Pen Rearing Pacific Salmon, *Oncorhynchus* spp., in San Francisco Bay

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Introduction

Saltwater net-pen culture of Pacific salmon, *Oncorhynchus* spp., is a recent development in salmonid management. The technique consists of transferring smolts directly from fresh water into saltwater net pens. The salmon are reared in salt water, where their growth rate is accelerated, and at the appropriate time or size of fish, they are released or harvested for marketing.

Research on saltwater pen rearing on the U.S. west coast was initiated in 1969 by the National Marine Fisheries Service's (NMFS) Northwest and Alaska Fisheries Center at its Manchester Field Station on Clam Bay in Puget Sound, Wash. (Novotny, 1975). Coho, *O. kisutch*, and chinook, *O. tshawytscha*, salmon held in saltwater net pens in Puget Sound beyond the time of their normal migration into the sea tended to remain in the Sound and were more accessible to recreational fishermen (Novotny, 1975; Moring, 1976). In addition, chinook salmon were found to return to streams closest to the pen-rearing site rather than to their natal or hatchery streams (Novotny, 1975). Such delayed release of pen-reared salmon resulted in improved returns to the fishery as well as better spawning escapement (Mahnken and Joyner, 1973).

Figure 1.—Pacific salmon pen-rearing study area.

ABSTRACT—Chinook, Oncorhynchus tshawytscha, *and coho,* O. kisutch, *salmon were pen-reared in San Francisco Bay from 1974 to 1979 at the NMFS Southwest Fisheries Center's Tiburon Laboratory, Tiburon, Calif. Environmental and experimental conditions varied from year to year and tag returns indicated an inconsistent contribution of the different pen-reared groups to the local sport fishery and ocean harvest. The best results were from chinook salmon reared in 1976. Although commercial applications of pen rearing in San Francisco Bay might succeed, we do not see the release of pen-reared fish as an effective management technique for increasing the ocean catch in California.*

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The Squaxin Indian tribe, Shelton, Wash., has pen-reared coho salmon since 1976 and is currently releasing over 1 million fish annually. This program has increased the tribal catch dramatically. Consistent returns of 15-20 percent are being achieved[1].

In 1974, the NMFS Southwest Fisheries Center's Tiburon Laboratory, Tiburon, Calif. (Fig. 1), in cooperation with the San Francisco Tyee Club (a

[1]Tim Tynan, Squaxin Indian Tribe, Shelton, Wash. Unpubl. data.

recreational fishermen's association), the California Department of Fish and Game (CDFG) and the University of California Cooperative Extension Service—Sea Grant (UCSG) began a series of salmon pen-rearing and release experiments to investigate the feasibility of pen rearing in San Francisco Bay. The primary objectives were to learn if seawater pen rearing of Pacific salmon would be possible in San Francisco Bay and if a recreational coho fishery could be established inside the Bay. As the study progressed, we added the ancillary objectives of measuring the contribution of pen-reared salmon to the ocean harvest and determining if pen rearing salmon in San Francisco Bay would be a cost-effective technique for augmenting the ocean harvest of Pacific salmon.

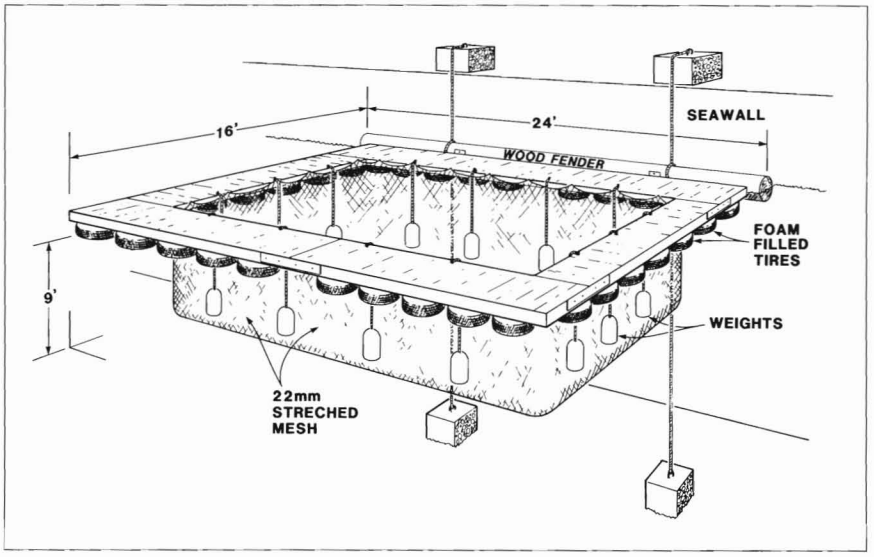

Figure 2.—Diagram of rearing pen.

Rearing Environment

The pen-rearing site at the Tiburon Laboratory was on the northeast shore of the Tiburon Peninsula on San Francisco Bay (Fig. 1). The pens were fastened alongside a concrete quay where the depth was 3.2 m at mean lower low tide and the mean daily tidal range was 1.75 m. Tidal currents typically reached 1 km/hour. The pens were exposed to wave action from wakes of passing ships and from wind waves ranging up to 1.6 m. Annual ranges in salinity and temperature recorded at the pen-rearing site were 9-31‰ and 9.5°-21.0°C, respectively.

Net-pen enclosures, constructed of nylon mesh in the form of topless rectangular boxes, were hung from floats which also served as walkways (Fig. 2, 3). Mesh sizes were 22-32 mm stretched measure. To prevent deformation of the net in tidal currents, plastic gallon jugs filled with sand were suspended from lines inside each corner, and at about 1.8 m intervals along the sides and ends.

Predaceous seabirds were excluded from the open tops of the net pens by nylon nets stretched over the pens about 1 m high on pipe stanchions and polypropylene rope crisscrossed over the pen structure.

Figure 3.—Rearing pen in place.

Pen-Rearing Procedures

Table 1 summarizes information on the nine groups of salmon reared during the study. Coho salmon were initially selected for the pen-rearing experiments on the basis of the NMFS Manchester Field Station reports and the evaluation guidelines given by Novotny

Table 1.—Summary of details pertaining to Pacific salmon pen-reared and released at the Tiburon Laboratory, 1974-79.

Group no.	Species	Brood stock	Last hatchery	No. fish delivered	Release date	Days in pen	No. fish released	Mean size (g/fish) at delivery	Mean size (g/fish) at release
1	Coho	Noyo R., Calif.	Mad R., Calif.	10,000	11/06/74	119	4,000	15	200
2	Coho	Kalama R., Wash	Mariculture N.W., Wash.	40,000	11/24/75	116	30,320	19	220
3	Coho	Alsea R., Oreg.	San Joaquin, Calif.	30,000	3/31/76	74	5,700	62	90
4	Chinook	Fall run Feather R., Calif.	Feather R., Calif.	20,250	12/17/76	78	6,900	34	103
5	Coho	Skagit R., Wash.	Mad R., Calif.	30,000	7/14/77	128	3,430	23	131
6	Coho	Toutle R., Wash.	Aqua Dell, Oreg.	28,250	9/12/77-11/08/77	53-110	9,220	22	86 206 233
7	Chinook	Fall run Feather R., Calif	Feather R., Calif.	100,480	6/13/78	53	24,700	3.2 3.5	7.9
8	Chinook	Fall run Feather R., Calif.	Feather R., Calif.	100,000	10/26/78, 11/03/78	129-136	19,900	6.7 8.5	68 85
9	Chinook	Fall run Feather R., Calif.	Feather R., Calif.	76,050	11/20/79, 11/21/79	92-93	12,720	14	75

Table 2.—Summary of tag release and return details for groups of salmon pen-reared at the Tiburon Laboratory, 1974-79.

Group no.	Tagged[1] fish released (no.)	Tag[1] returns (no.)	Percent return	Adjusted[2] return rate (%)
1	4,000 N 600 F	16 N 2 F	0.4 N 0.3 F	—[3] —[3]
2	7,631 C	67 C	0.9	3.9
3	4,717 C	42 C	0.9	3.9
4	2,645 C	144 C	5.4	23.5
5	2,417 C	2 C	0.1	0.4
6	6,433 C, B	13 C 0 B	0.2 C	0.8 C
7	16,300 N	275 N	1.7	—[3]
8	18,500 N 1,400 C	2,461 N 20 C	13.3 N 1.4 C	5.9 C
9	12,720 n	1,435 N	12.8	—[3]

[1]Tag types: B = Freeze brand, C = Carlin, F = Floy dart, and N = nose.
[2]Adjusted for tagging mortality/tag shedding.
[3]The tagging mortality/tag shedding adjustment factor of 4.32 demonstrated for Carlin tags only.

(1975). These reports indicated that cohos are more resistant to disease and handling mortality during saltwater culture than chinook salmon, and exhibit good first-year growth in salt water. Also, since coho salmon are not normally found in either the Sacramento-San Joaquin River system or the San Francisco Bay-Delta system (Hallock and Fry, 1967) we could assume that most cohos found near the rearing site or upstream had originated at our net pens.

Smolts (young fish physiologically capable of osmoregulating in seawater) were provided by State or Federal hatcheries in California or were purchased from commercial hatcheries in Oregon or Washington. The fish were delivered to Tiburon by hatchery trucks usually equipped with refrigeration and recirculating pumps.

Several factors led to our decision to use chinook salmon for the final three rearing experiments. They were readily available from California State hatcheries free of charge, whereas cohos were not, and funds were not available to purchase cohos from commercial hatcheries. In addition, we had successful results with the chinooks reared in the Group 4 experiment.

Groups 1, 2, and 5 (Table 1) were inoculated against *Vibrio anguillarum* by vaccine injection at least 2 weeks before transport. Group 9 was inoculated against *V. anguillarum* by immersion in vaccine. The other groups were not inoculated.

In 1974, the first year of the pen-rearing experiments, the fish were fed Oregon Moist Pellets[2] (OMP). Thereafter, rearing capacity was quadrupled and dry-pellet salmon diets were substituted because sufficient refrigerated storage capacity for the OMP was not available.

Feeding rates of 3-5 percent body weight per day were used, dividing daily rations into four feedings. For groups with a large size range, the daily ration was divided into three feedings so that toward the end of each feeding period there was food left for the smaller, less aggressive fish after the larger ones had fed to satiation.

Pen stocking did not exceed the recommended density of 16 kg/m^3 (Novotny, 1975). As the salmon grew, fish were transfered to avoid exceeding this capacity.

After release of the salmon, nets were removed from the Bay and hung to dry. The nets were cleaned of fouling growth, inspected, and mended. At the end of the rearing year, pen sections were disassembled in the water, lifted out, and inverted for drying. When the sections were dry, the fouling organisms were scraped away and repairs were made. The work was usually accomplished in less than 100 worker-days.

[2]Mention of trade names or commercial firms does not imply endorsement by the authors or the National Marine Fisheries Service, NOAA.

Tagging

All 10,000 coho salmon of Group 1 (1974) and many chinook salmon in Groups 7, 8, and 9 were internally nose-tagged with binary-coded magnetic wire tags (Jefferts et al., 1963) and adipose-fin-clipped for field recognition (Table 2). Additionally, 600 fish from the 1974 rearing were double-tagged with plastic dart tags (Dell, 1968). Carlin tags (Saunders, 1968) were used from 1975 through 1978. Tagged fish were held in recovery pens until normal feeding behavior resumed—usually 1-2 days. Mass releases into the Bay were timed for an ebbing tide when the water was turbid to help conceal them from predators.

In addition to being Carlin-tagged, one group (Group 6) was also freeze-branded (Mighell, 1969) to test the effectiveness of this less expensive marking procedure. For this test, a 6.35 mm dual brand (symbol IH) was applied under the dorsal fin. When fish were not

marked and therefore not counted, the number released was estimated by weighing and counting random samples of the fish as they were dipnetted from the pens.

Pen-Rearing Experience by Year

Between July 1974 and November 1979, nine groups of salmon were reared and released at the Tiburon Laboratory saltwater pen site. Tables 1 and 2 summarize details of rearing and tag returns. Because of the great experimental dissimilarity among the rearing groups, we present here notes, by group, on our experiences in rearing these fish. Group numbers match those used in Tables 1 and 2.

Group 1, 1974

In the first year of the project, 10,000 coho salmon were reared in one pen as a pilot study. The fish, from Noyo River brood stock, were hatched and reared by CDFG at the Mad River Fish Hatchery, Arcata, Calif. They were injected with vibrio vaccine when they were nose-tagged at the hatchery. They were delivered to the Tiburon Laboratory and placed in a floating pen on 10 July 1974 at an average size of 15 g.

Observed mortalities in this group of fish during pen rearing were 2,845, of which about 10 percent were found on the surface. The release of an estimated 4,000 fish revealed an inventory discrepancy of 3,000 fish. The problem of unaccountable inventory losses was also prevalent in each succeeding rearing throughout the later years, and has been reported by other workers who have reared salmon in pens[3].

Group 2, 1975

This group of coho salmon was obtained from a commercial salmon grower in Washington. They had already been injection-immunized for vibriosis. On 1 August, 40,000 fish were delivered to Tiburon and placed in one net pen.

For several days, the salmon were fed a mixture of OMP and dry pellet feed sprayed with fish oil. After this adjustment period, they were fed a straight diet of dry pellets. As the salmon grew, they were transferred to other net pens until they were about equally divided among four pens. This group experienced fewer problems and greater survival during rearing than any other group. On 24 November, the 30,320 fish remaining were released; 7,631 of these were tagged.

Group 3, 1976

Yearling coho salmon were the first of two groups reared in 1976. Because the fish were delivered on short notice, the pens and nets were not ready; however, two above-ground plastic swimming pools were available for use. These pools were supplied with Bay water by a submersible pump.

On 16 January the salmon were delivered and stocked in the two pools. One net pen was made ready, and 7,500 fish were transferred to it on 4 February. That night the pump supplying the pools failed and the 22,000 fish still in the pools suffocated by the next morning.

The salmon placed in the net pen were the largest received during the entire project and had a large size range (20-270 g), as they had never been graded during their year of hatchery rearing. This presented feeding problems due to the dominance of the larger fish.

Pen rearing lasted through March, and the fish were released on 31 March. Of the 5,700 released, 4,717 had been Carlin-tagged the week before.

Group 4, 1976

Cohos were not available but 20,250 fall-run chinook salmon were obtained from the CDFG Feather River Hatchery in Oroville, Calif. These fish were just under 1 year old, and upon delivery on 1 October they averaged 34 g. They had not been vaccinated against vibriosis.

On 14 November waves broke the first pen loose from its moorings and about 12,000 salmon escaped before the net was repaired and the pen returned to its mooring. The remaining fish were unharmed.

This group, the first chinook salmon reared in the project, was healthier than most others. Size range was small and all fish appeared to feed well throughout the rearing period. They were handfed dry pellets four times per day at a daily ration of 4 percent of their weight. No disease problems were encountered. We were impressed by the ease of rearing and the good growth rate for this first group of chinooks, both being contrary to reports that chinook salmon were more difficult to rear than cohos. On 17 December, after 78 days of rearing, the surviving 6,900 chinooks were released, 2,645 of which were Carlin-tagged.

Group 5, 1977

These coho salmon from the Mad River Hatchery were delivered to Tiburon on 3 March. At delivery, the 30,800 fish had a mean weight of 23 g (range 10-199 g). A high incidence of cannibalism was anticipated, and was verified by observation. The cohos appeared to be in poor health at delivery and suffered heavy mortality during their confinement. At release on 14 July, only 3,430 fish remained, of which 2,417 were Carlin-tagged.

Group 6, 1977

This group consisted of coho salmon from Toutle River (Washington) brood stock reared in fresh water at Aqua Dell Farms in Oregon. A total of 28,250 salmon, averaging 22 g, was delivered to Tiburon on 21 July. Initial mortality in this group was high: 33.1 percent of the number delivered died within the first 5 days.

Freeze-branding and Carlin-tagging began on 7 September, about 1½ months after the fish were introduced into the net pen. The number of marked fish released was 6,433. These were the last coho salmon reared and released during the project.

Group 7, 1978

Chinook salmon for the 1978 and 1979 rearings were obtained from fall-run Feather River brood stock spawned and reared by CDFG at the Feather River Hatchery, Oroville, Calif. The first 1978 group was delivered to Tiburon on 21 April and consisted of about 100,480 fish, of which 38,160 were nose-tagged.

[3]A. Novotny, NMFS Northwest and Alaska Fisheries Center, Seattle, Wash. Personal commun.

We planned to rear tagged and untagged fish in adjacent pens. However, the net pen into which the untagged fish were being stocked was of a slightly larger mesh size which allowed some of the fish to escape. After the problem was discovered, the remaining untagged fish were put into the smaller mesh pen with the tagged fish. On the third day after delivery, nose-tagged fish averaged 3.5 g and untagged fish averaged 3.2 g; these were the smallest salmon received during the project.

The fish were reared for 53 days and the 24,700 remaining after disease mortality and escape were released on 13 June. At an average weight of 7.9 g, these fish were smaller than those of any other release group. Indeed, they were smaller at release than the mean size of any other group at delivery.

Group 8, 1978

The second group of chinook salmon in 1978 was composed of 50,000 nose-tagged and 50,000 untagged fish, reared in separate pens. The nose-tagged fish were delivered on 19 June, and the untagged fish the following day. The same problem of fish escaping the pens occurred with these untagged fish as had occurred in the spring delivery; there were two distinct size modes of fish, and the smaller ones easily passed through the net. Weight samples were taken 2 days after delivery. Nose-tagged fish averaged 8.5 g and untagged fish 6.7 g.

For prophylactic treatment, Terramycin was administered in the food for 10 days, starting with the initial feeding. When the Terramycin was discontinued on 29 June, tagged fish began to die in increasing numbers, and heavy mortality occurred on 5 July. The dying fish exhibited whirling behavior, external lesions, and hemorrhaging fins.

On 7 July, live samples of tagged and untagged fish were examined at the State Fish Disease Laboratory. Preliminary diagnosis for the tagged fish was vibriosis. No disease organisms were detected in the untagged fish; however, a vitamin deficiency was found. Thereafter, Terramycin and vitamin supplements were added to the feed.

The untagged fish suffered a negligible mortality rate, but many had escaped. On 17 August the net pen with untagged fish was inventoried and at least 35,000 fish were unaccounted for. The counting process killed 25 percent of those remaining. Several factors, in particular heavy scale loss and high water temperature, may have been responsible.

The nose-tagged fish were released on 26 October. On the release date a tag-retention check was performed which indicated 98 percent retention of the coded-wire nose tag.

The remaining untagged fish were Carlin-tagged 30 October-1 November. Only 2,000 of the expected 9,600 were present in the net pen. These fish, the last to be Carlin-tagged in the project, were released on 3 November 1978.

Group 9, 1979

In the final rearing experiment, two separate groups of chinook salmon were used—one reared in net pens as in previous years and the other released at the pen site upon delivery. Each group was nose-tagged. The second group served as a control to learn the effects of saltwater rearing and delayed release on survival. Both groups received identical treatment during freshwater residence, including immersion vaccination against vibriosis. Fish were delivered on 20-22 August. Average weight of both groups at delivery was 14 g. The pen-reared group numbered 76,050 fish and the release group numbered 24,800.

Feed rations were maintained at 3 percent throughout the rearing period, and Terramycin and vitamins were added at regularly scheduled intervals. Sulfamethazine was administered for 5 days immediately following the removal of a few dead fish from two of the net pens; however, no epidemic problems were encountered as in the previous year's two rearings.

The fish were released 20-21 November. The number released, adjusted for tag recognition percentages provided by CDFG, was 11,223 at an average weight of 75 g. The total number released was 12 percent higher. The adjusted figure for the control group was 21,730. The adjustment for tag recognition purposes is an estimate based on the size of fish, the experience of the tagging crew, and other factors which might affect tag retention and recognition of the adipose-fin clip.

Results and Discussion

Growth

The average weight of salmon in all groups increased exponentially with time during the rearing period. Growth curves fit to average weight at delivery and release for all nine groups of salmon are presented in Figure 4. The mean weight of each rearing group (except 3, 4 and 5) doubled during each 30- to 32-day period they were in the pens.

Group 3 cohos, yearling fish delivered in January 1976, grew more slowly than any other group. Their mean size was large at delivery and the size range was extreme. Both factors, together with cool winter water temperatures, probably accounted for the slow growth.

Somewhat slower growth was noted in Groups 4 and 5 than in the remaining six groups. For Group 4, the likely cause was cool water; for Group 5 the range of size at delivery was so extreme that the growth curve based on mean size was of little significance.

Tagging Mortality, Tag Shedding, and Tag Recognition

The returning coho salmon from the 1975 and 1976 releases provided an opportunity to estimate the combined tag shedding and tagging mortality of these Carlin-tagged fish during their time spent at sea. The releases consisted of the 1975 fall and 1976 spring Tiburon releases, and a 1975 UCSG release which had been held at Tiburon for a week before transfer to and rearing in Tomales Bay. The Tomales Bay salmon apparently imprinted to the Tiburon site, as returns for this group were recorded only at Tiburon.

The estimation of tagging mortality and/or tag shedding involved comparing numbers of tagged and untagged salmon released with the numbers of tagged and untagged returning salmon captured in a gill net set at the pen site in 1976. All returning cohos were assumed to be returns from the 1975 and 1976 releases rather than wild stock, as

wild cohos were not normally found in the San Francisco Bay-Delta system. None of the adipose-fin-clipped cohos released in 1974 were caught in the gill net. The gill net was assumed to be an unbiased sampling gear with respect to untagged and tagged fish. A *t*-test was used to determine if the length of tagged and untagged fish had the same mean. Mean length was equal at the 0.01 significance level so the assumption seemed justified.

Given these circumstances, the percent tagging mortality and/or tag shedding while at liberty is:

$$M = \left[1 - \left(\frac{C_t}{R_t} \right) \div \left(\frac{C_u}{R_u} \right) \right] \times 100,$$

where M = tagging mortality and/or tag shedding,
C_t = number of tagged salmon recaptured by gill net,
R_t = number of tagged salmon released,
C_u = number of untagged salmon recaptured by gill net, and
R_u = number of untagged salmon released.

It was not possible to distinguish between tag shedding and tagging mortality, as only tagged vs. untagged fish were discernible after return to the gill net. The tagging mortality/tag shedding rates in these releases were very high. Only 20 tagged salmon were among the 159 caught in the gill net. Of the total of 43,118 salmon released, 16,552 were tagged. This would indicate a tagging mortality and/or tag shedding rate of 77 percent.

It follows that, in the absence of such tagging mortality/tag shedding, 4.3 times as many tagged fish would have been recaptured. This adjustment was used in estimating return rates (Table 2). An assumption has been made that the tagging mortality/tag shedding rates were the same for all groups of Carlin-tagged fish and has been used in estimating the percentage of tag recoveries for all groups released with Carlin tags.

In the case of nose-tagged fish, recoveries from the sport and commercial ocean catch are made by samplers at each port where the fish are landed. Total nose-tagged fish returns are then estimated by the CDFG by dividing the number of actual recoveries by the percentage of the landings sampled. This calculation estimates the number of nose tags that would be recovered if all the landings were censused.

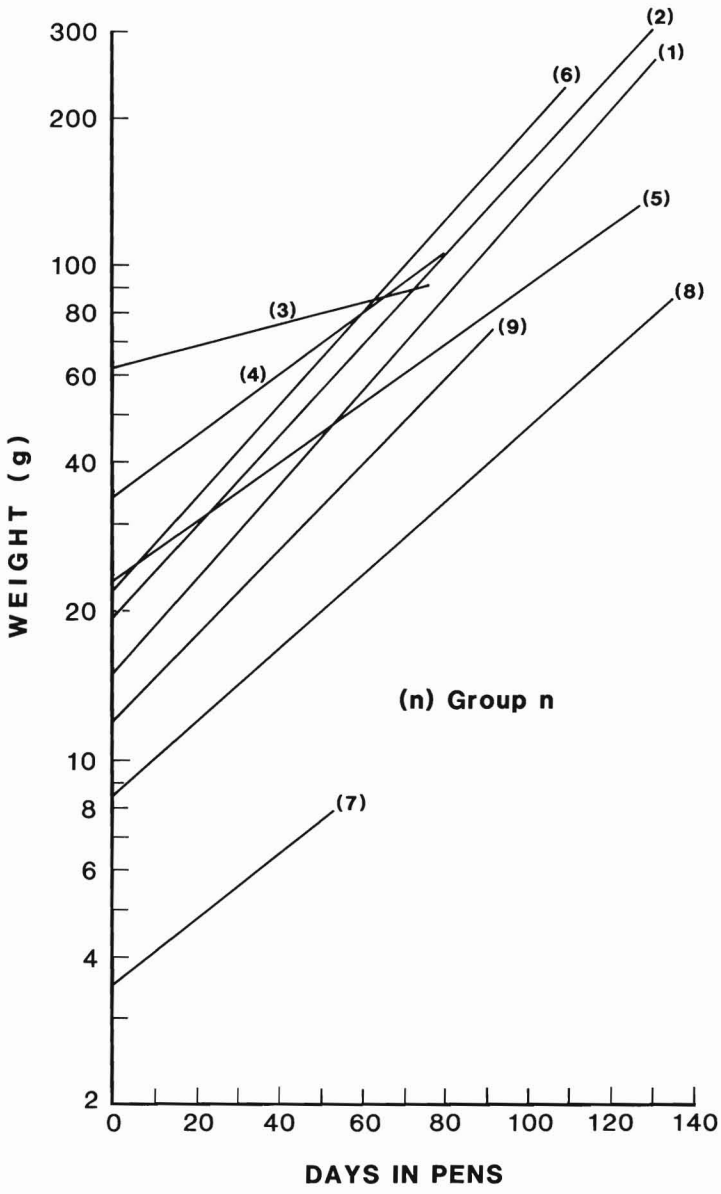

Figure 4.—Growth curves for pen-reared salmon by group.

Our freeze-branding trial produced no returns. It can be concluded that the marks faded, because Carlin-tagged fish that were recaptured from Group 6 showed no evidence of having been freeze-branded.

Tag Returns

Tag returns are important because they measure the contribution of each group to the fishery. Several factors in this study make it difficult to analyze the

tag return information and therefore to draw conclusions from it. There was a high degree of variability in the rearing experience from year to year. Changes in species, brood stock, hatchery, date, size, and uniformity of size at delivery were usually dictated by factors that were beyond the control of the experimenters. Varied environmental conditions, such as the drought in 1975 and 1976, not only affected rearing conditions but also caused some regulatory changes (season and size) that may have influenced tag return rates. It is also likely that the adipose fin clip identifying nose-tagged fish escaped observation in some groups more than others. For example, many cohos from Group 1 were caught by sportfishermen fishing along the shoreline of the Bay, where their catches were not censused. Group 1 returns therefore are probably underestimated.

Because a minimum mesh size of 22 mm was found to be necessary to assure adequate circulation and prevent the attendant problems of fouling and reduction of dissolved oxygen, many fish escaped soon after delivery and throughout the rearing period. Unfortunately this problem occurred in all the batches of nose-tagged fish that were received. To whatever extent such fish survived after their escape, the return rates are overestimated because the pool of tagged fish from which recoveries were drawn would have been larger than the number used to calculate the percentage or rate of recoveries. The groups most affected were 8 and 9. There also was a mass escape from Group 7, but it is unlikely that many of these pre-smolt fish survived[4].

As would be expected from the preceding discussion, the tag return rates varied greatly from group to group. Nonetheless, certain trends appear and we believe that despite the various dissimilarities and uncertainties from year to year, certain conclusions become apparent from a subjective analysis of the tag returns.

The best return rate was from Group 4, the first batch of chinooks reared. As stated, this group was healthy throughout the rearing period. Although more than half of the fish escaped, those fish had not been tagged and would not affect the return rate calculation. The mean weight at delivery was the second largest of all the groups, and the size variation was small. Also, these fish were reared in the autumn when the water temperature was cool. As noted, this was one of the groups that grew somewhat more slowly than most others. Whatever the reason, the tag return rate of 23.5 percent (adjusted) was four times as good as from any other of the externally tagged groups.

The worst return rate for external tags was from Group 5, the first group of 1977 cohos. Only two tags were recovered, for an adjusted rate of 0.4 percent. Apparently the extreme size range (10-199 g) and poor health at delivery were contributing factors.

The next lowest return rate for Carlin-tagged fish was from the second batch of 1977 cohos, Group 6. This group suffered a high initial mortality—about one-third—and the fish were much handled, having undergone freeze-branding as well as Carlin-tagging.

The Group 7 experiment, which was fraught with problems from start to finish, produced the lowest return rate of nose-tagged fish. The critical factor in this group probably was the small size of the fish at delivery and release.

Earlier in this section we suggested that nose-tag return rates for Groups 8 and 9 are overestimated. The release of Carlin-tagged fish as well as nose-tagged fish in Group 8 provides an opportunity to gauge the magnitude of the overestimate by comparing the return rates for the two types of tags. The 13.3 percent return rate estimate for the nose tags is about 2.25 times as high as the 5.9 percent return estimate for the Carlin tags. This "overestimate factor" is subject to some degree of uncertainty because the Carlin-tagged and nose-tagged fish had slightly different histories. Nonetheless, it is probably realistic to assume that at least as many nose-tagged fish escaped and survived as were released and counted at the end of the rearing period.

Table 3.—Nose-tag retuns from Group 9.

Years recovered	Subgroup: Control — Number recovered	Control — Percent of release (21,730)	Pen-reared — Number recovered	Pen-reared — Percent of release (11,223)	Pen-reared — Percent of delivery (67,900)
1980	0	0	14	0.1	0.0
1981	503	2.3	1,243	11.1	1.8
1982	69	0.3	178	1.6	0.3
Total	572	2.6	1,435	12.8	2.1

The Group 9 experiment compared the return rate from pen-reared fish with those from a control group released at the pen site at the beginning of the rearing period. Table 3 summarizes the tag recovery data from Group 9. The return rate for the control subgroup was 2.6 percent. The return rate for the pen-reared subgroup is given first as a percentage of the fish that were counted out of the pen after the rearing period. The 12.8 percent figure neglects the more than 55,000 fish (adjusted for tag recognition) that were not accounted for in the release, most of which escaped. The second tag recovery rate is given as a percentage of all the fish that were delivered to the pens for rearing. Even though only one-sixth of the fish that were delivered for pen rearing were actually pen-reared, the 2.1 percent return in this comparison suggests that pen rearing was not advantageous.

Cost Effectiveness of Pen Rearing

One problem with the preceding analysis of tag returns from Group 9 deliveries of chinook salmon is that the

[4]Fred Meyer, California Department of Fish and Game, Region 2, Rancho Cordova, Calif. Personal commun.

Table 4.—Annual pen-rearing costs for 40,000 fish for 3 months; labor = $50/worker-day.

Item	Cost (dollars)	
	Materials	Labor
Nets and pens amortized at 12% over 10 years	$2,650	
maintenance and repair	400	$1,800
Medications	800	300
Feed	3,000	4,500
Miscellaneous supplies	1,700	
Subtotal	$8,550	$6,600
Grand total, materials and labor	$15,150	

experience with Group 9 was not a best-case episode. The fact that a 23.5 percent return of tagged fish was achieved once suggests that under a certain set of circumstances pen rearing might be a cost-effective management technique for augmenting ocean harvest.

Critical to determining the benefits of pen rearing is the cost involved—specifically, the cost in producing the incremental increase in returns that can be attributed to the pen rearing. To deal with this question, it is necessary first to accept a return rate that might be expected from fish released directly into San Francisco Bay, as was the control portion of Group 9. Recent CDFG studies have led to their adopting a policy of releasing chinook smolts (45/pound or 10 g/fish), instead of yearlings, directly into San Francisco Bay. Return rates have been as good or better (up to 4 percent) than for yearlings and cost per fish is lower[4].

If we assume a cost of $0.06/fish to rear salmon to 45 fish/pound (an approximation using data from McCormack et al., 1984, which does not include an amortization of capital costs) and a 4 percent return, then each fish caught represents an operational investment of $1.50.

The annual costs of pen rearing 40,000 fish for 3 months are shown in Table 4. Capital expenditures are amortized over 10 years at 12 percent interest, and labor costs valued at $50 per worker-day. If we assume that good pen-rearing techniques will bring about an ocean harvest of 25 percent of those fish released, then the cost of adding 10,000 fish to the catch would be $15,150, or roughly $1.50 for each fish. This cost does not include fixed costs, lease fees, management salary, or the cost of hatching and rearing the 40,000 fish to the size at which they would be introduced into the pens.

The objective of establishing a sport fishery for coho inside the Bay was best met by Group 1. Sufficient numbers returned to and remained in the vicinity of the rearing site that a fairly extensive fishing effort developed. The local fishery was less evident in subsequent rearings, possibly because we were no longer able to obtain fish from the Noyo River brood stock. Further testing with Noyo River fish would be required to determine if a sport fishery for coho could be consistently established inside San Francisco Bay.

Summary

Our successful experience with the Group 4 chinooks demonstrated that pen rearing is, indeed, possible in San Francisco Bay, and that chinook salmon have excellent potential for the various forms of net-pen salmon ranching. On the other hand, we know that the hatchery production cost of 40,000 fish that can be either directly released or released after pen rearing is roughly $2,400. If we assume that the respective return rates for the two procedures would be 4 and 25 percent, then we can choose between getting 1,600 returns at a cost of $2,400, or an additional 8,400 returns for an additional cost of $15,050. The additional cost per additional return then, is about $1.80 for each fish. To the extent that our assumed return rates are valid, this project did not demonstrate that pen rearing would be a cost-effective management technique for adding to the ocean harvest in California. However, cost efficiency probably would improve if the project were scaled up.

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