CALIFORNIA COOPERATIVE FISHERY RESEARCH UNIT

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George H. Allen,[1/] Joe Miyamoto,[2/]
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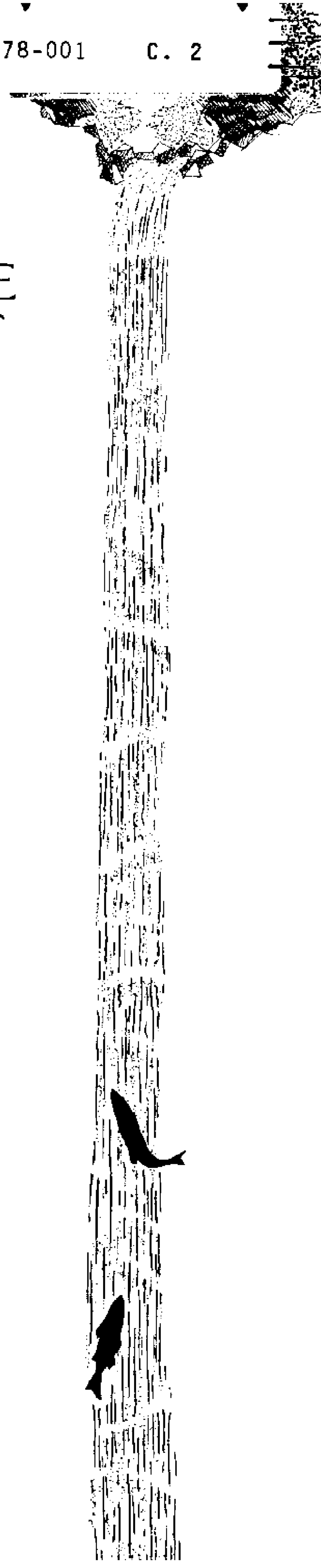
RESEARCH REPORT 78-1



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ABSTRACT

In spring 1976, 12,000 1974-brood coho salmon (Oncorhynchus kisutch) smolts were planted into an intertidal estuary of a small urban stream (Jolly Giant Creek) entering north Humboldt Bay, Arcata, California.

Straying was studied in the fall of 1977 by the capture of adult salmon in traps built into weirs constructed at the mouths of Jolly Giant Creek (home stream) and Jacoby Creek (adjacent stream). No salmon could pass the weir on Jolly Giant Creek, but in Jacoby Creek salmon could pass the weir during periods of high water. Escapement to Jolly Giant Creek was 0.30 percent of smolts released. An estimated 0.25 percent of the smolts released into Jolly Giant migrated to Jacoby Creek as determined from adult fish trapped at the weir and recovered by electrofishing. These data showed a rate of straying of about 45 percent as based on adults recovered in the two streams. A majority of the 3-year-old coho returning to Jacoby Creek in the fall of 1977 came from smolts released into Jolly Giant Creek. Improvement in the homing of smolts in the Jolly Giant Creek area may be improved by use of organic fractions in domestic wastewaters to be passed through two marshes and a lake to operate "imprinting ponds."

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OCEAN RANCHING CONCEPT

Native Americans historically harvested Pacific salmon (*Oncorhynchus*) as adult fish on their return to freshwater streams to spawn (Kroeber and Barratt 1960; Cooley 1963). The commercial salmon fishing industry in the 19th century also harvested salmon in freshwater (e.g. fish wheels in the Columbia River, Donaldson and Cramer 1971). The early salmon canning industry widely employed large stationary floating traps in near-shore marine or brackish waters to intercept stocks of salmon moving to freshwater spawning streams (Cooley, op cit). Gradually, economic, political, and social factors have shifted harvesting of salmon for commercial purposes from freshwater areas to estuarine areas removed from the mouths of spawning streams, and to areas of the open ocean. Purse seine, gill nets and trolling gear are the main methods of capture in these marine areas. Stationary gear first became illegal in freshwater and slowly became restricted in marine areas also. Most salmon now taken in freshwater are harvested primarily by recreational fishermen and Indian fisheries. Recent legal cases recognizing historical Indian-fishing rights (Bolt Decision) is resulting in an increasing share of the total catch of salmon being allocated to this user group, with a substantial portion of such catches again being made in freshwater.

Concurrent with these shifts in method and place of harvesting salmon, artificial culture activities were undertaken by federal and state officials. Initially such efforts were to produce more salmon to commercial fisheries (Cooley, op cit) and more recently to mitigate the destruction of natural production of salmon by man's activities, particularly the damming of rivers (Meacham 1973). Pacific salmon eggs were first taken and reared at a location now inundated by Shasta Dam in California (McCloud River, tributary to Sacramento River, California) (Atkinson et al. 1967). Because salmon and trout are easy to spawn, produce large eggs that are simple to incubate, and the young fry are easily reared for release to migrate to the sea, a large system of state and federal salmon hatcheries has been developed. By 1967, 64 state and federal hatcheries were in operation (Atkinson et al., op cit). In addition to the Pacific salmon, the steelhead rainbow trout (*Salmo gairdneri*) was cultured by agencies responsible for recreational fishing. Agencies responsible for either recreational or commercial fisheries operate salmon hatcheries for coho (silver) salmon (*O. kisutch*) and chinook (king) salmon (*O. tshawytscha*) since both are taken by recreational and commercial fisheries in the Pacific Ocean. Coho and chinook not caught in these ocean fisheries subsequently return (escape) to freshwaters to either spawn naturally or to be spawned artificially in hatcheries. In recent years escapement of adult salmon to some of these hatcheries has often exceeded hatchery capacity. Surplus salmon have been sold by contract to private entrepreneurs. Eggs from female salmon returning to some hatcheries has also been in excess of hatchery capacity. In response to these surpluses, some states have developed policies allowing private enterprise, under carefully regulated conditions, to utilize such excess of eggs to establish private hatcheries (Salo 1974). Such private salmon hatcheries sell excess male salmon to provide the revenues to support the capitalization and operation of the system, and to provide a profit to the owner. These operations have been termed "ocean ranching" (Joyner 1975), or "seafarming" (Hildingstam 1976).

Success of public hatcheries may be evaluated by use of benefit/-cost ratios. The major benefit is the contribution of salmon from the hatchery to sport and recreational fisheries. Success of ocean ranches depends on the number of salmon escaping to the facility. Successful public-supported salmon culture operations require lesser rates of return to the hatchery (escapement) than is necessary for a successful privately-operated ocean-ranching system. This is so because public hatcheries try to maximize contribution to fisheries while ocean ranches must maximize escapement. An ocean rancher's contribution to sport and commercial fisheries, although an overall social good, does not assist in establishing surplus salmon for sale to support the enterprise. Thus the break-even point in the rate of return (escapement) to the ocean ranch from planted smolts[1/] has to be much higher than for a successful public hatchery. Currently, an escapement rate of around 2 percent that has been attained by techniques of accelerated growth in smolt production (Garrison 1971; Donaldson and Brannon 1976) is considered necessary to produce a viable commercial private operation.

1/ Juveniles of anadromous salmon and trout, preparatory to moving from freshwater to estuarine or ocean waters, undergo dramatic morphological and physiological changes termed smolting. Freshwater-feeding juveniles are called parr based on distinct vertical bars on the sides of the fish called parr marks. Coho parr-smolt transformation involves loss of parr marks, becoming silvery, becoming slimmer and developing black bands along the edges of the fins.

To consistently achieve such an escapement rate, all facets of the culture system must be operated at utmost efficiency, since the average rate of return of yearling smolts released by public hatcheries is much less than this figure (0.4 percent; Ellis and Noble 1959). Recent improvements in diets and immunization against disease are slowly increasing the average percentage return to both private and public hatcheries (Hines 1975). Despite improvement in culture techniques, the marine environment may control overall survival rate in some years as witnessed by the drastic decline of the U.S. ocean troll fisheries for coho and corresponding poor escapement of coho in 1977 (1974 brood year) (Anon. 1977).

One technique to increase rates of escapement to an ocean ranch is to locate the facility near stream mouths or directly on saltwater. Such locations can reduce natural mortalities suffered by juveniles in freshwater (Allen 1968), as well as eliminating the catch of adults in freshwater. However, loss of escapement of adult salmon returning to facilities located directly on marine areas or near stream mouths occurs from adult fish migrating into adjoining streams (straying). Determining the rate of straying in natural salmon populations or for hatchery runs requires considerable effort. A sizeable portion of the smolts produced by the system under study must be marked or tagged, and nearby streams must be monitored for returning marked or tagged adult fish (Scholtz et al. 1975). The monitoring of adult returns can be accomplished by sampling fisheries, obtaining samples of fish from streams, seining or electrofishing, or by building weirs and traps in streams to examine all returning fish. Straying is not a critical factor to success of public hatcheries, since straying fish spawn naturally in the streams, and thus help sustain natural reproduction. Thus very little published data quantifying rates of straying exists (Table 1).

Rates of straying have varied around 20 percent for coho salmon in small California coastal streams (Shapovalov and Taft 1954). Seasonal dry periods prevent passage of fish into these California streams due to barrier reefs located at stream mouths. A small stream (Minter Creek) in southern Puget Sound, Washington showed a presumed rate of straying of 23 percent (Salo and Bayliff 1958). This rate is probably maximum since it was based on the percent of unmarked salmon taken in their runs at a weir. Natural spawning takes place below their weir, thus unmarked coho salmon are constantly produced in the stream. Puget Sound also tends to have more uniform and heavier rainfall than central California, and streams' mouths are without barrier reefs. Little straying was detected in marked coho salmon returning to the College of Fisheries hatchery at the University of Washington in the fall of 1954 (Donaldson and Allen 1958). Unmarked fish do stray into these facilities but no report on the contribution of unmarked salmon to these runs has yet been published (Hines, op cit). In contrast, coho salmon transplanted into the Great Lakes have shown considerable straying (Peck 1970).

In the spring of 1976, juvenile coho of the 1974 brood year were successfully reared to smolting in a marine pond fertilized with treated domestic wastewater (Allen 1976). These yearling smolts were released into a small urban stream (Jolly Giant Creek, City of Arcata, north arm of Humboldt Bay, Humboldt County, northern California) (Figure 1). In the fall of 1977, the number of adult coho salmon returning from these smolts were determined by placing a weir and fish

Table 1. Rates of straying for coho salmon.[1/]

Author	Location	Average or range in minimum stream flow (cfs)	Average or range in rate of straying (percent)	Nature of study	Remarks
Shapovalov and Taft 1954	Scott and Waddell Creeks, central California	0.7- 5 (8)	15-27 (5)	Evaluation ɔf native runs with upstream and downstream traps	Marshlands, sand dunes and sand bars at mouth
Salo and Bayliff 1958	Minter Creek southern Puget Sound, Washington	17 (?)	23 (5)	Evaluation of hatchery practices with upstream and downstream traps	Uncorrected for natural spawning below weir, thus straying rate a maximum estimate
Peck 1970	Huron River, Michigan. Lake Superior	(1)	"substantial"	Decoying experiments in Lake Michigan in area previously devoid of coho salmon	fingerlings (18 gr. av. wt.) planted May 16-17 into river
Donaldson and Allen 1958	University of Washington, College of Fisheries	1 (1)	virtually none	Transplantation study to establish a run to hatchery located on lake shore	fingerlings (15 gr. av. wt.) placed in water at release site Jan. 19 and released March 18-19

1/ Number of years of data contributed to listed factors shown in parentheses.

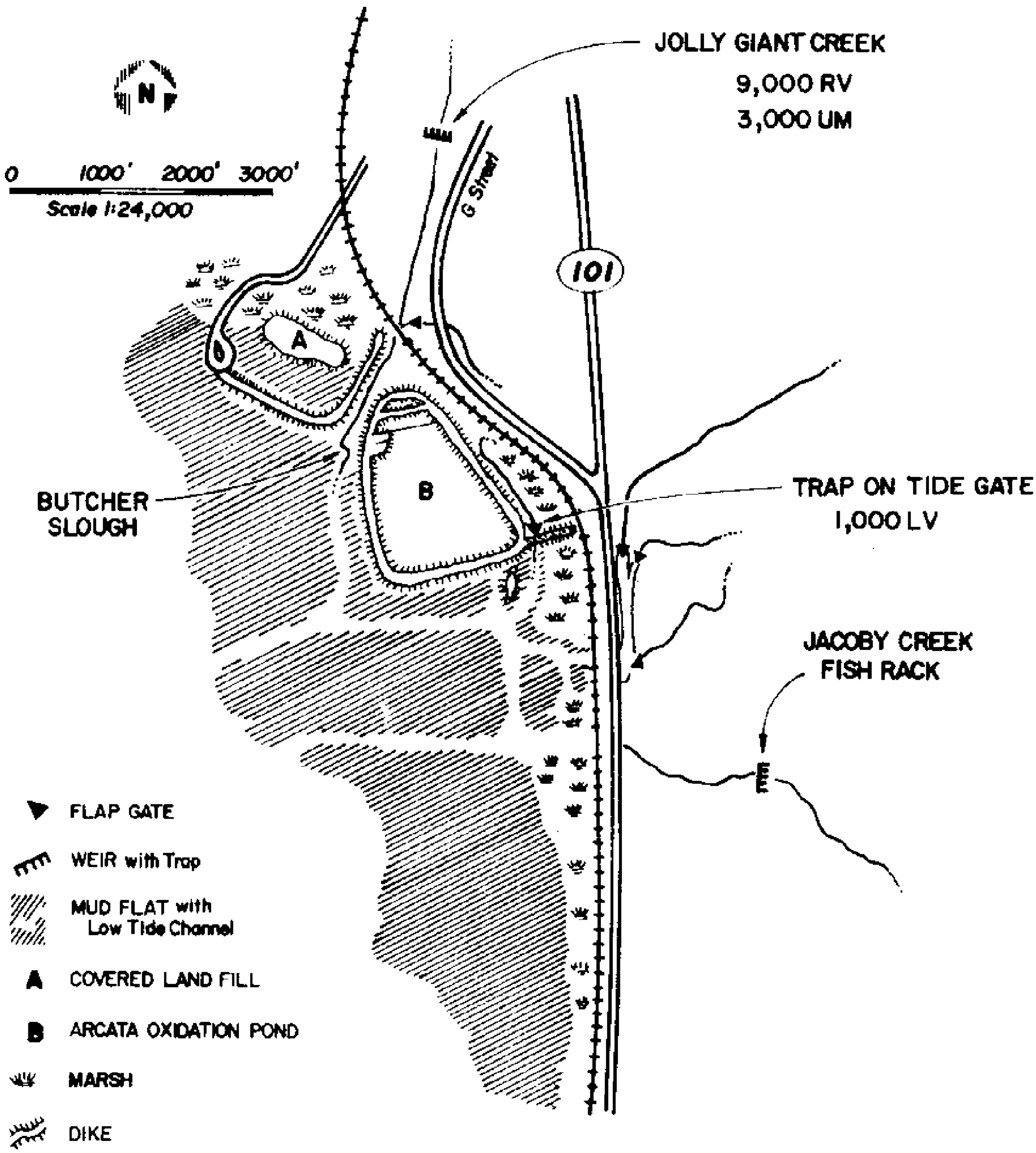

Figure 1. Number, fin-mark, and release points of 1974-brood coho salmon smolts reared in wastewater-weawater ponds, and location of traps and weirs used to recover returning adults.

trap into the lower end of Jolly Giant Creek (Figure 1). Straying of marked coho salmon into the nearest major adjacent stream located about one mile east of Jolly Giant Creek (Jacoby Creek) was studied from marked fish taken in a weir and trap located at the head of tidewater.

This paper reports on the return of 1974-brood coho salmon to these two streams. The overall escapement rate for marked 1974-brood-coho salmon released into Jolly Giant to the two creeks was about 0.5 percent. About 45 percent of the smolts released into Jolly Giant Creek strayed to Jacoby Creek. Straying of wild fish into Jolly Giant Creek appeared virtually zero.

HISTORY OF ARCATA WASTEWATER AQUACULTURE SYSTEM

Salmon culture systems strive to develop a water supply of high quality defined as of good clarity, high in dissolved oxygen content, and of suitable temperature (Leitriz and Lewis 1977). Traditionally, high water quality has been insured in salmonid aquaculture systems by use of spring water, well water, or locating salmon aquaculture systems on tributary streams whose waters are relatively unaltered by man's activities. The number of such suitable sites has been limited (Netboy 1958). Recirculating water systems have been one of the methods employed to overcome such problems (DeWitt and Salo 1960; Allen 1962). Although the use of wastewaters, either of domestic or industrial origin, for fish culture has been widely used in most of the world for non-salmonid species (Allen 1969), such use of wastewaters for aquaculture in the United States has been constrained by cultural, esthetic, and regulatory reasons (Kildow and Huguenin 1974). The use of wastewaters for trout and salmon culture in particular can also be limited by biological reasons because of the sensitivity of salmonids in freshwater to the gaseous form of ammonia (Brockway 1950; Burroughs 1964). Seawater, however, has considerable buffering capacity, and juvenile salmonids reared in seawater-wastewater mixtures have shown much higher rates of survival than would be expected from strictly freshwater experiences (Allen and O'Brien 1967; Crawford and Allen 1977). Thus wastewater-seawater operated rearing ponds is a new system, that if successful, can increase the number of potential salmonid aquaculture sites.

The Arcata system was established in 1971 when two 0.15-hectare ponds (North and South Ponds) were constructed within the periphery of a 55-acre oxidation pond located on Arcata Bay (north arm to Humboldt Bay, Humboldt County, northern California) (Figure 1). These ponds were operated as a pilot project to study the feasibility of using seawater enriched with secondarily-treated domestic wastewaters for rearing juvenile salmonids to smolts stage (Allen, et al. 1972). Initially, juvenile salmon reared in the ponds were released directly into Humboldt Bay, since facilities were unavailable for holding and marking young fish prior to release. Also an appropriate "homestream" for project fish had not been developed. Beginning in 1975, however, holding and marking tanks became available. Juvenile salmon and trout reared in the system could then be held for release into a selected "homestream." Jolly Giant Creek was selected on a temporary basis. This small urban stream rises in a second-growth redwood forest to the east of the city of Arcata, flows underground in concrete channels under downtown Arcata before emerging into a tidal channel (Butcher Slough) located immediately west of the wastewater fish ponds. Verified returns of salmon planted in the creek began in 1975 (Table 2).

Table 2. Number of adult Pacific salmon recorded near sites of release of parr and smolts reared in wastewater-seawater aquaculture system, Arcata Humboldt Bay, northern California, 1972-1976.

Years	Coho		Chinook	Remarks
	Jacks[1/]	Adult		
1973	0	2	0	One fish taken in gill net at oxidation pond outlet channel; one carcass recovered from salt marsh east of oxidation pond.
1974	0	0	0	Schools of large fish (thought to be salmon) sighted by wildlife management student in Butcher Slough in late October prior to rainy season. Species identification was not confirmed by project personnel.
1975	3	2	2	The adult coho were taken by gill net in Butcher Slough; other fish were taken about 2 miles inland by seine and electrofishing.
1976	3	0	1	1 RV coho jack recovered in Jacoby Creek by electrofishing; 1 RV jack and chinook taken in Jolly Giant trap. 1 small salmon carcass was reported early February (by City of Arcata Director of Public Works) on mud bar near mouth of oxidation pond but not recovered for species identification.
1977	0	42	3	Actual number of adult coho is the number of RV-marked fish recovered in Jacoby Creek, plus all recoveries at Jolly Giant Creek trap. See Table 9 for total estimated recovery of 1974-brood coho salmon. Total includes one salmon carcass on tidal channel bank observed at close range by a wildlife management student.

[1/] Jacks are precocious males that return after only 1 year in the sea, and are thus two-year-old fish. Adults are coho salmon that have spent one year in freshwater and two years at sea (three-year-old fish).

EXPERIMENTAL FISH

Coho salmon used in this study were provided by the California Department of Fish and Game from eggs taken in late fall 1974 (1974 brood year) from stocks in the Noyo River, Mendocino County, northern California. Eggs were incubated at the Humboldt State University fish hatchery. Fry were reared during the spring and summer of 1975 in the Humboldt State University fish hatchery and in 1,000-gallon aquaria located in a fish barn adjacent to the wastewater fish ponds. Small fingerling coho salmon were placed into South Fish pond in late September and early October 1975. The fingerlings were reared in South Pond from September 1975 to May 7, 1976. Pond water quality was maintained by use of forced-air delivered by a single line laid through the center of the pond. Although the system delivered oxygen, the major use of aeration was to keep the pond mixed. Most oxygen in the system was provided by photosynthesis of algae and macrophytes, particularly Enteromorpha sp. Supplementary feeding of ground Dover sole carcasses, shrimp wastes, and fresh crab offal began late winter to insure fish grew to sizes required for smolting (Allen 1976).

Salmon smolts were selectively removed from the pond from 6 April to 7 May 1976 by use of a simulated down-stream movement of water directed through a specially designed trap made to fit into a slot designed into the headgate structure of each pond (Hume 1976). Smolts removed from the trap were held in 1,000-gallon recirculating tanks located in a fish barn immediately adjacent to the ponds. Both marked and unmarked smolts were released. Marking was by fin excision (RV - right ventral fin; LV - left ventral fin). Smolts were held at least

24 hours for observation before release into two locations adjacent to the fish ponds (Table 3, Figure 1). Representative samples of smolts were periodically measured for fork length (mm) and weight (gm).

EXPERIMENTAL PLAN

Groups of smolts were released to investigate four questions: (1) would smolts imprint to a "homestream" water on planting immediately after being selectively removed from a wastewater aquaculture pond (RV-marked coho salmon smolts planted into Jolly Giant Creek, Table 3); (2) what degree of straying would occur from releasing smolts into an intertidal area of a stream rather than inland in strictly freshwater (electrofishing and by trapping returning adults in a weir located at head to tidewater in Jacoby Creek, Figure 1); (3) what degree of induced mortality from vibriosis (*Vibrio anguillarum*, marine bacteria) might result from exposing smolts to seawater immediately after fin excision (unmarked coho salmon smolts planted into Jolly Giant Creek as compared to marked smolts, Table 3); and, (4) could adult coho salmon imprint to a marine release site and return through a one-way flap gate (LV-marked coho salmon planted into tidal slough immediately east of oxidation pond, Table 3 and Figure 1).

SOURCES OF ERROR

The major source of error in this study was related to efficiency of recapture of returning adult salmon in streams adjacent to Jolly Giant Creek. Many small drainages enter Humboldt Bay through flap gates (Figure 1) and only one of these was fitted with a trap (slough immediately east of oxidation pond, Figure 1). At tide levels of 7 feet or higher occurring at times of southerly storms, water levels topped the

Table 3. Length, weight, and fin mark of 1974-brood coho salmon removed from South Pond, Arcata wastewater aquaculture system, April 6 - May 7, 1976, and location of sites of release on Arcata Bay.

	Release Locations		
	Intertidal area Jolly Giant Creek		Tidal Slough, immediately adjacent to east side of oxidation pond
Fin Mark	RV	Unmarked	LV
Number released	7,938	3,249	1,018
Date Released	Apr 20-May 12	May 10-12	Apr 20-May 12
Mean Weight			
Number per pound	33	32	35
Grams	14	14	13

dike and trap which would allow salmon to migrate inland without encountering the trap. Lack of manpower prevented surveys of these drainage for returning salmon.

A second source of error was the degree to which traps captured all returning adult salmon.

During the initial fall rains in September 1977 adult chinook salmon from prior releases returned to Jolly Giant Creek (Table 2). One of these fish was taken in the trap (Figure 2), while one escaped through a hole that developed under the base of the trap. A second jumped over the trap at high tide. Subsequently, a carcass from these two known salmon escaping the Jolly Giant Creek weir was recovered from the creek. With repair of the hole and placing a three-foot wire screen downstream from the trailing edge of the top of the trap, we consider a total recovery was made of coho salmon subsequently attempting to migrate up Jolly Giant Creek. Constant survey of the base of the trap during remainder of the study revealed no further holes. No coho carcasses were reported by City of Arcata personnel cleaning the numerous grates protecting the upstream face of culverts on Jolly Giant Creek.

During periods of heavy rain in mid-November, the weir on Jacoby Creek allowed fish to pass upstream when the banks were washed away at the edges of the weir (Figure 3). During another period a hole developed under the gabions anchoring the weir. Additional salmon probably passed over the weir on days when storm runoff produced stream flows sufficient to submerge the weir. Estimates of the number of fish passing through the weir undetected during November and December was made by sampling sections of the creek by electrofishing. Since all adult fish trapped at the weir were given a distinctive mark or tag prior to

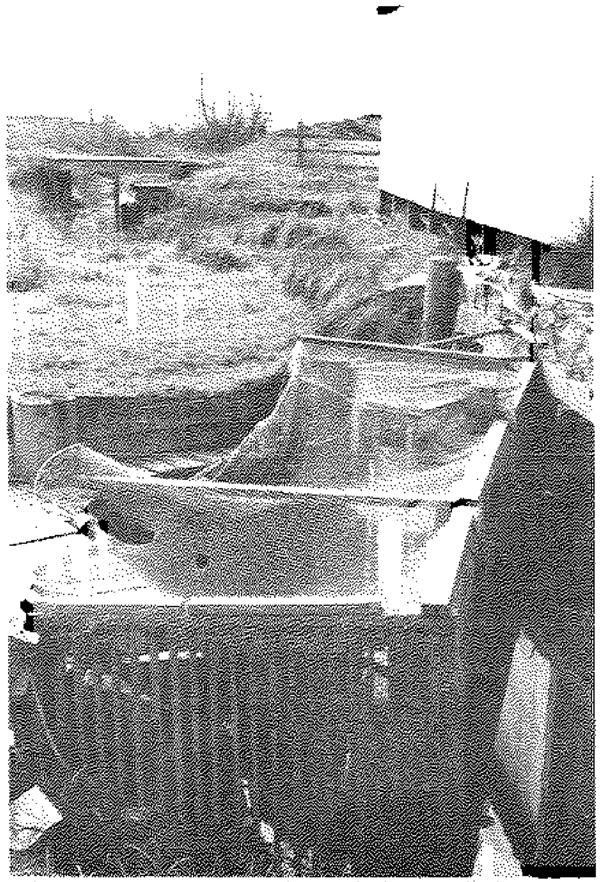

Figure 2A. Upstream view of weir and trap, Jolly Giant Creek. (Smolts were released into creek from bridge shown in background).

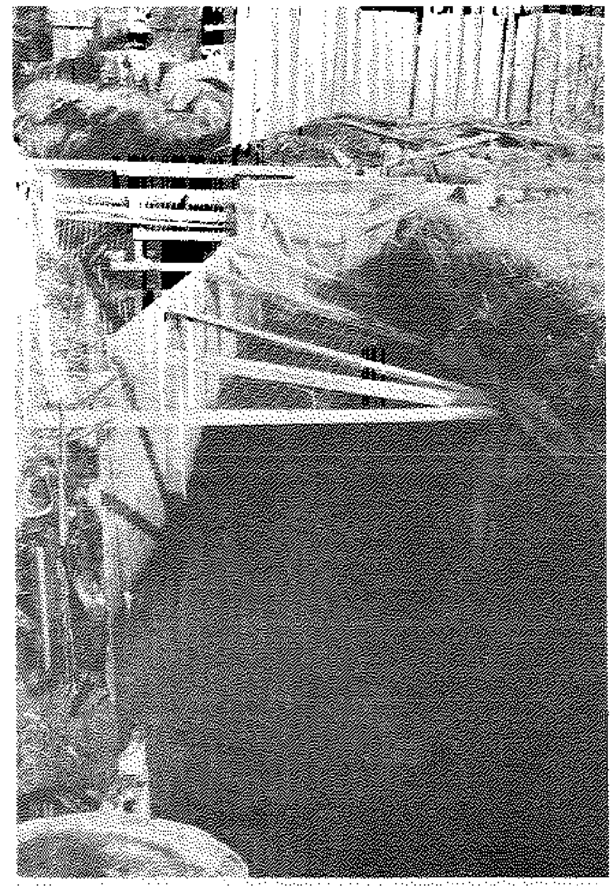

Figure 2B. Downstream view of weir and trap, Jolly Giant Creek. (Peak creek runoffs when coinciding with high tides produced water levels reaching top of weir. Fish were prevented from escaping system by netting placed over trap and mesh nailed on downstream edge of weir).

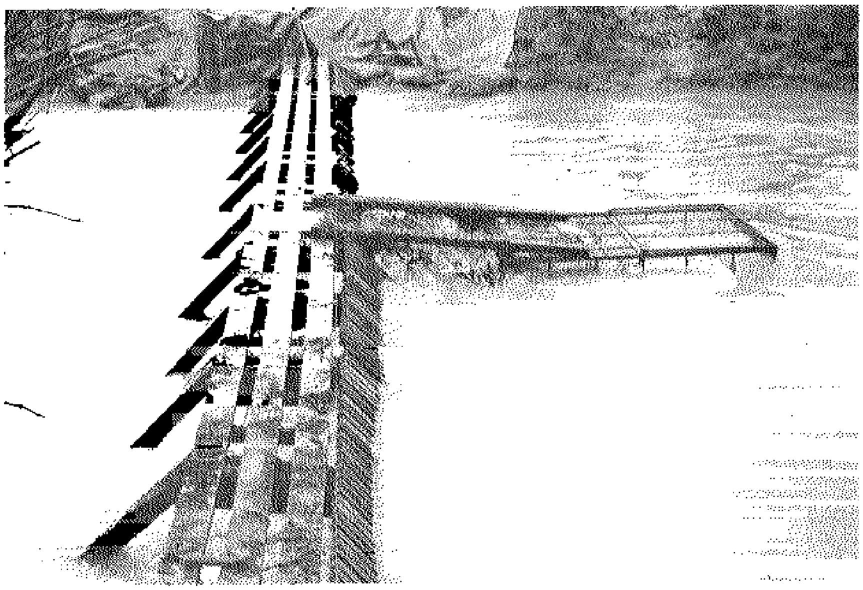

Figure 3A. Side view of weir and trap, Jacoby Creek. (Erosion of banks at edge of weir was prevented by covering with rubberized canvas and weighting with sand bags).

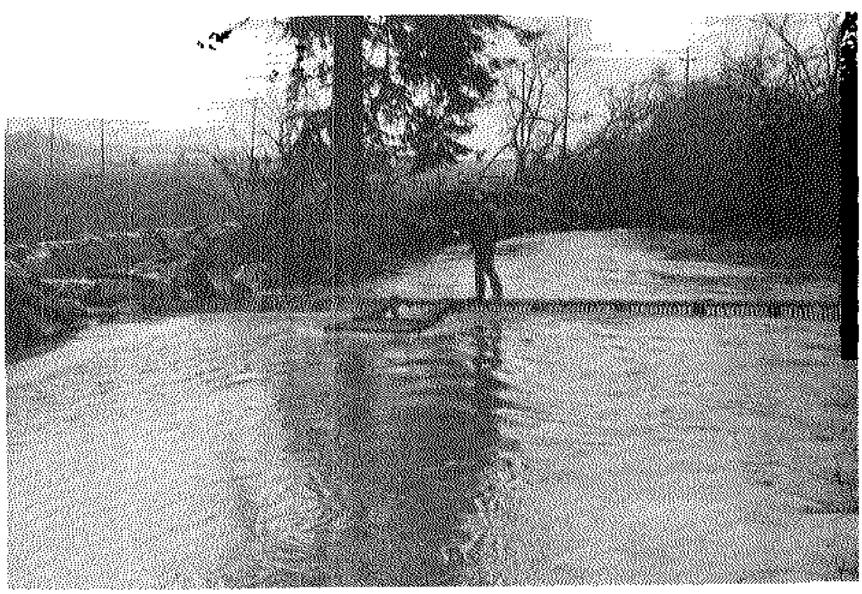

Figure 3B. Upstream view of weir and trap, Jacoby Creek. (At extreme flows, water submerged weir, with stream debris passing over walkway. At lower flows weir was cleaned continually by hand).

release above the weir, marked-to-unmarked ratio were available from these electrofishing samples to estimate the capture efficiency of the Jacoby Creek weir. These recoveries also allowed an estimate of the total population escaping the weir by the Petersen technique. Thus data were available to allow several methods of estimating the number of project salmon escaping the Jacoby Creek trap.

HYDROLOGICAL CONDITIONS

A serious drought occurred in northern California during the course of this experiment. 1974-brood year smolts released into Jolly Giant Creek in the spring of 1976 from a small bridge located immediately downstream from the trap (Figure 2) encountered freshwater when planted at low tide, and fairly saline waters when planted at high tide. Unfortunately, our records are incomplete and we are unable to state what percentage of the fish were planted into these different salinity regimes. Salmon planted at high tide (higher salinity waters) may have been less-well imprinted and thus tended to stray more to adjacent areas than salmon smolts planted at low tide (freshwaters).

Return in the fall of 1976 of jacks (precocious males - 2-year old fish) was probably influenced by very low flows in the streams in the fall of 1976. Such rains as occurred barely caused a rise in the flow of Jacoby Creek. Several short, brief rises in volume of flow did occur in Jolly Giant Creek since it is highly influenced by storm-water drainage from urban areas. Rains sufficient to cause consistent flows in Jacoby Creek only started late in the usual migratory period of the salmon (winter 1977). A small salmon carcass was reported off the oxidation pond outlet in early February 1977 (Table 2).

Drought conditions ended in northern California in the fall of 1977, when major storms appeared in September. These storms produced heavy flows in Jolly Giant Creek from storm-drain runoff but produced hardly any change in flow in Jacoby Creek due to maximum in-soak from extremely dry watershed conditions. During these early storms, adult chinook salmon were not recovered in Jacoby Creek, although taken in Jolly Giant Creek as noted previously (Table 2). Storms beginning in late October began producing increased water flow in Jacoby Creek so that transport water occurred in both drainages during the normal time for adult coho salmon migration in California coastal streams (November-December; Shapovalov and Taft 1954).

SIZE OF COHO POPULATIONS IN JACOBY CREEK

As part of the experimental design, about 25 percent of the coho smolts released into Jolly Giant Creek were unmarked (Table 3). Thus unmarked coho adults returning to Jacoby Creek in the fall of 1977 were either from natural reproduction in the creek or from unmarked salmon planted into Jolly Giant Creek. Thus some knowledge of the size of native runs into Jacoby Creek is necessary in assessing the impact of the 1977 run of adult coho straying from Jolly Giant Creek.

No systematic studies on juvenile and adult salmon in the creek have been made although cursory observations by residents on the creek have indicated that since 1974 the number of adult fish in the stream has been noticeably lower.

Although some electrofishing surveys (in intermittent pools along the lower portions of Jacoby Creek) in the spring of 1976 found steelhead trout juveniles but no coho, interpretation of the data is limited by the fact that no surveys were made of the headwaters of tributary streams (Van Kirk, R. 1978, Associate Professor of Fisheries, Humboldt State University, Personal Communication). In the summer of 1976, however, electrofishing surveys found coho in a two-mile section of the stream located approximately in the middle portion of the creek. The number of these smolts that migrated to Humboldt Bay in the spring of 1977 was estimated from the catch of smolts in a downstream-migrant trap constructed at the head of tidewater. An estimated 7,000 smolts left the stream (Harper, W. 1976, Unpublished Master of Science research data). We have no reason to believe that the abundance of unmarked juvenile coho of the 1974 brood in Jacoby Creek was any more abundant than the 7,000 smolts estimated for the 1975 brood. At an escapement rate of 0.5 percent, a total of 35 unmarked salmon would be expected from such a level of natural smolt production had it occurred to Jacoby Creek for the 1974-brood year.

No historical data exist on the size of adult runs in Jacoby Creek. A systematic study of adult steelhead and salmon runs was only initiated in the fall of 1976 (Van Kirk, R. 1977, Personal Communication). In the 1976-77 migratory season, salmonids could not enter the stream until the winter of 1977 due to drought conditions. Electrofishing surveys of the creek in January took 30 coho, of which 16 were jacks, including one RV-marked jack of Jolly Giant Creek origin. For the 1977-78 migratory season based on coho salmon trapped at the weir and obtained by electrofishing in the creek, we estimated a total run of about 150 fish occurring between October 25, 1977 and February 1, 1978. This estimated total run included unmarked native Jacoby Creek salmon, and both marked and unmarked salmon from Jolly Giant Creek. Of the total run, a majority were "jacks" (precocious male returning as 2-year-olds).

POND SMOLTING AND TIME OF RELEASE

The first coho smolt was taken in a Hume-downstream migrant trap in the South fish pond on April 6, and the last taken on May 7. Water temperatures on increasing to about 17.0 caused smolting to cease and coho salmon smolts to start reverting to parr (Del Sarto, G. 1978, Unpublished Master of Science research data). All coho in the pond on May 7 were removed to 1,000-gallon aquaria adjacent to the ponds where water temperatures were about 12° C allowed smolting to proceed. These smolts were planted unmarked on May 12 (Table 3). RV-marked smolts were released in small batches from April 20 to May 12 (Allen 1976).

Downstream migration of smolts in Jolly Giant Creek was monitored by releasing into Jolly Giant Creek groups of about 200 fish taken from the pond by seining and from catches in the Hume trap. Releases were made at about two-weeks interval from March 22 until June 25. Each group was given an identifying mark and migration to the sea was measured by catches in a downstream migrant trap. An extensive study of gill enzyme Na,K ATPase activity was conducted on juvenile coho salmon. All these data indicate that the wastewater-reared coho smolts removed from the ponds by selective trapping and planted into the upper intertidal area of Jolly Giant Creek migrated quickly into Humboldt Bay (Del Sarto, G., Personal Communication; Allen 1976).

RECOVERY OF COHO SALMON IN JOLLY GIANT CREEK

A total of 34 adult coho salmon (0.3 percent of smolts planted) was recovered from the Jolly Giant Creek weir and trap (Table 4). That at least one adult salmon returned to the local area but which was not trapped at the weir was shown by a reliable report of a fresh salmon carcass found in a small slough entering lower Butcher Slough (Table 3). The ratio of RV-marked salmon to unmarked salmon recovered from the trap was not different from the ratio of marked to unmarked smolts planted ($X^2 = 2.41$, $P > .05$ (NS)). These ratios rejected the hypothesis that recently fin-clipped smolts were subject to differential mortality from disease, presumably vibriosis.

Unmarked female salmon tended to appear in greater numbers at the end of the run. This phenomenon occurs normally in natural populations but may have also been related to the fact that unmarked smolts were the last fish to be planted into the stream. These adults may have been Jacoby Creek strays but this appears unlikely since no adult coho were trapped in 1976 when 30 adults at least returned to Jacoby Creek, and that no chinook salmon have been recorded in Jacoby Creek whereas chinook salmon have been recovered in Jolly Giant Creek for the past three years (Table 2).

Female coho salmon trapped were held for maturation in 1,000-gallon aquaria in the fish barn located adjacent to the fish rearing ponds. Ripe male and female salmon were transported to the Humboldt State University for spawning. Eggs from individual females were incubated separately. Eggs per female ranged from 2,500 to 3,900 with an estimated 47,000 eggs being produced by 15 females taken from Jolly Giant Creek. At time of this paper, survival of eggs and fry appears normal for our student-oriented hatchery operations.

Adult coho salmon were fairly large, ranging in fork length from 50.5 to 73.0 cm for males and from 62.5 to 75.6 cm in females. The largest male weighed 10.3 pounds and the largest female 13.7 pounds. The average weight of males was 7.4 pounds, and females 9.3 pounds.

Table 4. Number of 3-year-old 1974 brood coho salmon recovered at Jolly Giant trap site October-December 1977, by mark and sex.

Period of recovery	Fin Excision		Sex		Totals
	RV	None	Male	Female	
Oct 25	2	0	1	1	2
Nov 5	7 1/	1	5	3	8
Nov 21-26	14	7	13	8	21
Dec 10-13	0	3	0	3	3
Totals	23	11	19	15	34

1/ Includes one unauthorized marked fish (RP-RV). Between 1-2% of smolts released were incorrectly marked RP (Allen 1976).

For all fish the average weight was 8.2 pounds. One salmon had the dorsal lobe of the caudal fin completely removed by a recent bite by a seal or shark. No salmon showed deformed jaws. Female salmon were all silvery on arrival, while males tended to have a slight reddish tinge. All salmon took on very bright red colors when placed in freshwater aquaria. A few excess male salmon placed in pens in South Pond in water salinities of around 12 ppt lost their bright color, and returned to more silvery condition.

RECOVERY OF COHO SALMON IN JACOBY CREEK

As mentioned previously, high water flows in Jacoby Creek allowed coho salmon to by-pass the weir on several occasions either by passing over the weir when flood waters submerged the structure, or when holes developed either at the wings of the weir or underneath its base. Thus several methods were employed in estimating the number of marked Jolly Giant Creek salmon, unmarked Jolly Giant Creek salmon, and unmarked Jacoby Creek salmon that occurred in the 1977-78 run.

Progression of the run occurred in three stages. The initial phase was the return of marked Jolly Giant Creek fish in October and November, with a sizeable portion of this run by-passing the weir during high flow periods in mid-November. The second phase began in late November with the appearance of native unmarked Jacoby Creek salmon, overlapping the late returning portion of the Jolly Giant Creek run. The third phase was the return of native unmarked Jacoby Creek salmon from mid-December through January.

The first adult coho salmon was trapped on 25 October 1977 (Table 5), the same day that coho appeared in the Jolly Giant Creek trap

Table 5. Number of adult (3-year-old) 1974 brood coho salmon recovered at Jacoby Creek trap site, October 25, 1977-January 9, 1978, by mark and sex.

Period of recovery	Fin Excision		Sex		Totals	Remarks
	RV	None	Male	Female		
Oct 25	0	1	0	1	1	Weir passable
Nov 5	1	0	0	1	1	Weir submerged
Nov 21-26	2 1/	2	1	3	4	Weir passable Nov 22-26
Nov 29-Dec 1	1	3 3/	4	0	4	Weir effective Nov 30-Dec 1, weir passable Nov 29
Dec 10-13	0(3) 2/	1	0(3) 2/	1	1(3) 2/	Trap effective
Dec 16	0	1	1	0	1	Weir passable Dec 14-15
29	0	1	0	1	1	Weir effective Dec 16-29, passable Dec 30
Jan 9	0	1	0	1	1	Weir passable Dec 31-Jan 3
Totals	7	10	9	8	17	

1/ Includes one unauthorized marked (RP-RV) (see footnote, Table 4).

2/ Fish that had escaped past weir, presumbaly spawned, and were recovered dead on the upstream side of weir shown in parentheses.

3/ Includes one adult unmarked male taken by electrofishing on November 30.

Table 5. Number of adult (3-year-old) 1974 brood coho salmon recovered at Jacoby Creek trap site, October 25, 1977-January 9, 1978, by mark and sex.

Period of recovery	Fin Excision		Sex		Totals	Remarks
	RV	None	Male	Female		
Oct 25	0	1	0	1	1	Weir passable
Nov 5	1	0	0	1	1	Weir submerged
Nov 21-26	2 1/	2	1	3	4	Weir passable Nov 22-26
Nov 29-Dec 1	1	3 3/	4	0	4	Weir effective Nov 30-Dec 1, weir passable Nov 29
Dec 10-13	0(3) 2/	1	0(3) 2/	1	1(3) 2/	Trap effective
Dec 16	0	1	1	0	1	Weir passable Dec 14-15
29	0	1	0	1	1	Weir effective Dec 16-29, passable Dec 30
Jan 9	0	1	0	1	1	Weir passable Dec 31-Jan 3
Totals	7	10	9	8	17	

1/ Includes one unauthorized marked (RP-RV) (see footnote, Table 4).

2/ Fish that had escaped past weir, presumbaly spawned, and were recovered dead on the upstream side of weir shown in parentheses.

3/ Includes one adult unmarked male taken by electrofishing on November 30.

(Table 4). Although the run peaked in late November in Jolly Giant Creek (Table 4), it was difficult to establish the time of peak migration in Jacoby Creek because salmon could pass the weir and trap during this period (Table 5).

A total of 9, 3-year-old 1974-brood coho salmon were recovered at the weir on Jacoby Creek from late October to December 5, 1977 (Table 5). From December 6 to 16, three RV-marked adult fish recovered as carcasses washed down the creek onto the face of the weir. During this period two adult unmarked fish were trapped. Through December 16, 11 adult coho were recovered from all sources, of which seven were marked Jolly Giant fish.

The number of salmon taken in the trap and those tagged and released above the weir are shown in Table 6. Surveys of Jacoby Creek to establish tagged to untagged ratios were made on five days when stream conditions were favorable and manpower available (Table 7). Only nine fish were taken in these surveys and of these only one (1) was a salmon tagged at the weir. No fin-marked (RV) Jolly Giant Creek fish appeared in these electrofishing samples.

Under normal conditions, precocious male salmon (jacks) are the first to appear on the spawning grounds. Thus the appearance of jacks at the Jacoby Creek weir should have indicated the start of the native run into the creek. The first jacks (two fish) were taken on 24 November, another on November 25, one on December 5 and another three jacks recovered on 11 December (Table 6). In late November, extremely heavy rains brought in the last of the Jolly Giant Creek fish and the start of the natural Jacoby Creek run. Thus we considered that only those samples of adult fish taken by electrofishing on November 30, December

Table 6. Actual number of coho salmon captured in trap in Jacoby Creek weir, and number tagged and released above above weir, October 25 to December 5, 1978.

Period	Age and sex of salmon			Total	Total number 3-year-olds tagged	Weir operation	
	3-year-old						
	Male	Female	Jack			Number days	Days weir passable to salmon
25-30 Oct	0	1	0	1	1	6	3
1-30 Nov	3	4	3	10	6	30	9
1-5 Dec	1	0	1	2	1	5	0
6-30 Dec	1	2	6	9	3	25	3
1-9 Jan	0	1	1	2	2	9	4
Totals	5	8	11	24	13	75	19

Table 7. Number of tagged and untagged 1974-brood 3-year-old coho salmon recovered above Jacoby Creek weir by electrofishing November 1977 - January 1978. (All tagged coho released above weir were unmarked fish).

Date of sampling	Areas of creek sampled	Number of salmon recovered	
		Tagged	Untagged
Nov 30	Middle section 1/	0	1
Dec 20	Middle section	0	3
Dec 26	Lower section	1	0
Jan 3	Upper section	0	1
Jan 12	Middle section	0	2
Jan 26	Middle section	0	1
Totals		1	8

1/ Based on surveys in winter of 1977, the middle section appears to have the best spawning beds. The upper section is in an area of sharp gradient not considered very suitable for coho salmon. Lower section is very low gradient located adjacent to the upper tidal reaches of the creek.

20 amd 26 could be used to estimate the size of the runs which had escaped the weir (Table 8). Since only RV-marked carcasses were collected from off the rack in mid-December (Table 5), the estimated run was probably biased toward the later-running native Jacoby Creek fish.

Using data for mark and recapture of both adult and jack coho salmon as presented in Table 8, we estimated a coho run to December 26 of about 145 fish of which the majority are jacks (Table 9). The total adult run includes strays from Jolly Giant Creek.

An estimate of the run of Jolly Giant fish in the run was made as follows. The number of tagged and untagged fish recovered in electrofishing in samples obtained November 30 - December 26 (1 tagged to 5 untagged salmon, Table 7) is a measure of trapping efficiency. Since four RV-marked coho salmon were actually recovered in the trap, we estimated 20 RV-marks occurred in the total run (trapped RV-marked salmon x trap efficiency; 4 x 5). Since unmarked salmon of Jolly Giant Creek origin would also be in the run, we used the unmarked-to marked ratio found in the Jolly Giant Creek run to estimate that 10 unmarked coho were also of Jolly Giant Creek origin (20 x 11:23). Combining estimated marked and unmarked Jolly Giant fish in the run, about 30 adult coho of Jolly Giant Creek origin were in the Jacoby Creek run from October through December. These 30 salmon would be about 0.2 percent of the smolts released into the Jolly Giant Creek estuary. This is more than half of the total adult coho run estimated for the creek through December (Table 9).

Straying also occurred in the return of "jacks" (precocious males or 2-year-old fish). In the fall of 1976, a single RV-marked jack was recovered from the Jolly Giant Creek trap. No weir was in place in

Table 8. Number of tagged and untagged coho salmon taken by electrofishing sampling above Jacoby Creek weir during period when Jolly Giant Creek salmon were most likely to have been recovered (Nov. 30 - Dec. 26, 1977).

Sampling date	Age and sex of salmon recovered: 3-year-old Male	Age and sex of salmon recovered: 3-year-old Female	Jack	Total	Number of tagged salmon theoretically available for recovery: Adults	Jacks	Total	Actual number of tagged salmon recovered: Adults	Jacks	Total
30 Nov 77	1	0	0	1	7	3	10	0	0	0
20 Dec 77	0	3	8	11	9	8	17	0	1	1
26 Dec 77	0	1	4	5	9	8	17	1	0	1
Totals	1	4	12	17	9	8	17	1	1	2

Table 9. Estimated number of jack and adult coho salmon returning to Jacoby Creek through December 26, 1977, based on data as listed in Table 8.

Category of salmon	Type of Estimate (Ricker 1957)	
	Petersen index 1/ $N = \frac{(m)(c)}{(r)}$	Bailey modification $N = \frac{(m)(c + 1)}{(r + 1)}$
Jack	96	52
Adult	45	27
Combined	145	102

1/
N = Estimate of number of fish
m = Number of marked fish
c = Number of fish sampled
r = Number of marked fish recaptured in sample

1976, and electrofishing surveys of fish in the creek only began in January of 1977 after heavy rains started substantial flows in the creek. Of 16 jacks recovered, only one (1) RV-marked jack was recovered, and that occurred on January 8, 1977, which was the first day of sampling. Since at least two RV-marked jacks were actually recovered, we consider at least one of the unmarked jacks recovered in Jacoby Creek was a Jolly Giant Creek fish. It is possible that some Jolly Giant Creek jacks actually died in Humboldt Bay in the 1976-77 migratory season. A moribund, small-sized salmon was sighted in early February 1977 on the banks of a small island just adjacent to the outlet of the oxidation pond but the carcass was not recovered for detailed examination (Table 3).

RESULTS AND DISCUSSION

Smolts reared in a wastewater-seawater pond selectively removed from the pond and planted into the intertidal reaches of a small urban stream successfully returned to their "homestream" and closely adjacent areas. In comparison, LV-marked smolts planted into a highly saline intertidal slough, failed to appear in the escapement.

A minimal estimate of the total escapement to freshwater from Humboldt Bay of the 1974-brood coho reared in a wastewater-seawater pond was 67 fish, or about 0.5 percent of the 12,000 smolts released (Table 10). This is about the average escapement to hatcheries reported for Washington State salmon hatcheries (Ellis and Noble 1959). It appears to be average to above average for 1974 brood coho salmon returning in 1977 to all United States area except Southern Puget Sound (Allen, G. 1978, Personal observation March 19-24, field trip to coastal Oregon and lower Columbia River hatcheries).

Table 10. Total number of 1974-brood coho salmon returning to Jolly Giant Creek and estimated return to an adjacent watershed (Jacoby Creek) from smolts released into Jolly Giant Creek, spring, 1976.

Year of return	Jolly Giant Creek			Jacoby Creek			Total return		
	Marked	Unmarked	Total	Marked	Unmarked	Total	Marked	Unmarked	Total
1976	1	0	1	1	1	2	2	1	3
1977	23	11	34	20	10	30	43	21	64
Total	24	11	35	21	11	32	45	22	67

Considerable straying occurred in Jolly Giant Creek smolts to Jacoby Creek (the nearest open drainage). This rate was about 45 percent of the planted smolts recovered as adults. This straying produced most of the adult coho run to Jacoby Creek during October-November, and about half of the total adult run in the 1977-78 migratory season.

The selection of streams for spawning by returning adult coho salmon has been shown as an olfactory response (Hasler 1966). The use of artificial compounds, such as morpholine, has been used to greatly increase the precision of return to a stream by "imprinting" smolts to these substances, then metering in small quantities of the chemical into a desired point of return (Scholtz et al. 1975). Streams decoyed with morpholine have attracted from 7-8 times more salmon imprinted with morpholine than salmon not imprinted (Table 11). However, imprinted salmon in these studies were not planted into a stream but into a lake, and then decoyed to a stream. Thus, of more significance to our study is the percentage of salmon that were imprinted but did not return to a morpholine-decoyed stream. Comparison 1-2 (Table 11) appears most like the present experiment and showed 33-76 percent straying. Comparison 5 shows the degree of improvement possible by decoying techniques (decrease from 85% straying to only 9 percent).

A new and inexpensive method of possibly decoying salmon to capture sites in order to minimize straying is being proposed by the use of "imprinting ponds" to be operated with wastewaters from a reclamation unit of a domestic wastewater treatment system (Figure 4). The organic compounds in the water from the wastewater treatment-reclamation system will provide the imprinting compounds. Juvenile salmonids will be planted into the imprinting ponds prior to the onset of smolting and

Table 11. Improvement in returns of coho salmon to artificial homestream through decoying techniques using morpholine (from Scholtz et al. 1975).

Comparison	Experimental design: Return year	Experimental design: Decoy stream	Percent return of fin-marked adult salmon to stream decoyed with morpholine: Smolts imprinted to morpholine	Percent return of fin-marked adult salmon to stream decoyed with morpholine: Smolts not imprinted (controls)	Ratio: Imprinted / Controls
	Smolts released at mouth of river, and no morpholine added to river during adult run				
1	1974	Oak Creek	1.02 (34) 1/	1.10 (33)	0.9
2	1974	Bear Creek	0.48 (76)	0.50 (75)	1.0
	Smolts released at mouth of river, and morpholine added to river during adult run				
3	1971	Oak Creek	0.62 (50) 2/	0.69 (50) 2/	
4	1972	Oak Creek	2.31 (73) 2/	0.31 (73) 2/	7.7
5	1974	Manitowac River	4.04 (9.42)	0.60 (85.51)	6.7

1/ and 2/ See footnotes, next page.

1/ Straying rate determined from number of strays and total number of adults recovered.

2/ Straying rate determined from unmarked experimental fish plus strays since there was no way to separate imprinted smolts from controls.

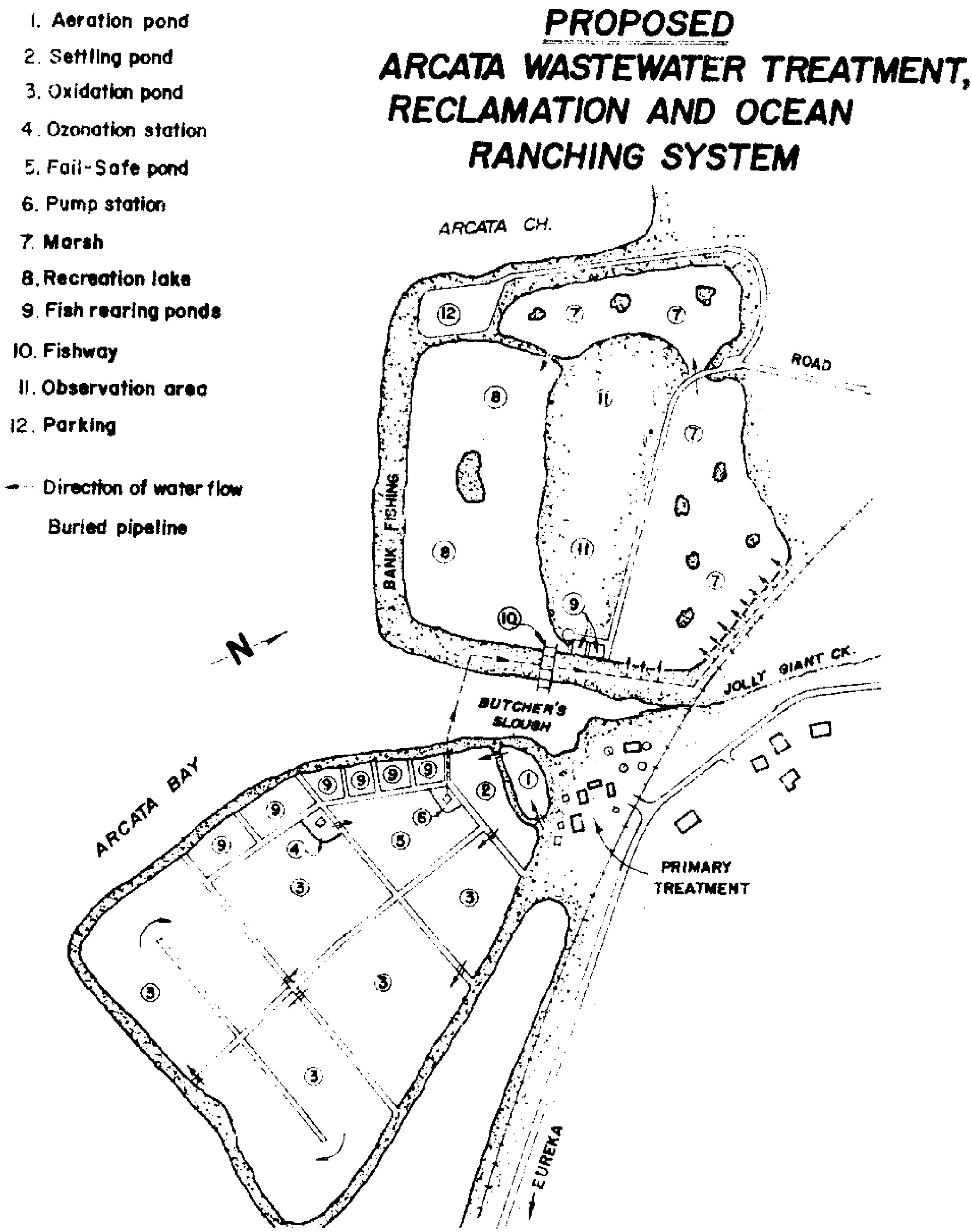

Figure 4. Proposed integrated wastewater treatment and reclamation system that will use reclaimed water for rearing juvenile anadromous salmonids, and utilize final water flow into Butcher Slough as a "homestream" for imprinting smolts and capturing returning adults.

allowed to smolt and migrate in a natural sequence to Butcher Slough by the water directed through a fishway. The same reclaimed wastewater stream will be used to attract adult salmon into the fishway on their return to the area during their spawning migration. Manipulation of the flow of water in the fishway leading into Butcher Slough will be possible by the use of water to be stored for this purpose in the recreational lake. Should homing not be improved by this technique, morpholine-decoying techniques can be tested as outlined by Scholtz et al. (1975) in the proposed system.

ENHANCEMENT

Smolts that have been released in pilot project studies have contributed to ocean fisheries but lack of studies on adult returns has prevented estimates of such value. For the 1974 brood coho, a gross value to the local fishing economy can be calculated based on recorded escapement of adult salmon. Assuming a minimal 3:1 catch-to-escapement ratio, we estimate that about 200 salmon were contributed to the ocean fisheries. Assuming that salmon were only taken in the commercial troll fishery, that the average weight per salmon caught was about eight pounds, and that the price to the fisherman was about two dollars per pound, this catch added at least $3,200 to the fisherman's revenue. Since a portion of the catch undoubtedly went to recreational fishermen, our estimate is conservative since the value of a sport-caught fish is higher than for a commercial fish. There are dollar values associated with eggs deposited in Jacoby Creek by Jolly Giant Creek salmon, and those eggs taken in Jolly Giant Creek for hatchery incubation. We did not attempt to estimate this value for 1977 since the commodity was virtually unavailable due to poor returns to hatchery facilities along the entire coastal areas of the United States.

It is clear that the Arcata pilot-project ocean-ranching program is enhancing the beneficial uses of local fresh and marine waters beyond that which would have occurred in the absence of the wastewater-seawater aquaculture system. Expanded enhancement of Humboldt Bay waters is being proposed by the City of Arcata by use of reclaimed wastewaters in an "ocean ranching" project (Figure 4) to meet the 1972 Clean Water Act (PL 92-500) mandate for beneficial use of wastewaters to aid in meeting wastewater treatment costs.

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Appendix I. LV-marked chinook (king) salmon recovered from Jolly Giant Creek trap, September, 1977.

(Courtesy Arcata Union)

Appendix II. RV-marked silver (coho) salmon recovered from Jolly Giant Creek trap, November, 1977.

(Courtesy Arcata Union)