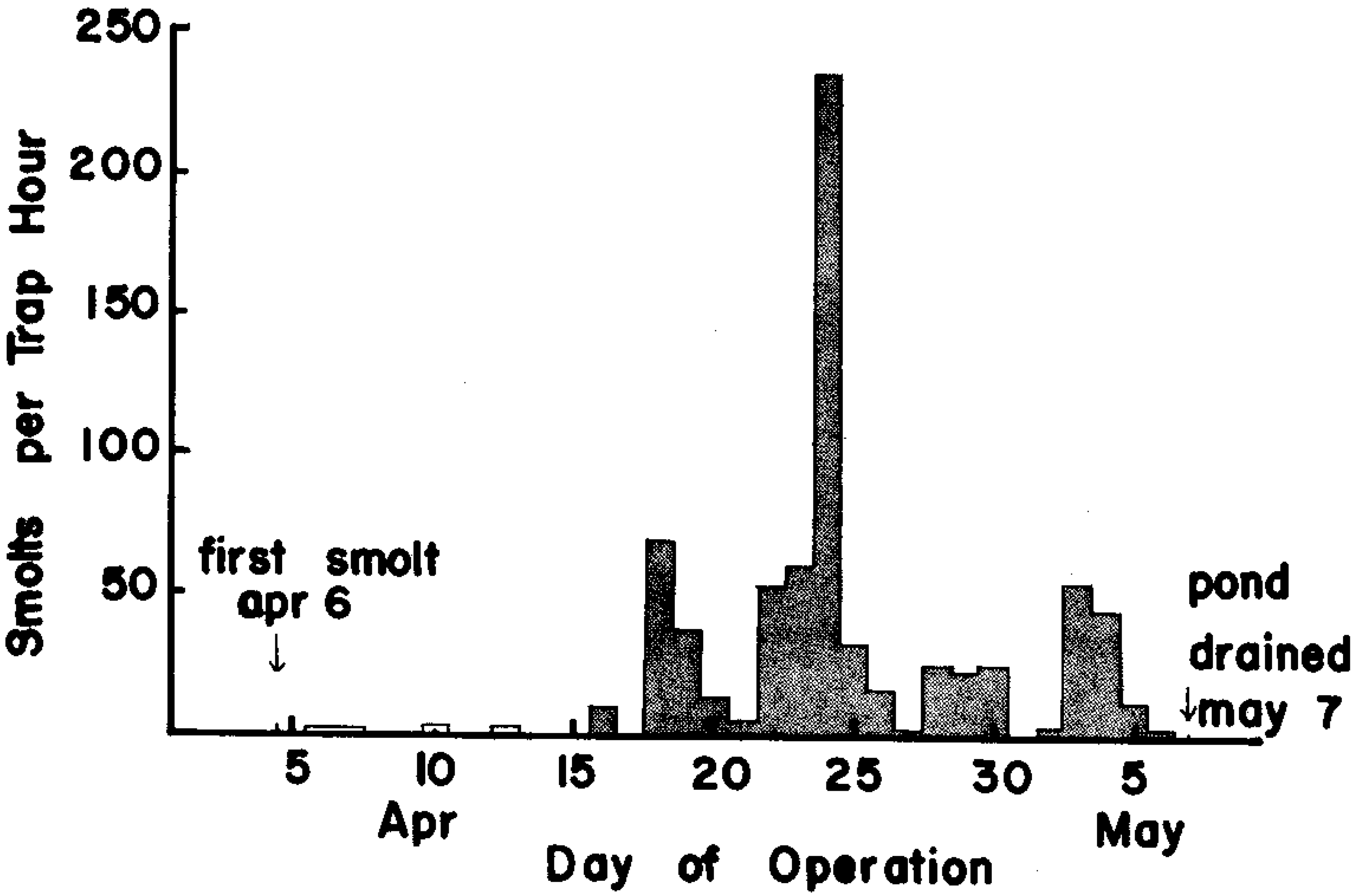


Figure 8. Catch-per-unit effort (smolts per hour of fishing) in trap located in a simulated outlet stream, South Pond, April-May 1976 (Experiment XII).

in trapped smolts in late April and early May (Del Sarto 1976) indicating fish were ready for saltwater at this time. Levels of Na^+ and K^+ ATPase were always high in trap-caught fish as compared to the same length of fish sampled from the pond (Del Sarto 1976). Coho smolts planted in Jolly Giant Creek in mid-April had the highest rate of recovery in a DSM trap operated just above tidewater, confirming the assumption that coho classified by external features were migrating quickly to the ocean on planting. Thus we are certain that little "residualization" (Royal 1972) occurred in these fish. Details of these studies cannot be reported here in the interests of space.

It appeared likely that the capacity of the smolt trap had been exceeded during the period April 23-25 when nearly 2,000 fish were captured (Table 8), and a maximum rate of catch was experienced (Figure 8). Thus we initiated a program of seining to assist in smolt harvesting. A small, deep, gravel-bottomed area existed between two sets of pens in the northwest corner of South Pond (Figure 1). By luring groups of coho into this area with feed, large samples of fish could be easily obtained. Seined fish were removed to holding tanks in the fish barn for processing. All LV-marked fish were segregated and planted. On April 26, unmarked fish were all given an RV-mark, with parr returned to the east end of South Pond and smolts retained for planting. After April 26, any RV-marked coho recaptured were also segregated into smolts and non-smolts, with non-smolts also returned to the pond. Of the 6,600 fish handled, only 843 smolts were obtained from this seining program. This was due to the fact that less than 1/5 of the pond population were in smolt conditions at any one time (Table 9). The smaller RV-marked parr returned to the pond only started approaching full smolting stage by early May. This is consistent with general relationship that smolting is not only dependent on temperature and photoperiod, but on size of fish (Hoar 1976).

Table 9. Percentage of smolts by mark in random samples of coho seined from northwest corner of South Pond, April-May 1976 (Experiment XII).

Date sampled	Number coho examined	Number of non-smolts and smolts by mark				Unmarked		
		LV[1]	RV					
			non smolts	smolts	Percent smolt	non smolts	smolts	Percent smolt
April 26	1,008	89[2]	-	-	-	826	93[2]	1.0
April 27	1,514	85	235	12	0.5	944	238	20.1
April 28	1,122	91	225	15	6.2	696	95	12.0
April 30	121	5	41	2	7.0	61	12	16.4
May 1	647	45	186	10	5.1	343	63	15.5
May 3[3]	2,163	96	629	85	11.9	1,135	218	20.6
Totals	6,575	411	1,316	124		4,005	719	
May 7[4]	2,189	134	569			1,486		

1/ No separation of LV-marked fish into smolts and non-smolts attempted.

2/ Initial use of data recording system resulted in some confusion and loss of data. These were our best estimates from existing records.

3/ Part of this sample processed on 4 May and part on 5 May, consequently a portion of the increased percentage of smolts may have been induced by holding. However, temperatures in aquaria in fish barn were consistently 4-5° C lower than in South Pond, thus acting to retard smolting processes.

4/ No separation of remaining coho removed into non-smolt and smolt categories attempted, since it was imperative to move fish quickly to planting sites as entire population was reverting to parr status.

About 2,200 coho remained in the pond on May 7 and were removed by draining (Table 9, Footnote 4). Applying the rate of smolts found in random samples taken May 3, about 1,700 of the fish in the pond on May 7 were probably either parr not going to smolt, or presmolts in the process of reverting to parr. These fish were roughly 12 percent of all coho recovered from the pond. In the future, it may be possible to have virtually all smolts in the residual population simply by retaining the salmon in the fish barn in colder water, and feeding standard salmon pellets for a short period.

The effect of size of coho on time of smolting could be discerned primarily by comparing size of smolts planted, percentage of parr, presmolts, and smolts from coho reared in 4-square meter pens, and size of coho recovered in Jolly Giant Creek downstream migrant trap. Prior to planting, smolt size was measured by counting the number of fish in a 1-pound sample (rarely a 2-pound sample) (Table 10). We felt that early-trapped smolts were somewhat larger than those taken later in the trapping season, however, we failed to take sufficient systematic samples in the early part of the trapping to prove this (Table 11). In later portions of smolt trapping, weights of from 26-38 per pound characterized all fish, with the LV-marked fish being consistently smaller in size than unmarked salmon (or recently RV-marked fish). In all cases, from April 20 until May 7, the average size tended to remain fairly uniform. The lengths of a random sample of RV-marked and unmarked coho salmon recovered when the pond was drained on May 7 were representative of smolts weighing 31 per pound (RV-marked) and 33 per pound (unmarked) (Figure 9). Assuming that any fish under 100 mm is probably not a smolt, then 80 percent of these fish would be in the size range suitable for smolting. In contrast, coho reared in 4-square meter pens had a much smaller average size (Table 7) and were roughly 70 percent parr (Table 12). However,

Table 10. Number of smolts in 1-pound samples taken prior to planting, South Pond, April-May 1976 (Experiment XII).

Date	Group of fish		
	RV	Unmarked	LV
April 20	34		
April 27	32		
April 28	34		
April 30	26		35
May 1	31		
May 3	33		33
May 4	30, 28		35, 37
May 5	33		
May 10	33, 35	37	34
May 11	34, 36, 38	29, 30, 33	34, 36
May 12	35	29, 32, 34, 35	34
Number samples	15	8	8
Range	26-38	29-35	33-37
Mean	33	32	35

Table 11. Length and weight of LV - and RV-marked coho salmon taken in smolt trap South Pond, 4-26 April 1976 (Experiment XII).

Mark	Sample Size	Sample Date	Fork length (mm)			Weight (gr)			Number per pound
			Min	Mean	Max	Min	Mean	Max	
None 1/	20	4 Apr	95	112	155	9.0	15.0	41.5	30
LV 2/	10	22 Apr	112	127	145	15.9	20.0	27.4	23
RV 3/	50	23 Apr	89	111	148	8.4	15.1	30.5	30
LV 4/	42	26 Apr	77	101	128	5.2	10.1	20.1	45

1/ These were the first 20 smolts taken in actively fished Hume trap.

2/ 10 LV fish from a sample of 118 coho taken in smolt trap Apr 22.

3/ RV - marked during seining of samples of South Pond fish to determine percent of smolts in pond population. Unmarked coho were given RV mark, with smolts planted into Jolly Giant Creek, and parr and presmolt returned to South Pond.

4/ LV - 10 percent of coho marked at HSU hatchery prior to planting. The sample represented all of LV coho taken in Hume trap up to 23 April.

the few fish in the pens that had smolted were all over 100 mm and 12 grams, but with some of the presmolts, and even parr, exceeding this minimum size (Table 13).

The size of smolts from South Pond were very similar to wild DSM coho in Waddell Creek, California: "Despite variations caused by seasonal conditions, within any season 95 percent of the migrants passed the dam during the nine-week period April 8 to June 9 at age 1 and at an average size of from 103.11 to 116.61 mm" (Shapovalov, L. and A. C. Taft 1954).

Growth

Beginning at a mean length of 74-86 mm and mean weight of 5.3-7.9 grams depending on time of planting (late September to mid-October, 1975, Table 5), the fish attained an average length of 111 mm and 15 grams average weight by May 7 (Figure 9). Little growth in the ponds occurred during the fall (Table 14), nor during winter (Table 15). With increasing water temperatures and supplemental feeding in March, the coho grew rapidly during the spring (Table 15). Salmon with a LV clip when placed into the ponds were always smaller in size than unmarked fish (Table 10 and 11).

As noted previously, the larger fish smolted first, and these fish were selectively caught in the Hume trap. This idea was supported further by the size of fish seined from the pond on April 21 (Table 15) as compared to the size of the fish taken in the Hume trap on April 23 (Table 11). It is also shown by size of smolts as compared to non-smolts in pen-reared fish (Table 13).

Fish Health

Coho smolts were uniformly free from any external signs of parasites or disease. Very little loss of scales during holding and marking were recorded.

Table 12. Percent smolting maturity of coho salmon attained May 7, 1975, from 100 salmon planted in 4-square meter pens, October 1975 (Experiment XII).

Maturity	Pen Substrate		
	Gravel	Mud	Shell
Smolt	3.7	2.4	6.7
Presmolt	25.6	31.0	24.7
Parr	70.7	66.6	68.6

Table 13. Fork length in mm and weight in gm by stage of maturity of coho salmon recovered from 4-square meter pens, May 7, 1976 (Experiment XII).

Maturity	Length			Weight		
	Min	Mean	Max	Min	Mean	Max
Smolt	103	113	121	12.3	15.9	22.2
Presmolt	80	95	115	6.8	10.2	16.4
Parr	60	81	117	3.1	7.0	15.8

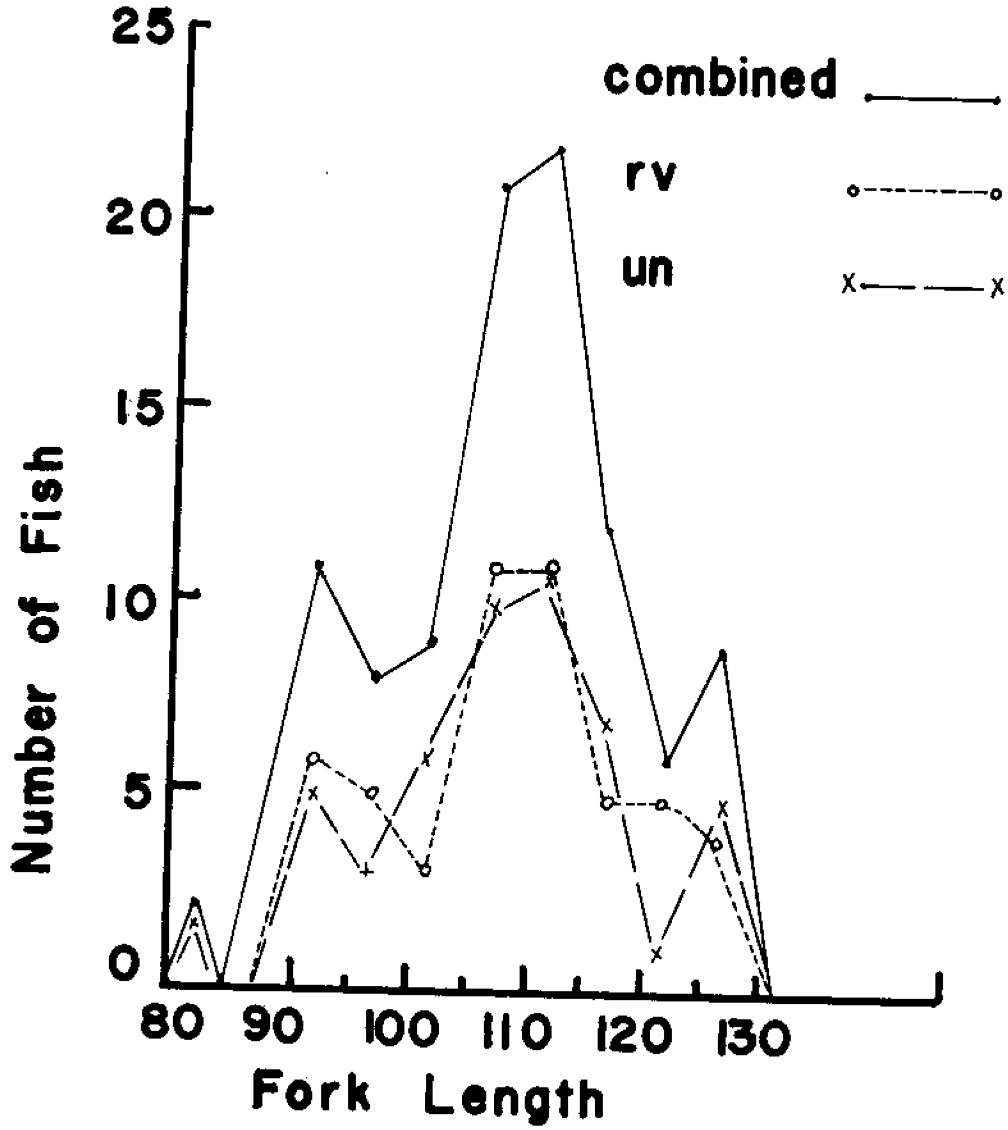


Figure 9. Fork length (mm) of random samples of RV-marked and unmarked coho salmon (N = 50) from about 200 fish taken from South Pond on May 7, 1976 (Experiment XII). (Weight (gm): RV mark - mean 14.8 and range 8.6 - 20.8; unmarked - mean 13.7 and range 6.5 - 21.3).

Table 14. Length and weight of coho salmon caught in 1-meter long, single-funnel cylindrical traps fished throughout South Pond, October - December 1975 (Experiment XII).

Date traps examined	Number of traps fished	Number of coho salmon measured	Fork length		
			Min	Mean	Max
Oct 30	11	57	75	78	96
Nov 1	10	55	60	82	115
Nov 4	11	18	78	85	96
Nov 20	10	24	68	81	100
Nov 22	10	19	63	79	93
Nov 25	10	41	64	83	105
Dec 4	10	33	76	92	111
Dec 19[1/]	7	0	-	-	-

1/ Study discontinued due to dramatic decrease in turbidity due to partial pond draining on 17 November 1975 making traps ineffective (see Figure 6).

Table 15. Length and weight of coho salmon obtained by seining, North Pond, March-May 1976 (Experiment XII). (Number sampled for measuring - 20).

Date Captured	Number planted 1/	Number Measured	Fork Length (mm) Min	Fork Length (mm) Mean	Fork Length (mm) Max	Weight (gm) Min	Weight (gm) Mean	Weight (gm) Max	No. fish per pound	Mark 2/
March 22	192	20	70	84	105	3.8	7.8	11.8	58	RV
April 6	213	20	69	89	117	5.5	9.2	15.1	49	RV + TC
April 21	211	20	85	89	117	8.4	10.6	17.4	43	RV + BC
May 6	100	10	84	110	124	9.1	15.9	22.5	28	RV + ROP
May 24 3/	100	10	84	110	130	7.4	14.4	21.8	32	LV + LOP
June 25 3/ 4/	53									LV + ROP

1/ Jolly Giant Creek about 1/2 mile above tidewater and above location of downstream migrant trap.

2/ TC - punch, dorsal lobe of caudal fin
BC - punch, ventral lobe of caudal fin
LOP - punch, left opercle
ROP - punch, right opercle

3/ Taken from a sample of about 300 fish retained in two movable live cars in North Pond following draining of South Pond on May 7. Fish were crowded and water temperatures had started to rise sharply.

4/ Data misplaced. Fish were in poor condition.

Virtually no mortalities due to handling could be identified, with mortalities being mechanical injuries or from fish jumping out through openings left by improper placement of screens over holding tanks.

In late May and June, chinook salmon from North Pond and rainbow trout fry from the HSU hatchery all contacted vibriosis when held in recirculating aquaria with water employed during holding and marking of coho smolts in early and mid-May. Heavy mortalities were manifested in 5-10 days after exposure. From May 28 to June 9, a Vibrio challenge experiment was conducted by project personnel at the HSU fisheries department fish pathology laboratory on coho salmon smolts. Only three mortalities occurred among the 30 coho smolts tested in three solutions subjected to a single initial inoculation of Vibrio at a concentration in the tank of 10^6 organisms/ml of water (Table 16). The Vibrio was grown from a stock isolate taken from North Pond in 1975. Kidney smears from mortalities were studied for bacteria but no bacterial infection was confirmed. These observations are not at variance with the results of Antipa (1976) indicating that coho salmon have considerable natural resistance to vibriosis.

Crab Rearing

A sample of juvenile crabs (Cancer magister) was obtained by trapping in Humboldt Bay in an effort to obtain a large sample of sublegal male crabs planned for a pen-rearing experiment. When the crab study was abandoned due to lack of crabs of the correct size and number, 30 juvenile crabs being held in aquaria were measured for weight in grams and placed in a 6' x 6' fixed pen located in the northwest corner of South Pond on 5 December 1975 (Welsh crab pen W, Figure 1). When South Pond was drained on 7 May, 27 of the crabs (90 percent) were recovered (Table 17). As no attempt was made to feed the crabs, no growth occurred, and no moltings were noted in the pen. The crabs, however,

Table 16. *Vibrio* bacteria challenge of coho salmon utilizing 10-gallon aquaria filled with water, forced-air aeration and cotton filters, May 28-June 9, 1976 (Experiment XII) (Fish placed into tanks May 26, and 1 ml of 3-day old culture of 10^{10} organisms per ml was added to each tank on 28 May). (Fish fed OMP).

Factor	Tank Number 1	2	3
Type of Water	South Pond	South Pond	Trinidad Marine Laboratory
Vibrio concentration	10^6/ml	10^6/ml	ambient level
Salinity ppt	10	10	34
Temperature ^oC ranges May 26-29	15-17	15-17	12
Number of salmon tested			
Unmarked (UN)	5	5	4
RV-mark (1 month since marking)	5		3
LV-mark (marked just prior to testing)		5	3
Total per tank	10	10	10
Number of mortalities (13 day period)	1-RV	1-UM	1-RV

were healthy, maintaining themselves well in the sand-shell substrate which had been specifically provided for them in this pen. The crabs were living in salinities of 8-10 o/oo for three months (Figure 2). From May 7-20, the crabs were held in pens in North Pond (in water of 5 o/oo), but only one crab survived this low salinity. This result indicates that polyculture with a commercial crab-salmonid combination exists using chinook salmon, as well as coho salmon and trout.

Miscellaneous Observations

Four other species of fish were recovered from the pond, with the major biomass being a large number of sticklebacks (around 13,000 at 2.2 grams mean weight) (Table 18). The stickleback had recently spawned and a vast quantity of stickleback fry were released into Humboldt Bay.

Many people, students and non-students, volunteered to assist in the fish marking program. With continuous trapping of smolts keeping the fish barn well supplied with fish requiring sorting and marking, it was difficult to maintain control on the quality of marking or on the degree of error from excising the wrong fin. On May 5, 500 coho smolts were being marked to provide five experimental groups of fish. These fish were examined for right pectoral marks which we had been encountering during earlier marking. This group yielded 11 RP marks (2 percent unauthorized marks). To study the problem further, a careful examination was made of a sample of 92 coho mortalities which had been preserved during the April-June marking period. These mortalities were from fish that had jumped out of the holding tanks. Six unauthorized marks were found in this sample giving a rate of unauthorized marks of 6.5 percent (Table 19).

Because of supplemental feeding, no analysis of natural pond productivity was made for coho reared throughout the pond. However, the standing crop of fish reared in 4-square meter pens without supplemental feeding produced the highest such value calculated for any group of fish yet studied whether in ponds or pens - over 2,000 kg per hectare (Table 20).

Several interesting catches of coho salmon occurred in 1-meter single funnel traps. On 18 November, the day following a major addition of seawater into South Pond, a single trap located next to the headgate contained 67 juvenile coho. This catch was probably associated with salmon reacting to the incoming water of high salinity (Table 21). On 19 December, inspection of five single-funnel traps showed no fish in four traps located away from the headgate, but 74 juvenile fish in a trap located next to the headgate. No obvious reason for this high catch could be discerned.

Water Quality

As part of water quality monitoring required to protect Humboldt Bay aquatic values as determined by the California North Coastal Water Quality Control Board a bacteriological survey was conducted on North and South fish pond waters on 28 April 1976 (Table 22). The work was performed by Mr. Andrew Morton under supervision of Dr. Robert Busch, in the Humboldt State University fish pathology laboratory.

Untreated oxidation pond water and Jolly Giant Creek water showed much higher counts in all parameters studied than fish culture water except total bacteria. Oxidation pond water leaking into North fish pond had values about one order of magnitude lower than the oxidation pond water, suggesting that considerable natural purification had taken place. The length of the path of leakage water or the exact substrate traversed is not known, however, it is undoubtedly relative short and either through a sand or sandy-loam material. Fecal coliforms were virtually absent from fish culture water, and very low counts of fecal streptococci were also recorded. Of these latter two parameters, Jolly Giant Creek had higher counts than the unchlorinated water in the oxidation pond. These data suggest a probable contamination from human sources in Jolly Giant Creek water, although both the fecal coliform and fecal streptoccoci tests are not specific for human strains (Kenner et al. 1960).

Table 17. Growth and survival of juvenile commercial crab (*Cancer magister*) over sand-shell substrate 5 December 1975 - 7 May 1976, South Pond (Experiment XII).

Survival			Growth in weight (gm)								
			Start			End			Gain		
Planted	Recovered	Percent	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
30	27	90	44	68	112	42	70	116	-2	+2	+4

Table 18. Number target fish species recovered from South Pond, 7 May 1976 (Experiment XII).

Common name	Scientific name	Number	Size: Length Min	Length Mean	Length Max	Weight Mean
Atherinids (top or jacksmelts)	Atherinidae	11	130	138	145	
Staghorn sculpin	*Leptocottus armatus*	9	80	112	140	
Stickleback	*Gasterosteus aculeatus*	13,000[1/]				2.2
Bay shrimp	*Crago*	few				
Goby	Gobiidae	few				

1/ Total weight of 62 pounds was converted by the average weight per fish as determined in a 1 pound sample.

Table 19. Occurrence of fin-marks in 92 coho salmon which had jumped out of holding tanks (April-June 1976) (Experiment XII) (Fish formalin-preserved, processed on 10 June).

Unmarked	Authorized		Unauthorized					Total
	RV	LV	BV	Ad	LP	RV RP	RV LP	
59	21	6	1	1	2	1	1	92

Table 20. Biomass (standing crop) of coho salmon and sticklebacks in 4-square meter pens, 7 May 1976 (Experiment XII).

Species	Pen substrate		
	Gravel	Mud	Oyster shell
Coho	730.3 1/	677.3	749.0
Stickleback	79.7	211	197.0
Total	810.0	888.3	946.0
Kilograms/hectare	2,025	2,220	2,340

1/ Grams

Table 21. Salinity profile in South Pond one hour after addition of 10-inches of seawater from Humboldt Bay of 26 o/oo salinity, November 3, 1976.

	West Side (headgate)	Middle	East Side
Surface	20.0	19.5	18.5
Mid-depth	21.4	21.0	
Bottom	26.0	24.0	19.0

Table 22. Results of bacteriological survey of North and South fish pond and adjacent waters, 28 April 1976.

Parameter and Technique[1/]	Oxidation Pond (dock east of fish ponds)	South fish pond	North fish pond	Leakage into North fish pond	Jolly Giant Creek (off Northern Pacific R.R.)	Rearing Tank 2, Fish barn
Total Bacteria Plate Count	1.3×10^{8}	2.4×10^{5}	3.6×10^{5}	9.5×10^{6}	1.9×10^{6}	1.6×10^{6}
Total Coliform Membrane Filter	31,000	328	156	3,400	11,600	984
Most Probable Number (MPN)	2,400	350 (120-1000)	220 (57-700)	2,400	2,400	540 (180-1400)
Fecal Coliform Membrance Filter	2,200	2	2	240	3,250	2
Fecal Streptococci Membrane Filter	650	20	42	160	1,150	30

1/ Water samples were obtained at 0930 hours (low tide conditions) and stored at 4 C for a maximum of one (1) hour prior to laboratory examination. Total bacteria counts were done by the pour plate method on TSA media with serial dilutions in 0.5% sterile tryptone water. Total coliform counts were run in duplicate with MPN and MF techniques as approved and outlined in Standard Methods (13th edition) utilizing the most accurate and sensitive 5/10 - 5/1 - 5/0.1 dilution series as outlined in Table 37 for the MPN technique and the MF technique without enrichment. Fecal coliforms were run in the approved MF mode without enrichment. Fecal streptococci were run in the approved MF mode with prior enrichment in m-PYC enrichment broth for 3 hours.

All values as number per 100 ml.

EXPERIMENT XIII
(November 1975 - September 1976)

Background

Since our initial attempt at higher density planting levels using two ponds failed (Experiment X - fall chinook), Experiment XIII was designed to repeat Experiment X, but using only a single pond (North Pond).

Spring chinook salmon from the Trinity River Hatchery were made available by the California Department of Fish and Game for this study. In contrast, fall chinook salmon from the Iron Gate Hatchery on the Klamath River were used in all but one previous chinook experiments.

In previous experiments using fall-run chinook salmon, ponds were drained in May or June, since fall chinook migrate to the estuaries at this time in local streams (Taniguchi 1970). Reimers (1973) showed that fall chinook salmon in the Sixes River, Oregon, did not migrate out of the estuary into higher salinity waters until autumn. Taniguchi (1970) and Bailey and Gibbs (1954) both indicated fall chinook migrants did not leave the Mad River estuary (Humboldt County) until mid-July. Experiment XIII was designed to have a group of chinook salmon reared at the HSU Hatchery be released into Jolly Giant Creek in May marked left pectoral (LP), a group of unmarked chinook salmon trapped out of North Pond released in spring and summer, and the final group of fish either trapped or taken from the pond by draining, released in August or September with a right pectoral mark (RP). To provide the higher salinity water presumably required by these fish in their estuarine residence, the salinity of the ponds was to be increased throughout the summer.

About 12,000 salmon were retained in the hatchery for this program, as well as for a source of fish for analysis of gill enzyme levels (smolting studies) and for Vibrio-immunization studies. The remainder of the salmon available (30,000) were planted into North Pond.

Pond Operation

No major pond modifications were made for this experiment. There was, however, some re-arranging of artificial reefs and the addition, along the north bank, of a series of reefs consisting of shredded plastic grain sacks weighted with bricks. A small extension of the area covered by oyster shell in the western area of the pond was made to allow better access to mid-pond drainage channels and to the center portion of the pond. The southwest portion of the pond bank was bird-proofed by making a steep bank and extending netting out over the pond bank. This completed bird-proofing of pond banks except for the western bank which has always been very steep and thus not attractive to wading-type fish-eating birds.

North Pond, drained on 17 November 1975, remained empty until 25 November, when oxidation pond effluent was mixed with Humboldt Bay water to provide a mixture near 15 o/oo salinity. In early December, the pond was partially drained to allow the addition of more oxidation pond water in order to produce a salinity of near 10 o/oo, target level for the experiment. No major additions or subtractions of water into the ponds occurred, except for some minor released to reduce elevated pond levels caused by seasonal rainfall, until July and August when saltwater was added to slowly increase salinities as required by the experiment.

Physical-Chemical Properties

Water properties were studied in the same manner as for Experiment XII (Table 2). North Pond received a very high amount of wastewater effluent during this experiment, roughly 1 part seawater to 1 part wastewater during early stages of pond conditioning (Figure 10). The ratio then changed to 2 parts wastewater to 1 part of seawater during January and February. Further reduction in salinity occurred from rainfall with salinities around 8 ppt on introduction of chinook

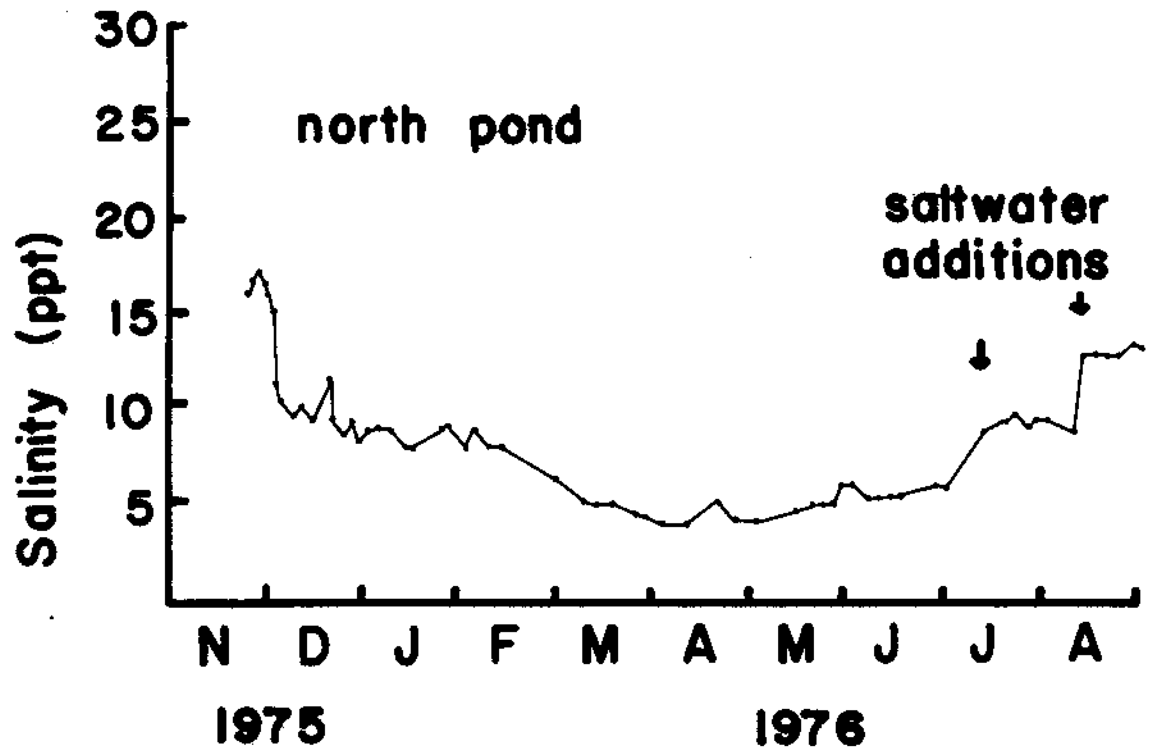


Figure 10. Salinity, surface water, North Pond, November 1975 - August 1976 (Experiment XIII).

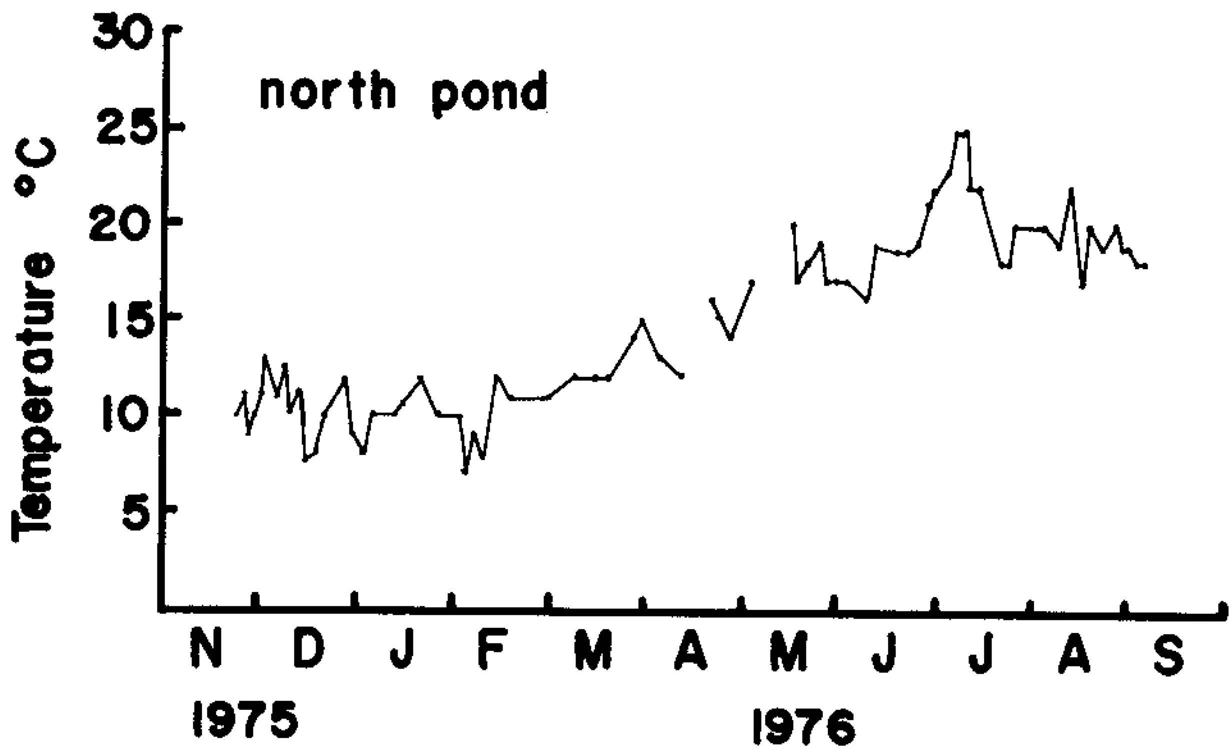


Figure 11. Temperature, surface water, North Pond, November 1975 - August 1976 (Experiment XIII).

fry on February 8. Water temperatures began at about 10^{o} C, rising steadily to near 20^{o} C during June, then jumping sharply to very warm waters, especially by late evening, of over 25^{o} C in early July (Figure 11). This extreme warming was caused by a very long period in late June and early July of no cloud or fog cover, usually normal by this time of the year, coupled with warm air temperatures. From mid-July through August, heavy cloud cover resulted in relatively normal summer temperatures for local shallow estuarine and lagoon habitats (18-20^{o} C). Hydrogen ion concentrations were very stable during most of the rearing period, fluctuating a little below a pH value of 8 (Figure 12). In late June and early July, the pH regime rose suddenly to around 9. This change in pH was correlated with a change in phytoplankton community. During most of the experiment, pond was an amber color, and fairly clear (Figure 13), but in late June it changed almost overnight into a green color with much lowered visibility. This phytoplankton was identified as primarily Chlorella, with small amounts of Chaetoceros. The bright sunlight, high temperatures and increased number of phytoplankton increased the rate of photosynthesis. This caused a pronounced change in the dissolved oxygen regime in late June (Figure 14). It is likely the lowering of the oxygen level to near 5 mg/l signalled a change in phytoplankton community, with a new vigorous population then producing an excess of oxygen. Early oxygen levels at first fluctuated widely with pond water additions and subtractions, maintaining high levels (13 - 15 mg/l) in early winter, before starting a slow downward trend during the time the fish were in the pond (10 to 6 mg/l from February to late June). August showed stable values around 10 mg/l of dissolved oxygen.

Nitrogen as ammonia, nitrite and nitrate, all showed extreme fluctuations in the early phase of the experiment when pond water stabilization was occurring (November and December). High values of ammonia as measured in Hach index units,

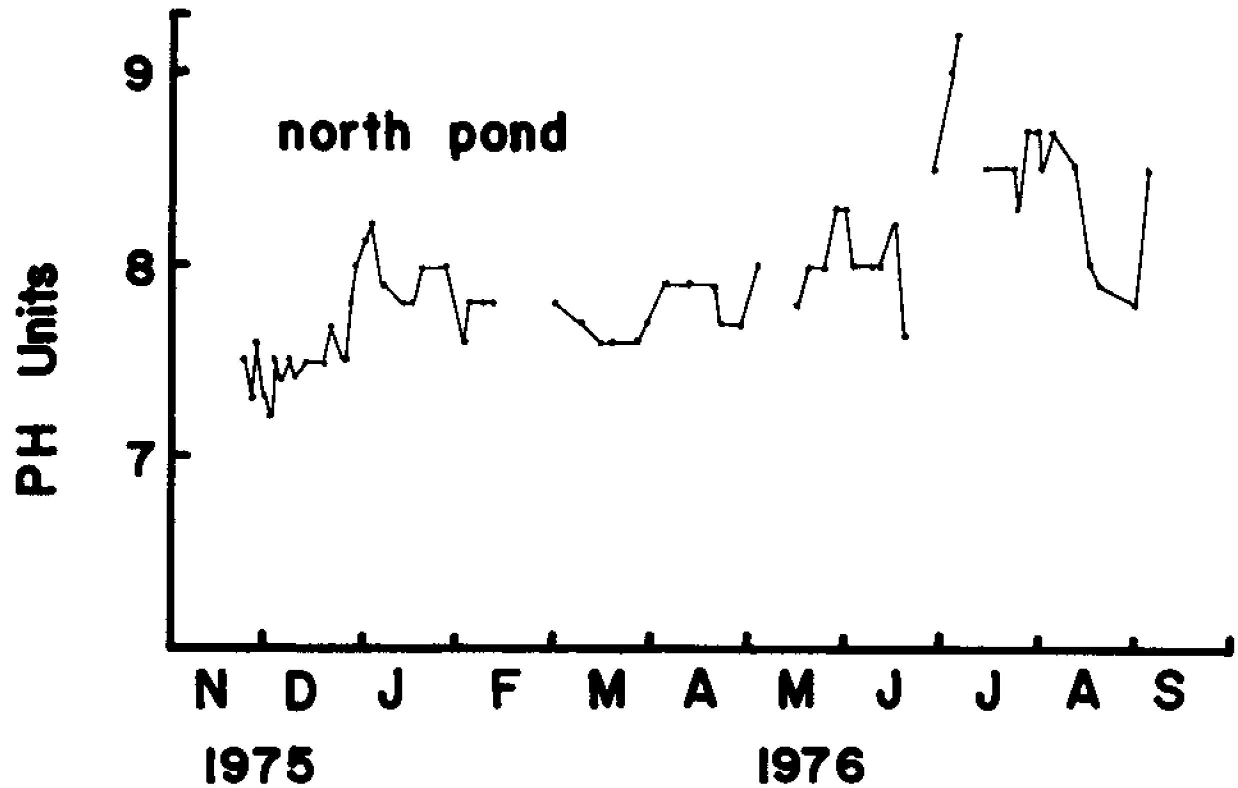


Figure 12. Hydrogen ion concentration, surface water, North Pond, November 1975 - September 1976 (Experiment XIII).

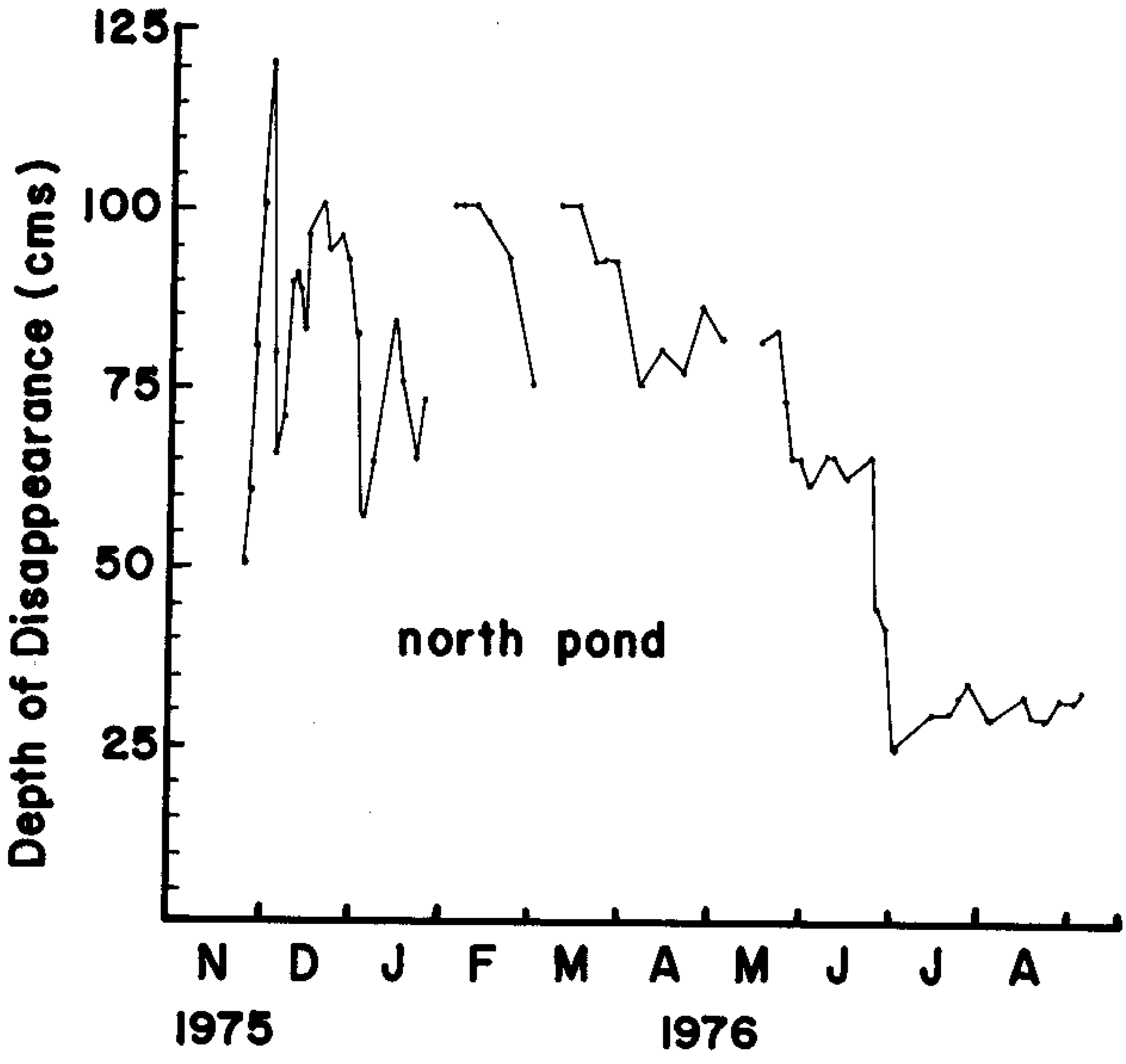


Figure 13. Clarity, North Pond, November 1975 - September 1976 (Experiment XIII).

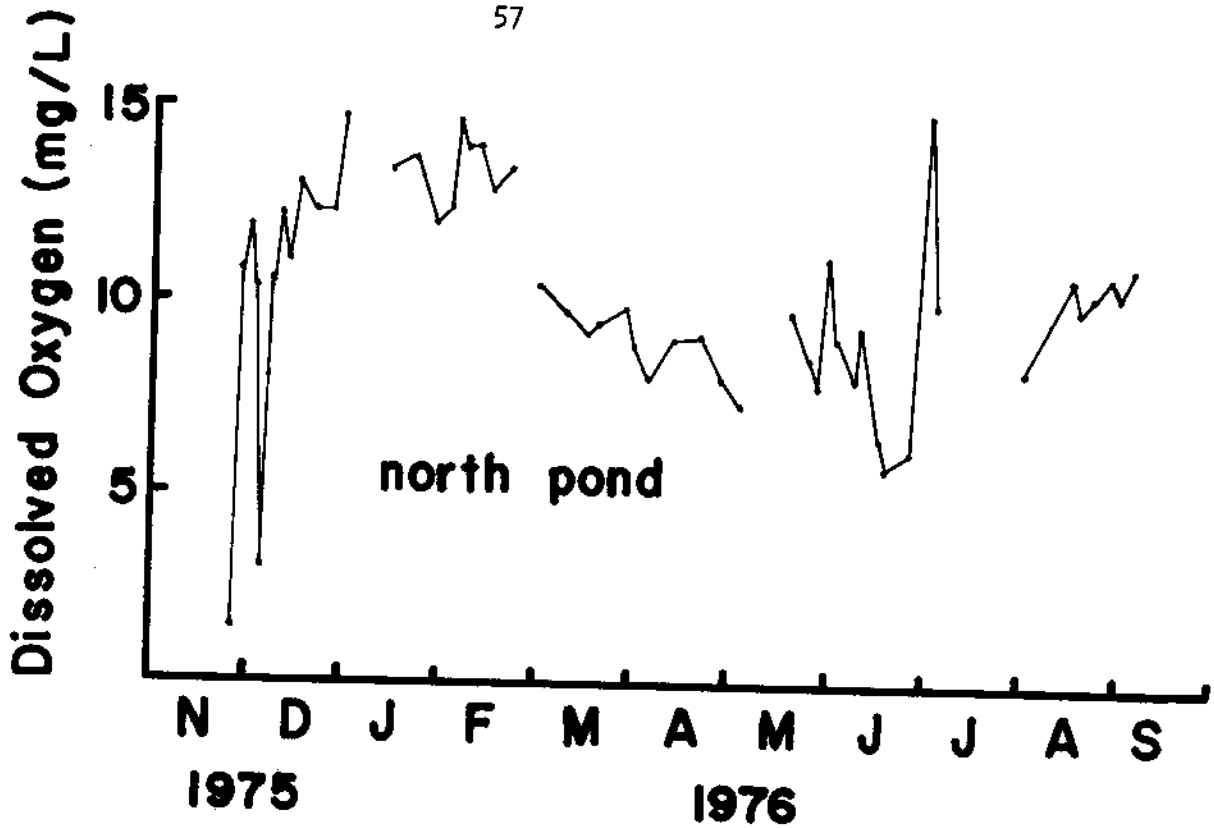


Figure 14. Dissolved oxygen, North Pond, November 1975 - September 1976 (Experiment XIII).

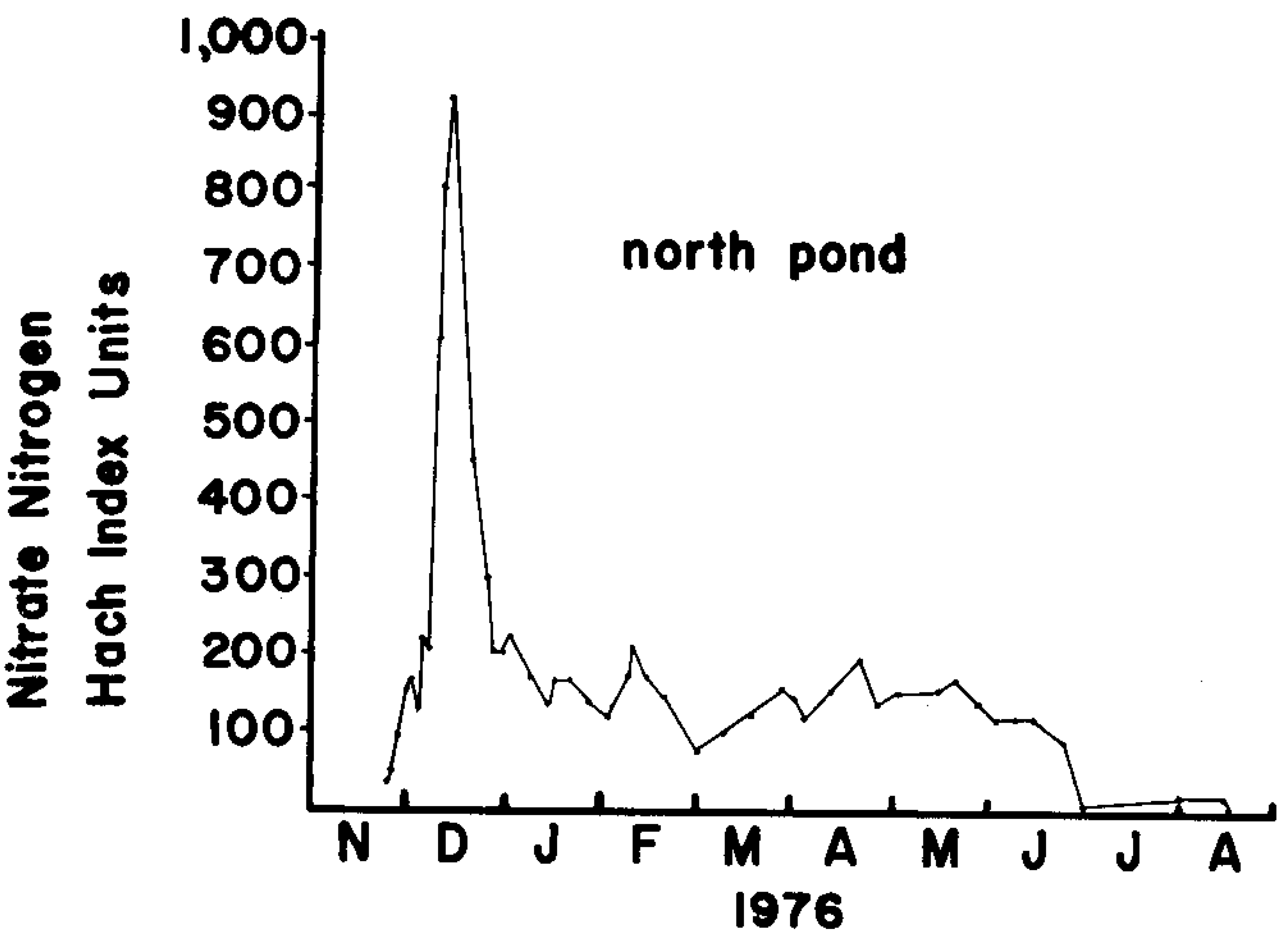


Figure 15. Relative nitrate nitrogen, North Pond, November 1975 - September 1976 (Experiment XIII).

were present only during water stabilization (Table 23), with low values during periods of fish rearing. Nitrate initially climbed sharply, probably due to death of freshwater algae introduced with the wastewater from the oxidation pond, since nitrate values were initially low (Figure 15). With no pond water manipulations during the experiment, a stable system developed with nitrate remaining around 100 mg/l Hach units. This nitrate value disappeared with the change in phytoplankton population in late June. Apparently the new growing phytoplankton consumed all pond nitrate. Nitrite was always low, in the period 25 November - December 31, with most values within the range of 0-24-0.55 mg/l Hach units (N = 6), and other values less than 0.1 mg/l (N = 3). In the period 1 January - 25 June 1976 ammonia values were all less than 0.1 mg/l Hach units (N = 12).

During the experiment, alkalinity ranged from 122-150 mg/l (N = 7).

Supplemental Feeding

A total of about 600 pounds (wet weight) of supplemental feed was given to spring chinook salmon (Table 24). Supplemental feed consisted mainly of live *Daphnia* obtained from studies or harvesting methods from the oxidation pond (Harrington, J. 1976, personal communication). Feeding *Daphnia* was primarily to monitor the distribution and behavior of the salmon rather than increase production since there appeared to be sufficient natural feed in the pond to sustain adequate growth. Small amounts of frozen, ground Dover sole carcasses and fresh crab offal were also used to observe feeding behavior of the chinook salmon on this type of material. More feed was given during May and June than during the winter months. On 28 June, the fish stopped feeding, at least at the surface, with the development of a dense phytoplankton bloom as noted earlier, and little additional food was given after this date.

Table 23. Ammonia nitrogen, North Pond, 25 November 1975 - 25 June 1976 (Experiment XIII).

Class interval ($N-NH_3$ mg/l Hach units)	Period of pond stabilization (25 Nov - 31 Dec 75)	Period of fish rearing (1 Jan - 25 Jun 76)
0.0-0.49	0	7
0.5-0.99	1	3
1.0-1.49	2	2
1.5-1.99	1	0
2.0-2.99	0	0
3.0-8.00	5	0
Number determinations	9	12

Table 24. Wet weight in pounds of supplemental feeds, chinook salmon, North Pond, 11 February 76 – 27 June 1976 (Experiment XIII).

Feeding Period	Type of feed		
	Live *Daphnia*	Ground, frozen, Dover sole carcasses	Fresh crab offal
11 Feb - 6 May	253		
7 May - 27 Jun	274	42	40
Subtotal	527	42	40
Grand Total	607		

Survival Rates

On February 9, 1976, 30,000 spring chinook fry averaging 40 mm in fork length and 0.6 grams in weight were placed into North Pond. In order to obtain comparable rates of survival from this experiment which could be compared to fall chinook salmon survival rates from past experiments, a mark-and-recapture study was made on May 8, 1976 (Table 25). A total of 1,639 salmon, captured by seine, were marked by removal of the right pectoral fin (RP) and released in the pond. Subsequent sampling of the pond by seine and dip-netting, plus examination of salmon taken by active fishing of the Hume-trap from South Pond, allowed several estimates of the population using simple marked-to-unmarked ratios (Table 26). On July 17, chinook salmon were seined from six 4-square meter pens, marked by removal of the adipose fin (AD), and planted into two locations. A sample from the pond gave an additional estimate of size of the population by use of a marked-to-unmarked ratio (Table 26).

Survival of spring chinook salmon from May through July varied from an estimated 77 percent on May 8 to a low of 17 percent on July 17 (Table 27). The estimate of 77 percent on May 8 was undoubtedly too high since the Schnabel technique produces only good estimates with many more trials than could be completed. Thus additional sampling on 14 May, which added to the Schnabel data, probably produced a more accurate estimate (60 percent). No abnormal conditions were recorded in the six days between May 8 and May 14, giving no reason to believe any undue mortality had occurred in either marked or unmarked salmon during this interval. In the period May 14 - 20 the estimated number of salmon in the pond from seven separate point-estimates ranged from 60 to 37 percent (Table 27). Any of these estimates were higher than any previous survival rates for chinook rearing experiments conducted during a comparable spring season. The degree of improvement in survival rate from the best prior experiment was in the range of 6 to 33 percent.

Table 25. Estimates of size of spring chinook salmon in North Pond, May, 1976, using Schnabel[1/] mark-and-recapture technique (Experiment XIII).

Date	Trial number	Number fish caught (C_t)	Marked fish at large (M_t)	Marked fish re-captured (R_t)	C_tM_t	ΣR_t	ΣC_tM_t	Estimate of number of fish in pond [2/] [3/] $\frac{\Sigma C_tM_t}{R + 1}$
May 8	1	264	0	0	0	0	-	-
	2	432	264	0	114,048	0	114,048	-
	3	316	696	22	219,936	22	333,984	14,521
	4	314	1,012	3	317,768	25	651,752	25,067
	5	313	1,326	21	415,038	46	1,006,790	22,698
May 14		236	1,639	36	386,804	82	1,453,594	17,728
May 18-19		1,291	1,639	167	2,115,949	249	3,569,543	14,335
May 20		407	1,639	68	667,073	317	4,236,616	13,364

1/ Method outlined in Ricker, W. E. 1975. Computation and interpretation of biological statistics for fish populations. Fish. Res. Bd. Canada, Bull. 191, 382 pp.

2/ 95% confidence limit on range of x (recaptures): $X + 1.92 \pm 1.960 \sqrt{x + 1}$.

3/ As removal of fins from small fish is difficult, especially when they are also poor quality (pinheads), mortality would be high when put back into pond. Therefore, pinheads were not marked, nor counted in the number of fish caught (C_t).

Table 26. Estimates of number of spring chinook salmon in North Pond, May, 1976, using marked to unmarked ratios in single samples of fish (Petersen or Lincoln index) (Experiment XIII).

Date	Number of fish in sample (A)	Number of marked fish in pond (B)	Number of marked fish captured (C)	Estimate of number of fish in pond (A)(B)/(C)	
				Small fish excluded	Small fish included
May 14	236	1,639 1/	36	10,745	
	317	1,639	36		14,432
May 18-19	1,291	1,639	167		12,670
May 20	407	1,639	68		9,810
July 17	140	154 2/	4	5,390	
	170	166 2/	4		7,055
	140	1,639	24	9,560	
	170	1,639	24		11,610

1/ Total number of salmon with right pectoral fin removed placed into pond on 8 May (See Table 25).

2/ Fish from six 4-square meter pens removed, adipose fin removed, placed into pond at 2 points and 2 seine samples taken to obtain marked-to-unmarked fish.

Table 27. Estimated number of spring chinook salmon in North Pond during May-July, 1976, as determined by mark-and-recapture techniques, and number of salmon recovered on draining pond, (Experiment XIII).

Date of study	Schnabel technique (small fish excluded)	Petersen technique		Estimated percent survival
		Small fish included	Small fish excluded	
May 8	23,000			77
May 14	18,000	14,000	11,000	60-37
May 18-19	14,000	13,000		46-43
May 20	13,000	10,000		43-33
July 17		7,000	5,000	23-17

Reef Studies

As part of continuing investigations on the potential of under-water reefs to enhance growth and survival of pond-reared juvenile salmonids, groups of salmon were reared in pens fitted with two kinds of structures:

1. New Zealand flax plants

New Zealand flax plants obtained from University construction sites were employed in two pens (Table 28). Roots and fronds of each plant were loosely bound with nylon cord. As the plant's roots were heavier than water, each unit remained on the bottom without weights. Two plants of about six feet in overall length were used in each pen. These plants were utilized as construction material by native New Zealand people because of the large amount of fibrous materials in all parts of the plant. It appeared reasonable to assume that this same property would be useful as a substrate for benthic organisms. A number of these plants have been used for landscaping around project buildings so that trimmings will be always available for underwater reef construction.

2. Sock-rock reefs

The second type of underwater structure utilized mainly inert materials. Sections of tubular plastic mesh about 50 cm in length and 10 cm in diameter were filled with substrate material, weighted at one end with a piece of brick and buoyed at the other with a plastic float. The units stood vertically in the water. Substrate material consisted of pieces of burlap or upholstery scraps (cotton and plastic). Substrate material consisting of about 50 small live oysters per unit were also employed.

Two different planting densities were selected in reef-pen studies (Payne pen, Figure 1). "Inside" locations next to the fish pond bank were supplied with 50 salmon each. These pens are subject to poor circulation and to seepage of oxidation pond water. "Outside" pens were located away from the pond

Table 28. Survival rates and size of spring chinook salmon recovered from 4-square meter pens, northwest corner of North Pond, 17 July 1976 (Experiment XIII).

Pen No.	Location[1/]	Type of Reefs	Number Planted	Number Recovered	Percent survival	Other fish
1	Inside	None	50	13	26	1 sculpin
3	Inside	13 plastic mesh socks filled with burlap and scrap cloth	50	20	40	4 stickleback
5	Inside	2 New Zealand flax plants	50	29	58	8 stickleback 1 goby
Total Inside			150	37	37	
2	Outside	2 New Zealand flax plants	100	37	37	
4	Outside	7 plastic mesh socks filled with small live oysters	100	33	33	3 stickleback
6	Outside	None	100	34	34	3 stickleback
Total Outside			300	106	35	
Total Inside Plus Outside			450	166	37	

1/ Three pens in contact with pond bank recessed, while three pens not in contact, extend about one meter into pen, and thus receive ambient pond waters.

bank and are subject to water circulation from the fish pond as the pens extend their full length into the pond. "Outside" pens were seeded with 100 salmon per pen.

We monitored the activity of fish in these pens during the experiment by feeding live Daphnia. The fish showed the same vigorous growth and feeding behavior as pond-reared fish. They also reflected the stress from high water temperatures and associated water quality changes in late June and early July by decreased feeding and activity. It was always possible, however, to attract feeding fish to the surface. The appearance of thin, lethargic fish in mid-July suggested that the experiment be terminated at that time in order to obtain some information from the study. Consequently, on 17 July 1976, the pens were seined and all fish placed in 1,000 gallon tanks. Each fish was subsequently weighed and measured, the right pectoral (RP) fin excised, and returned in equal portions to each corner of North Pond.

Survival in the pens ranged from 26-58 percent, with an overall rate from all six pens of 37 percent. This was higher than survival of pond-reared fish (Table 27). This result is consistent with all past experiments in having survival of pen-reared fish higher than pond-reared fish. The average size of pen-reared fish were slightly smaller than the size of salmon obtained from the ponds by seining at the same time (Table 29). Visual observations in late June strongly suggested that some salmon in the pens had reached 90-100 mm. Undoubtedly the high water temperatures in late June reduced the salmon's natural defense mechanisms against disease. We assume that salmon died of vibriosis, although positive confirmation was not made due to lack of personnel during summer at our fish pathology facilities to conduct the tests. Fish with obvious hemorrhaging were noted while measuring of pen-reared fish, and it is very clear that the larger fish definitely had more serious external evidences

Table 29. Length and weight of spring chinook salmon recovered from 4-square meter pens, northwest corner of North Pond, 17 July 1976 (Experiment XIII).

Pen 1/ No.	Fork Length (mm)			Weight (gm)		
	Min	Mean	Max	Min	Mean	Max
1	55	64	73	2.4	3.2	5.1
3	50	61	78	1.5	3.0	5.0
5	52	62	83	2.1	3.2	6.8
2	45	60	88	1.5	3.1	7.8
4	45	57	77	1.5	2.6	3.8
6	48	58	77	1.6	2.8	5.0

1/ Location and modifications of each pen shown in Table 28, as well as number of fish recovered.

of disease. About 8 percent of pen-reared salmon were infected to the point where obvious external symptoms could be readily detected (Table 30).

There was some indication that underwater reefs in these pens improved survival. For both the inside and outside location, pens with New Zealand flax plants had the highest survival (Table 28), and also produced the largest fish (Table 29). No meaningful differences in growth or survival occurred between pens on the inside positions and those on the outside positions, although variability in survival between the pens was greater for inside than outside pens (Table 28), but the reverse appeared for size (Table 29). Thus, it seems more likely that water quality probably was the most significant factor in determining growth and survival between pens. Explanations as to the increased survival in pens as compared to fish reared in the pond remain speculative.

Salmon were reared in 4-square meter pens (Sharp pens, Figure 1) at a density of 100 fish per pen. Two of the pens developed holes during the seven month rearing period. Recovery in September in the remaining two pens was: over gravel, 3 percent and over oyster shell, 1 percent, rates much higher than for pond-reared fish.

Growth

No systematic trapping of samples of spring chinook salmon during Experiment XIII was carried out due to lack of manpower. There were, however, a number of samples of salmon from North Pond which gave some rough picture of the growth during pond rearing (Table 31). Samples of salmon were obtained by use of a small seine near the headgate structure for downstream-migrant studies (Del Sarto 1976), and for samples of larger fish for gill enzyme analysis as part of smolting studies. Samples were also available from active fishing by the Hume trap which was moved on May 18 from South Pond, and placed in operation in slot behind North Pond headgate. The trap caught chinook salmon until

Table 30. Number, percent, and length of spring chinook salmon with obvious hemorraghing, 1-square meter pens, northwest corner of North Pond, 17 July 1976 (Experiment XIII).

Pen[1/] No.	Number recovered	Number hemorraghing	Size of salmon with hemorraghing		
			Min	Mean	Max
1	13	0			
3	20	4	60	67	78
5	29	3	60	65	65
2	37	2	69	69	70
4	33	3	60	69	77
6	34	1		48	
	166	13			

1/ Location and modification of each pen shown in Table .

Table 31. Growth in length and weight of spring chinook salmon, Feb - Sept 1976, North Pond (Experiment XIII)

Date	No. Fish	Fork length (mm)			Weight			Sampling method	Number per pound[2/]
		Min	Mean	Max	Min	Mean	Max		
Feb 9	-		40			0.6		Dip net, hatchery	825
Mar 15	19[1/]	35	47	55	0.3	1.0	1.8	Seine, pond edge	453[1/]
Mar 30	20	40	48	60	0.6	1.6	3.5	Seine, near headgate	284
Apr 12	20	43	50	56	0.8	1.3	1.9	Seine, near headgate	349
Apr 30	25	40	48	55	0.5	1.3	2.8	Seine, near headgate	349
May 14	20	47	55	70	1.0	1.9	3.8	Seine, near headgate	239
May 18	70					1.4		Hume trap, headgate	324
May 19	84					1.2		Hume trap, headgate	378
May 20-26	60					1.7		Hume trap, headgate; and seining pond	267
May 27	40					2.5		"	182
May 29-Jun 8	30	57	72	93	2.2	4.7	9.1	Hume trap, headgate	97
Jun 8	24					4.2		"	108
Jun 17	12	63	71	81	2.0	4.2	6.6	Seine, near headgate	108
Jun 21	8	50	66	92				Hume trap, headgate	
Jun 23	14	57	68	75	2.0	3.0	3.8	Hume trap, headgate	151
Jun 24	10	55	63	73	2.2	4.7	3.9	Seine, pond periphery	174
Jul 17	166	45	60	88	1.5	3.0	7.8	6 4-square meter pens	151
Jul 17	15	60	69	79	2.4	3.5	4.7	Seine, pond periphery	130
Sept 3	12	66	81	104	3.6	6.8	12.7	2 4-square meter pens	67
Sept 3	4	63	69	76	3.8	4.4	5.0	2 4-square meter pens	103

1/ 1,132 salmon were seined from 3 locations around the pond periphery, with the total weight of these fish 2.5 pounds (1.0 gm mean wt; 453 fish per pound). A random sample of 19 fish weighed individually for weight also showed a mean weight of 1.0 gm.

2/ Commonly employed unit of size of salmon in west-coast salmon hatcheries.

July 1976 (Table 32). Average weight was taken periodically on fish taken in the Hume trap.

A general trend of increased growth throughout the rearing period is apparent from the accumulated growth data (Table 31), however, the picture is erratic reflecting sampling biases, as well as the complexity of the life history and physiology of chinook salmon (Hoar 1976, Scholz et al. 1975). Mean length and weight reached a maximum in late May and early June (72 mm and 4.7 g from fish taken in Hume trap). This size is only slightly larger than the mean size attained by fall chinook in early May 1974 (Table 33) and in 1975 (about 68 mm and 3.0 gm). The much smaller size of salmon recorded in samples in the April - mid-May period in 1976, was felt to be sampling bias, since in late May and June fish of much larger size than the average in the pond were clearly seen at less than a foot distance when feeding live Daphnia from a raft moored directly in front of the pond headgate. This is the deepest area in the pond, and over a forced-air manifold located in the pond's fish collecting sump. Two of these larger fish appeared in the samples taken during smolt trapping (26 May: 130 mm, 25.3 gm; 6 June; 130 mm, 25.2 gm).

During most of the experiment, "pinheads" (small fish obviously very thin and debilitated) were quite abundant. A similar group of small fish was also obvious in the companion lot of spring chinook salmon reared in freshwater at the HSU hatchery. As previously discussed, pinheads were excluded from the mark-and-recapture studies on the size of the salmon population in the pond (Table 25, Footnote 3). On several occasions, samples of pinheads were placed into 10-gallon aquaria and fed live Daphnia. Although they readily consumed the daphnids, all fish died in a few weeks. No evidence of bacterial infections could be detected externally. All appearances appeared normal except for the fish's thin condition. Available data on the percent of these fish in the

Table 32. Catch of unmarked and marked (RP) spring chinook salmon in actively fished Hume trap, North Pond headgate, 18 May - 2 June, 1976 (Experiment XIII).

Date	Number salmon trapped Unmarked	RP mark1/	Ratio UM/RP	Salmon trapped but marks not recorded
May 18	797	100	8.0	
May 19	327	67	4.9	
May 20	7	0		
May 21	30	3		
May 22	1	0		
(May 20-22	38	3	12.7)	
May 24	106	23	4.6	
May 25	112	17	6.6	
May 26	42	5	8.4	
May 27	2	2		
May 28	59	8		
May 29	1	0		
Jun 1	1	0		
Jun 2	8	0		
May 27-2 Jun	71	10	7.1)	
Jun 4	98	23	4.3	40
Jun 7	176	60	2.9	
Jun 8	32	5	6.4	
Jun 9	7	2		
Jun 10	50	14		
Jun 11	7	3		
(Jun 9-11	64	19	3.4)	
Jun 12				20
Jun 15	35	14	2.5	
Jun 21	69	15	4.6	
Jun 22	13	6		
Jun 23	6	1		
(Jun 22-23	19	7	2.7)	
Jun 24	0	0		
Jun 28	0	0		
Jun 30	0	0		
Jul 1	60	15	4.0	
Jul 2	41	10	4.0	
Jul 6	8	0		
Jul 7	2	0		
Jul 8	1	0		
Jul 12	0	0		
Jul 13	0	1		
Jul 14	0	0		
(Jul 6-14	11	1	11.0)	
Aug 30 3/	0	0		
Aug 31	0	0		
Sep 1	0	0		
Total trapped	2,098	394	5.3	60
Jul 17 2/	140	30	4.7	

1/ A total of 1,639 salmon with right pectoral fin (RP) excised released into pond May 8-14, 1976).

2/ Seine sample.

3/ Continuous operation, Aug 30 - Sept 1.

Table 33. Length and weight of fall chinook salmon, North and South Ponds, May 7, 1974 (Experiment VII) based on 4-day formalin preserved samples.

Factor	North Pond	South Pond
Sample size	129	134
Fork length (mm)		
Mean	66	68
Range	55-91	57-90
Weight (gm)		
Mean	3.4	4.1
Range	1.7-9.0	1.8-7.3

population was not precise. During mark-and-recapture studies (Table 25, May 8, Samples 1-5, and May 14, Samples 1 and 2) smaller, obviously thin, fish were set aside as "pinheads" but no length measurements were made of a sample of these fish. The size of "pinheads" noted in the recovery of pen-reared salmon on 17 July, indicated that any fish less than 2.0 grams in weight in samples taken after April could be so designated. An examination of all data which could be used to estimate a percentage of pinheads (Table 34) suggested that throughout the experiment about one fifth of the salmon were in this category (excluding earlier periods when all fish were small).

Smolting

With completion of smolt-trapping in South Pond and processing of all coho salmon, the Hume trap was placed into operation in North Pond on May 18, and operated until July 14 when the trap ceased catching salmon (Table 32). About 2,000 salmon were taken in the trap. The initial surge of salmon taken on May 18 and 19, were all small fish, and could be classified as "pinheads" on the basis of size. However, the fish were not thin and debilitated as typical pinheads. Reimers (1968, 1973) has reported downstream movement of small chinook salmon. As the trapping progressed, the number of salmon taken decreased steadily. Unfortunately measurements of length of salmon were not taken in the latter part of this trapping period due to reduced manpower. The fish taken later in the season appeared to be larger but we have no supporting quantitative data.

A thorough analysis of chinook salmon smolting was made by Del Sarto (1976). The study consisted of Na^+ and K^+-ATPase gill enzyme analysis of salmon from the pond and compared to those from the Hume trap, and studying the time of migration of presumed smolts and non-smolts, marked and planted into Jolly Giant Creek above a down-stream migrant trap (Table 35). Although details of these studies will be reported elsewhere, cursory analysis of chinook salmon planted into Jolly Giant Creek caught in a downstream migrant trap, showed

Table 34. Percent of small fish (pinheads or fish less than 2.0 grams) in samples of spring chinook salmon, North Pond, May-July 1976 (Experiment XIII).

Date sampled	Type of sampling		Percent pinheads, or size of fish
Mar 31	Seine		75
Apr 14	Seine		100
Apr 30	Seine		88
May 8	Seine	Sample 1	18
		Sample 2	13
		Sample 3	21
		Sample 4	14
		Sample 5	16
May 14	Seine	Sample 1	23
		Sample 2	31
May 15	Seine		60
May 18	Hume trap		1.4 gms mean wt.
May 19	Hume trap		1.2 gms mean wt.
May 20	Dip net		2.0 gms mean wt.
	Seine		1.8 gms mean wt.
Jun 17	Seine		0
Jul 17	Seine		0
Jul 17	Seine	Sample 1	18
		Sample 2	17
Jul 17	Removal of all fish reared in 4-square meter pens		12 1/

1/ All fish listed as a "pinhead" (usually 1.5-1.7 grams) plus all others weighing less than 2.0 grams.

Table 35. Number and mark of spring chinook salmon obtained by seining pond planted above down-stream migrant trap, Jolly Giant Creek, March-July, 1976 (Experiment XIII).

Date Planted	Number	Mark
Mar 31	271	RP
Apr 14	250	RP + RO
Apr 30	200	RP + LO
May 15	200	LP
Jun 17	100	LP + LO
Jul 17	100	LP + RO
Total	1,121	

RP - right pectoral; LP - left pectoral; RO - partially excised right opercle; LO - partially excised left opercle.

salmon planted June 17 appearing quickly in the trap. Gill enzyme levels in spring chinook salmon were always quite low, and only a few of the larger fish taken in June showed slight increases in gill enzyme activity. Most spring chinook trapped or seined from the pond planted below the Jolly Giant trap were planted from mid-May to early June (Table 36). Final analysis of the experiment will have to wait for adult returns to the creek (roughly 2-4 years).

Chinook Salmon Planted

The decision to not drain North Pond until September reduced drastically the actual number of salmon that could have been planted into Jolly Giant Creek (our designated "home-stream", Scholz et al. 1976). Nevertheless, over 4,000 spring chinook from the pond were planted from March 31 to July 17 (Tables 36 and 37). When ponds were drained only 14 fish were caught, and these were held for observation. About 6,500 salmon reared in the hatchery were also released into the stream in May. Thus the total number of spring chinook released into Jolly Giant Creek from all sources was about 10,500 fish (Table 37).

Causes of Mortality

Identifying precisely the various causes for mortality in juvenile chinook salmon in our experiments in the ponds has always been difficult. In the present experiment, however, at least five sources of mortality can be discussed in some detail. These factors are as follows: water quality, genetically inferior fish (pinheads), bird predation, fish predation, and finally stress-related factors (smolting, high-water temperatures, and disease occurring synchronously).

From February to early May, a very high survival of chinook salmon occurred (roughly 60 percent over a 18 week rearing period), which correlated with no periods of unacceptable water quality values to chinook salmon in physical-chemical parameters monitored. Their was always evidence during this period of

Table 36. Number of unmarked spring chinook salmon planted below downstream migrant trap, Jolly Giant Creek, (2,147 from Hume trap, remainder from seining pond) May-July, 1976 (Experiment XIII).

Date Planted	Number	Remarks
May 18	797	Hume trap
May 19	327	Hume trap
May 26	619	Hume trap, plus fish seined
May 27	661	Hume trap, plus fish seined
Jun 8	359	Hume trap
Jun 15	156	Hume trap
Jun 21	79	Hume trap
Jul 1	73	Hume trap
Total	3,071	

Table 37. Summary of chinook salmon downstream migrants planted in 1976 into Jolly Giant Creek from 1975 brood spring chinook salmon reared in North Pond and HSU hatchery. (Experiment XIII).

Fin Mark	Number	Time of Release	Study	Remarks
LP	6,500 1/		Spring plant - effect of marking	
None	3,071 2/		Spring plant - effect of marking	Table 36
RP	721		Downstream migration study	Table 35
LP	400		Downstream migration study	Table 35
RP	0 3/	Sept	Fall plant - evaluate rearing to larger size, and later planting time.	

1/ Group of salmon reared at Humboldt State University hatchery and released in a single group, thus representing routine hatchery procedures.

2/ Unmarked salmon captured in Hume-trap plus remainder of total seined from pond.

3/ Planned release of larger-sized fish not made as salmon did not survive stress of high water temperatures encountered in North Pond in late June-early July period.

acceptable pond conditions by steady fish growth, and the presence of vigorously feeding fish in all parts of the pond. This period of rearing was analagous to the freshwater feeding stage in natural environments (parr stage). Mortalities suffered during this stage in the pond were related to the presence of inferior fish (pinheads - probably around 20 percent) that were destined to die under any circumstances. Additional losses were from predation by birds and fish.

No specific study on bird predation was undertaken on North Pond during Experiment XIII, but Villegas (1975) during November 1975 when fingerling coho salmon were present in South Pond at a density of about 50,000 per acre (close to the density in North Pond in April-May in Experiment XIII) recorded mainly Forester's Tern (Sterna forsteri) and Bonaparte's Gulls (Larus philadelphia) catching coho. The overall estimated catch by all birds observed was less than 1 percent of the fish in the ponds and would only represent 5 percent of the population if the rate was extrapolated to the entire rearing period. These same species of birds appeared over the ponds during spring, with up to 20 birds appearing over the ponds on several occasions. The birds, however, concentrated on South Pond (coho), not North Pond (chinook). Pond personnel kept the terns and gulls from feeding efficiently during their short appearance. Consequently I feel there was no indication that significant bird predation on the salmon occurred in North Pond and that modifications made to the banks to prevent predation by wading predators was proving successful.

Both staghorn sculpin (Leptocottus armatus) (34 fish) and rainbow trout (6 fish) occurred in North Pond during chinook rearing (Table 38 and 39). Chinook salmon were found in about one-half of the stomachs of a sample of the staghorn sculpin caught. Trout were not sacrificed so that their degree of precation on chinook is assumed the same as that for sculpin. Assuming that the conversion rate (wet weight) from chinook salmon to predator was about 10 to 1, about 7 percent of the salmon probably were consumed by predator fishes (Table 40).

Table 38. Growth and survival of five yearling rainbow trout accidentally introduced into North Pond, May 10, and recovered September 3, 1976 (Experiment XIII[1/]).

Size on 10 May[2/]						Size on 3 September						Mean increase[3/]	
Length (cm)			Weight (gm)			Length (cm)			Weight (gm)			Length (cm)	Weight (gm)
Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max		
12	12	13	17.4	21.5	24.8	23	25	27	168	218	262	13	240

1/ On March 9, 1976, 150 rainbow trout were moved from holding tank in the fish barn to fixed pen in South Pond (mean length 12.4 cm and 22 gm). On May 7, 132 of these fish were removed from South Pond and placed into holding tank in the fish barn. On May 10, 127 of these fish were placed into a temporary holding pen in North Pond. On 17 June, 121 rainbow from the holding pen were returned to fixed pen in South Pond. This discrepancy of six fish is a measure of the maximum number of rainbow trout that escaped into North Pond. This possibility was noted on May 10, when trout were seen jumping at the corner of the pens, and a cover was hastily placed over the pen.

2/ As manpower was limited during the last-minute marking and counting of coho salmon from South Pond on May 7, only the mortalities (5) from rainbow trout jumping out of the holding tank were measured for length.

3/ For a 114 day growing period, these fish average 1.9 grams per day per fish increase in weight. On May 25, a rainbow trout was captured in seining the pond for chinook salmon samples. The fish was 160 mm and 53.7 gm in weight. The size of this fish is in agreement with this rate of growth (15 days x 1.9 gm/day + 21.5 av. wt on May 10 = 50 gm).

Table 39. Size of staghorn sculpin (*Leptocottus armatus*) taken in 1-meter, single-opening, cylindrical traps, 17 March - 2 August, 1976, North Pond (Experiment XIII).

Date trap examined	Number caught	Total length (mm)	Mean length
17 Mar	4	-	
27 Mar	1	-	
30 Mar	7	-	
7 Apr	4	56, 80, 92, 95	81
10 Apr	4	-	
14 Apr	3	68, 78, 100	82
21 Apr	2	100, 120	110
25 Apr	1	85	85
13 Jul	1	145	145
14 Jul	1	160	160
15 Jul	1	125	125
30 Jul	3	100, 120, 135	118
2 Aug	2	115, 155 1/	135
Total	34 2/	56 - 160	107

1/ Hemorraghing around base of fins.

2/ No sculpin recovered 3 September 1976 when pond drained.

Table 40. Method of estimating number of chinook salmon consumed by predatory fish, North Pond, February-June, 1976 (Experiment XIII).

A. Estimate of live weight in grams of predator fish produced

Species	Number of fish	Live weight of fish produced (gm)	Remarks
Staghorn sculpin	34	578	Assuming mean length of 11 cms, and mean weight of 17 grams
Rainbow trout	6	1,232	Data from Table 38
Total Weight		1,810	

B. Estimate of salmon consumed

$$\frac{\text{(Weight of predator flesh produced)(conversion ratio)}}{\text{(average size of salmon consumed)}} = \frac{(1{,}810)(10)}{(3.0)} = 6{,}000$$

Adjusted assuming only half the diet was salmon and for five months feeding period (February-June):

$$6{,}000(0.5)(5/7) = 2{,}000$$

Percent of salmon planted consumed:

$$\frac{2{,}000}{30{,}000} = 6.7$$

A listing of the causes of mortalities during the parr stage of spring chinook salmon reared in North Pond from February-early May indicated that most of the salmon could be accounted for (Table 41). The survival could have been about 5-10 percent higher had not rainbow trout been allowed to escape into the pond.

As noted previously, during early summer (late June and July), a very unusually long, hot, cloudless weather pattern caused steadily rising pond water temperatures. This triggered a dramatic shift in the phytoplankton population, and on June 28, 1976, the pond changed to a green color from a bloom of *Chlorella.* One day later, all fish stopped feeding, and essentially did not resume any obvious vigorous feeding during the remainder of the experiment. By the end of August, virtually all of the spring chinook salmon that were retained in the pond by late June were lost. The salmon during summer were under stress from a combination of rising water temperature and smolting. The two factors working in conjunction induced vibriosis, from which the salmon were not able to recover even when pond water temperatures returned to a more normal summer regime. The details of our study leading to this conclusion follows.

Examination of length-frequency data for periods from late May onward, strongly indicated that with the onset of down-stream migration, and presumably concurrent adaptation to a slowly increasing salinity regime, larger fish were disappearing from the population. Salmon taken from the pond in July and September were only slightly larger than salmon appearing in late May samples. Only a single fish over 100 mm was recovered from July and September samples. An early indication of this phenomenon was one of the larger fish taken in the Hume trap (3 June; 130 mm, 25.2 gm) showing caudal hemorraghing, and subsequently was confirmed as infected with *Vibrio*. The phenomenon was quite evident in the larger average size of fish with obvious hemorraghing as compared to all other pen-reared salmon examined on 17 July 1976 (Table 30). Under ordinary

Table 41. Gross estimates of the percentage losses in spring chinook salmon parr reared in North Pond, February-early May, 1976 (Experiment XIII).

Factor	Percentage of original 30,000 fry planted
Estimated survival	60
Inferior fish (pinheads)	20
Fish predation	7
Bird predation	3
Unaccounted or from estimating error	10
Total	100

conditions, a salmon population entering higher-salinity water through an estuary would have some normal average rate of susceptibility to indigenous Vibrio in such waters; however, the elevated water temperatures in late June added additional stress that even non-smolting fish could not combat in resisting the disease. This probably was the reason for virtually no mortalities in chinook salmon taken in the Hume trap in May as opposed to fish taken in June which showed high mortalities when held in tanks.

Chinook salmon from North Pond reared in North Pond water innoculated with Vibrio at a relatively low concentration, produced no mortalities over a 21 day challenge at water temperature levels existing in the pond (Table 42). Water temperatures were fluctuating between 18 and 20^{o} C from mid-May to late June (Figure 11). The chinook salmon apparently were able to resist vibriosis in the pond system as non-smolting fish at temperatures under roughly 18^{o} C. Even at elevated temperatures the salmon showed considerable resistance as indicated by the existence of a substantial population of fish through July. Therefore, some simple, inexpensive technique to insure that pond water temperatures remain below 22-23^{o} C maximum over short periods or below 20^{o} C over extended periods would enhance summer rearing of chinook salmon. This may be accomplished simply by hanging inexpensive strips of synthetic material across the pond, or developing a small area of cool water in the pond sump by use of a recirculating pump and a water chiller. Standard drug therapy (terramycin, oral vaccines etc.) just prior to the occurrence of elevated water temperatures would appear feasible in future attempts to rear chinook salmon through summer periods, even though some years conditions might not require it (Allen 1975).

Reimers (1973) reported that populations of fall chinook salmon reached a maximum in the Sixes River of Oregon by early July, then dropped gradually to a minimum that remained fairly stable until movement of the salmon into the ocean in early winter. Reimers suggested that food may have been a limiting factor.

Table 42. Vibrio bacteria challenge of spring chinook salmon 10-gallon aquaria fitted with forced-air aeration and cotton filters, June 23-July 13, 1976 (Experiment XIII) (Fish placed into tanks June 16, and on June 23, 1 ml of 3-day old culture of 8.0×10^4 organisms per ml added to tanks) (Fish fed OMP).

Factor	Tank Number 1	Tank Number 2
Type of water	North Pond	North Pond
Vibrio concentration	8.0×10^4/ml plus ambient	8.0×10^4/ml plus ambient
Salinity ppt	5.5	5.5
Temperature °C range June 21-23	15.5-18.5	16.0-18.5
Number of salmon tested		
Unmarked (UN)	5	5
RP-mark (previous mark)	5	
LP-mark (marked just prior to testing)		5
Total per tank	10	10
Number of mortalities (21 day period)	0	0 1/

1/ One fish died when it became lodged in siphon tube of filter system.

If average estuarine temperatures in the estuary reached 20-22° C range or higher where the salmon resided, our data indicates that vibriosis may also have been involved in reducing the population.

Miscellaneous Observations

Only two non-target fish species (stickleback and rainbow trout) were obtained from South Pond at the termination of Experiment XIII on 3 September 1976. About 4,000 stickleback (Gasterosteus aculeatus) averaging 1.1 grams in weight were recovered. All sizes of stickleback were in the sample, including some very large individuals (70-80 mm TL). The second non-target species was rainbow trout. An examination of our records indicated that a maximum of six rainbow trout had escaped from a temporary holding pen into which a group of these fish had been placed on 10 May 1976 (Table 38). Five extremely deep-bodied, small-headed, very silvery rainbow trout were removed from the pond. The sixth fish had been previously seined from the pond (Table 38, Footnote 3). Without competition, and with an unlimited food supply, including presumably moribund chinook salmon, these fish over a 114 day rearing period, increased in weight over tenfold, with an average daily increase per fish of 1.9 grams. Two fish showed some slight erosion of the outer margins of the paired fins, while another fish had one small reddish patch (5 sq mm) near the lateral line. Another specimen had missing scales in two closely parallel lines on the sides of the body, indicating a recent attack by a large avian predator, a likely occurrence since the pond was drained over a two-day period, allowing easy access to the fish by wading birds.

No staghorn sculpin were found on draining North Pond on 3 September 1976. There were, however, 34 sculpin taken in sporadic trapping throughout the experiment (Table 39). As five sculpin were taken in traps during late July-early August, the traps appeared effective in controlling the sculpin. Sculpin could also have died from vibriosis, but personnel were not available to run tests on trap-caught fish.

Water Quality

Since North Pond water was pumped into South Pond when the pond was dewatered at the end of rearing Experiment XIII, a bacteriological survey, as required for meeting public health requirements prior to bay discharge, would not have been necessary. Fortunately, personnel at our fish pathology laboratory were just organizing for a scheduled survey of bacteriological parameters of Humboldt Bay and were able to include a series of samples from North Pond and some adjacent waters (Table 43). Water samples from Jolly Giant intertidal area and Humboldt Bay were taken at a low tide level, and thus would represent a period of peak bacterial concentration from incoming freshwaters. Fish culture water and Humboldt Bay water showed the highest water quality (lowest counts) for those parameters currently used in public health monitoring (total coliform, fecal coliform). Jolly Giant Creek water showed the poorest water quality but still of good quality (MPN fecal coliform - 110). Oxidation pond water being discharged into Humboldt Bay on 1 September 1976, and upper estuarine water of Gannon Slough, were intermediate in water quality. The low counts of total coliforms and fecal coliforms in fish pond waters probably resulted from two factors. Fish ponds with high algal blooms are good wastewater treatment systems so that the retention of the oxidation pond effluent for a long period of time would be expected to produce high water quality with regards to these parameters. The low counts relative to adjacent waters, however, may be due to the lack of introduction of non-human coliforms since few birds rest on fish pond waters in contrast to adjacent waters where heavy concentrations of birds always occur. Three of the waters sampled showed counts of fecal streptococci in the 100-200 range contrasted with a count of 1,400

Table 43. Results of bacteriological survey of North fish pond and adjacent waters, 1 September 1976.

Parameter and Technique[1/]	Oxidation pond (effluent entering Humboldt Bay	North fish pond (off headgate)	Jolly Giant Creek (off Northern Pacific RR)	Humboldt Bay (Gannon Slough near HWY 101)
Total Bacteria Plate Count	650,000	1,750,000	3,160,000	180,000
Total Coliform Membrane Filter	6,400	40	2,300	1,380
Most Probable Number (MPN)	1,600 (640-5,800)	11 (2-25)	1,600 (640-5,800)	1,600 (640-5,800)
Fecal Coliform Membrane Filter	10	0	100	30
Most Probable Number (MPN)	-[2/]	-[2/]	110 (31-250)	31 (11-89)
Fecal Streptococci Membrane Filter	170	140	1,400	100

1/ Techniques listed in Table 22.

2/ MPN technique not run on these samples.

from Jolly Giant Creek from untreated domestic wastewaters. Similar relationships were found between fish pond and creek waters sampled on April 28, 1976 (Table 22).

Aged fish pond waters showed very low counts in currently used parameters to monitor public waters in protecting human health. Pond waters would probably be rather high in total suspended solids due to the high count of algal cells. Batch discharge of such water into the usually turbid waters of an intertidal area of Humboldt Bay, such as Jolly Giant Slough, would have an insignificant negative impact on the aquatic values of the area.

SUMMARY

Experiment XII

Of 24,900 coho fingerling salmon planted into South Pond in October, 1975, 15,848 smolts were recovered (45 percent survival). Of this total production, 6,263 were selectively trapped from 6 April until May 7, 1976. Smolts exhibited distinct external morphological features, high Na^+ and K^+ - gill ATPase activity, and active seaward migration when planted in Jolly Giant Creek. Smolt catch peaked 23-24 April when 34 percent of all smolts taken by selective trapping were captured. All smolts were marked and were in excellent external condition. A few fish had abnormalities but showed no positive bacterial infections. A culture of *Vibrio* (bacteria) isolated from a chinook salmon in another pond was cultured and 10 recently fin clipped coho smolts were challenged at 18 C for 17 days. No mortalities occurred. It was possible that smolts produced had been immunized naturally in the pond. This continues to support a possible explanation that there was therapeutic effects on wastewater-reared chinook salmon (Allen and O'Brien 1967). High survival's were found for fish reared in three fixed pens (84-89 percent) but the fish grew much more slowly than pond fish. No pen produced over 7 percent smolts in reared salmon by time of pond draining (7 May). A period of mortalities in ponds apparently occurred in early November but could not be related to any particular factor. Pond fish were given supplemental foods (about 2,400 pounds wet weight) in order to insure fish attaining smolting stage in early spring in order to avoid reversion to parr with the onset of higher summer pond temperatures. Supplemental feed consisted of 1,474 pounds of live *Daphnia magna* (water flea) collected by pumps or traps in an oxidation pond adjacent to the fish ponds, 645 pounds of ground Dover sole carcasses (5 cents per pound), 137 pounds of shovel-chopped fresh crab offal, and 120 pounds of ground shrimp offal.

Loss of smolts from handling and marking was negligible, with mortalities occurring mainly from fish jumping out of holding tanks. Water temperatures in holding tanks average 5^{o} C cooler than pond temperatures. Smolts taken by trapping were planted soon after marking in small lots to simulate natural schooling conditions, and to avoid overloading the home streams.

Smolting appeared size-dependent, with very few fin fish less than 100 mm fork length ever smolting, and practically no fish over 110 mm not smolting. This relationship was most clearly shown by samples of coho reared in pens.

Fish pond waters were very low in fecal coliforms and fecal streptococci.

Experiment XIII

Of 30,000 spring chinook fry planted into North Pond in February, 1976 about 18,000 (60 percent) healthy, growing fish were in the ponds by mid-May. This represented a major increase in the survival rate over past experiments utilizing fall chinook salmon reared through the same season (late winter to spring). About 4,000 salmon were taken by trapping or seining from North Pond and planted into Jolly Giant Creek, while the remainder were left in the pond to be reared to early fall. A period of high water temperatures in late June (over 25 C) combined with smolting by larger salmon, induced Vibriosis which eventually destroyed all fish. Attrition, however, was slow with an estimated 12,000 fish in the pond in mid-July. Six rainbow trout known to have escaped into the pond were all recovered, and showed a growth rate of about 2 grams per day per fish. Resistance to vibriosis was exhibited by the rainbow trout reared in this experiment and by spring chinook to a much lesser degree. Inexpensive methods for preventing stress of salmon from the peak water temperatures of summer appear feasible. Precise smolting and downstream migration periods in spring chinook salmon reared in North Pond was not clearly defined as were demonstrated by coho in South Pond. Salmon reared in pens had consistently higher survival rates than pond-reared fish, and were only slightly smaller in size than pond-reared fish. Spring chinook salmon reared at the HSU hatchery, plus salmon netted and trapped from North Pond in mid-May, allowed release of about 10,000 fingerlings into Jolly Giant Creek to continue testing this creek as the potential "home-stream" for wastewater-reared salmon smolts. Bacteriological indices used to monitor water quality for human health (total coliform, fecal coliform) were very low in North fish pond water at the end of the fish rearing.

ACKNOWLEDGEMENTS

To all Humboldt State University students who assisted with seining, trapping, marking, and planting of coho and chinook salmon during these studies, grateful appreciation. During the past year, three individuals contributed immensely to successful operations: Mr. Glen Del Sarto and Mr. Barry Collins, graduate students in fisheries, and Mr. Jim Harrington, CETA employee assigned to the wastewater aquaculture project. The California Department of Fish and Game supplied salmon used in rearing experiments. Sea Grant funding was available until December 31, 1975. Mr. Glen Del Sarto received the San Francisco Tyee Club annual scholarship for the 1975-76 academic year which allowed completion of his research work on smolting of pond-reared coho and chinook salmon. Fingerling coho salmon and chinook salmon fry were produced at the Humboldt State University hatchery, Mr. Al Merritt, hatchery superintendent. Surplus fish and shellfish offal were kindly provided free by Mrs. Gay Gilchrist, Seafoods, Arcata, California.

Bacteriological surveys were conducted by Mr. Andrew Morton and Mr. Dan Viele under supervision of Dr. Robert Busch, fish pathology laboratory, department fisheries. The assistance with these water quality studies has been particularly helpful to the wastewater aquaculture program.

Terryl Allen was responsible for drafting most of the figures. Especially crucial to completing this report was the typing of drafts and final manuscript by Mrs. Ellen Spurling, California Cooperative Fisheries Unit.

Continued support and encouragement of the Council for the City of Arcata, and of city administrative staff and employees is gratefully acknowledged.

Finally, I wish to acknowledge the sabbatical leave granted to me by Humboldt State University during the 1975-76 academic year to conduct field work, write reports, and undertake travel associated with wastewater aquaculture.

LITERATURE CITED

Allen, G. H. 1973. Rearing Pacific salmon in saltwater ponds fertilized with domestic wastewater July 1971 - June 1972. Humboldt State University, Coherent Area Sea Grant Program, Data Report, 88 p.

Allen, G. H. 1975. Rearing Pacific salmon in saltwater ponds fertilized with domestic wastewater July - September 1974. Ibid., Data Report, 42 p.

Allen, G. H. 1976. Rearing Pacific salmon in saltwater ponds fertilized with domestic wastewater October 1974 - November 1975. Ibid., Data Report.

Allen, G. H. and R. L. Carpenter, In press. The cultivation of fish in municipal wastewater lagoons as an available protein source for human beings with emphasis on salmonids. The International Conference on the Renovation and Recycling of Wastewater through Aquatic and Terrestrial Systems, Bellagio, Italy, July 16-21, 1975. Holland. Marcel Dekker.

Allen, G. H., G. Conversano, and B. Colwell. 1972. A pilot fishpond system for utilization of sewage effluents, Humboldt Bay, northern California. Humboldt State University, Coherent Area Sea Grant Program, HSU-SG-3: 25 p.

Allen, G. H. and L. Dennis. 1974. Report in pilot aquaculture system using domestic wastewaters for rearing Pacific salmon smolts. In, Wastewater use in the production of food and fiber - Proceedings. U.S. Envir. Prot. Agency, Off. Res. and Develop., Envir. Prot. Tech. Series, No. EPA-660/2-74-041: 162-198.

Allen, G. H., R. A. Busch and A. W. Morton, In press. Preliminary bacteriological experiences with wastewater-fertilized marine fish ponds. FAO Technical Conference on Aquaculture, Kyoto, Japan, 26 May - 2 June 1976. Proceedings.

Antipa, R. 1976. Field testing of injected Vibrio anguillarum bacterins in pen-reared Pacific salmon. J. Fish. Res. Bd. Canada, 33(6):1291-1296.

Bailey, E. D. and E. D. Gibbs. 1964. Observations of the seaward migrations of hatchery-reared and wild juvenile king salmon. California Department of Fish and Game, Marine Resources Branch, Administrative Report No. 64-5, 13 p.

Collins, B. 1976. Na^+, K^+-ATPase activity as a smolt index for chinook salmon reared in brackish water. Master of Science Thesis, Humboldt State University, Unpublished draft, 49 p.

Del Sarto, G. 1976. Master of Science research, unpublished data. Humboldt State University. Personal Communication.

Dennis, L. 1975. Master of Science research, unpublished data. Humboldt State University. Personal Communication.

Fiske, C. H. and Y. Subbarow. 1925. The colorimetric determination of phosphorous. J. Biol. Chem. 66:375-400.

Hoar, W. S. 1976. Smolt transformation: evolution, behavior, and physiology. J. Fish. Res. Bd. Can. 33(6):1233-1252.

Hume, D. 1976. Selective trapping of chinook salmon smolts in a wastewater mariculture pond. Master of Science Thesis, Humboldt State University, 40 p.

Hume, J. D. and G. H. Allen. Under review. Selective trapping of chinook salmon smolts in a wastewater mariculture pond. Calif. Fish and Game.

Kenner, B. A., H. F. Clark and P. W. Kabler. 1960. Fecal streptococci. II. Quantification of streptococci in feces. Am. J. Pub. Health, Vol. 50:1553.

Lowery, O. H., N. J. Rosebrough, A. L. Farr and R. J. Randall. 1951. Protein measurement with the Folin phenol reagent. J. Biol. Chem. 193:265-275.

Reimers, P. E. 1968. Social behavior among juvenile fall chinook salmon. J. Fish. Res. Bd. Can., 25(9):2005-2008.

Reimers, P. E. 1973. The length of residence of juvenile fall chinook salmon in Sixes River, Oregon. Oregon Fish Commission, Research Reports, 42(2): 43 p.

Royal, L. 1972. An examination of the anadromous trout program of the Washington State Game Department. Report to Director, Washington State Game Department, 30 October 1972, 176 p plus appendices.

Scholz, A. T., R. M. Horrall, J. C. Cooper, A. D. Hasler, R. J. Poff and R. I. Daly. 1975. Artificial imprinting of salmon and trout in Lake Michigan. Wisc. Dept. Nat. Res., Fish. Mgt. Report No. 80, 45 p.

Scholz, A. T., R. M. Horrall, J. C. Cooper and A. D. Hasler. 1976. Imprinting to chemical cues: the basis for home stream selection in salmon. Science 192 (4245:1247-1249.

Shapovalov, L. and A. C. Taft. 1954. The life histories of the steelhead rainbow trout (Salmo gairdneri gairdneri) and silver salmon (Oncorhynchus kisutch) with special reference to Waddell Creek, California, and recommendations regarding their management. Calif. Dept. Fish and Game, Fish Bull. No. 98, 375 p.

Taniguchi, A. 1970. Interval of estuarine residence and out-migration of juvenile chinook salmon in the Mad River, California. Master of Science thesis, Humboldt State College, 87 p.

Villegas, J. 1975. Bird predation on coho salmon reared in a wastewater aquaculture pond, November 1975. Humboldt State University, Senior field problem in fisheries. Unpublished report, 13 p.

Welsh, J. P. 1974. Mariculture of the crab Cancer magister (Dana) utilizing fish and crustacean wastes as food. Humboldt State University, Coherent Area Sea Grant Program, Development of Living Marine Resources of Northern California, HSU-SG-4: 76 p.

Zaugg, W. S. and L. R. McLain. 1970. Adenosinetriphosphatase activity in gills of salmonids: seasonal variation and saltwater influence in coho salmon Oncorhynchus kisutch. Comp. Biochem. Physiol. 35:587-596.