A Production Economic Analysis of the Little White Salmon and Willard National Fish Hatcheries

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CONTENTS

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APPENDIX

DESCRIPTION OF THE LP MODEL

As mentioned in the section, MAXIMIZATION OF FISH PRODUCTION FOR GIVEN RESOURCE LEVELS, rearing pond space and fish food were the main constraints limiting production of the hatcheries. Therefore, the main body of the LP model consisted of 24 equations of monthly space requirements for the two hatcheries, and 2 dquations for the fish food requirements. Since rearing pond space requirements were potential bottlenecks only for March, April, and May, the equations for the other months are not presented here. Thus, the initial equations can be written as:

	Description of equation		
(A-1)	L.W. Mar. space:	$30.6914X_1 + 3.1531X_2 + 18.5876X_3$	$\leq$ 75,752 cu. ft.
(A-2)	L.W. Apr. space:	$32.6924X_1 + 5.061628X_2 + 18.5876X_3$	$\leq$ 75,752 cu. ft.
(A-3)	L.W. May space:	$8.800X_1 + 5.061628X_2 + 4.300X_3$	$\leq$ 75,752 cu. ft.
(A-4)	L.W. fish food:	$118.667X_1 + 11.6356X_2 + 56.768X_3 - 1.0X_5$	$\leq$ 236,040 lbs.
(A-5)	Willard Apr. space:	$12.991683X_4$	$\leq$ 67,167 cu. ft.
(A-6)	Willard May space:	$12.991683X_4$	$\leq$ 67,167 cu. ft.
(A-7)	Willard fish food:	$67.5336X_4 - 1.0X_6$	$\leq$ 210,195 lbs.

In the above equations, X_1 denotes the release of 1,000 spring chinook, at 14.67 per pound, from the Little White Hatchery; X_2 denotes the release of 1,000 fall chinook, at 100 per pound, from Little White; X_3 denotes the release of 1,000 coho, at 25.8 per pound, from Little White; X_4 denotes the release of 1,000 coho, at 22 per pound, from the Willard Hatchery; and X_5 and X_6 denote purchase of additional fish food for Little White and Willard, respectively.

To maximize the pounds of fish released from the two hatcheries, the LP objective function needs merely to be the pounds of fish represented by one unit of X_1, one unit of X_2, etc. Since one unit of X_1 denotes 1,000 spring chinook smolt at 14.67 per pound, one unit of X_1 also represents the release of $1{,}000 \div 14.57 \doteq 68.17$ pounds of fish. Following the same procedure for X_2, X_3, and X_4, the LP objective (or total revenue) function can be written as:

ABSTRACT

Under July 1, 1972 - June 30, 1973 cost levels for the Little White Salmon and Willard National Fish Hatcheries, small budget reductions made by reducing expenditures for fish food resulted in sharp increases in average total cost per pound of salmon produced. However, assuming no cuts in fish food, linear programming estimated annual economic benefits of \$1.85 to \$1.94 million, compared to annual costs of about \$215,000 for the Little White Salmon Hatchery. For the Willard Hatchery, economic benefits ranged from \$1.49 to \$1.66 million, with annual costs of about \$198,000. Furthermore, for Willard, heavier concentration of fish in the rearing ponds, along with an assumed increase in fish food, gave a predicted increase in benefits of about \$1 million with an additional cost of only about \$26,400.

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the rearing ponds. For the Willard Hatchery, an increase in economic benefits of about $1 million was predicted with an increased cost of fish food of only about $26,400, given the assumption that survival in the river and ocean would not be lessened from the increased loading.

Given the substantial economies resulting from increased production, other alternatives for increasing output should be investigated, as well as the increased loading of present rearing facilities. For example, use of warm water from nuclear or thermal electric generating plants might be economically feasible for accelerating production during the winter months when stream water is too cold for good fish growth. Various alternatives, such as these, could conveniently be evaluated by means of the linear programming models used in this study.

The choice of fall chinook versus coho salmon production was surprisingly sensitive to changes in assumptions regarding the value of sport-caught salmon. Although it may be better for some hatcheries to specialize in the production of a single species, considering the output of all hatcheries, a continuation of the present policy of balanced production of both coho and chinook would appear to be prudent, based upon the LP results of this study.

A PRODUCTION ECONOMIC ANALYSIS OF THE LITTLE WHITE SALMON AND WILLARD NATIONAL FISH HATCHERIES

William G. Brown and Ahmed Hussen

INTRODUCTION

Operation and maintenance of the 21 salmon and steelhead hatcheries funded by the National Marine Fisheries Service within the Columbia River System involves annual expenditures of about $2.5 million. Given the magnitude of resources involved, a systematic study of these fish hatcheries, from a production economic point of view, appeared to be justified since such a study, if successful, could suggest alternative means of increasing net economic benefits by maintaining or enhancing harvest and returns of salmon and steelhead at minimum cost.

For purposes of this study, two hatcheries were selected, the Little White Salmon National Fish Hatchery and the Willard National Fish Hatchery. These hatcheries are on the Little White Salmon River, a tributary of the Columbia River, about 60 miles above Portland. Both hatcheries are of medium size, with the Willard Hatchery producing about 141,000 pounds of coho salmon during fiscal year 1973 (July 1, 1972 to June 30, 1973). The Little White Salmon Hatchery has the capacity to release from 150,000 to 158,000 pounds of salmon per year, depending upon the species produced.

Each hatchery employs one manager, four persons for fish production, and one person for maintenance. In addition, the Little White Salmon Hatchery's labor force includes a clerk.

Facilities of both hatcheries include troughs and incubators for the hatching of salmon eggs. The Little White Salmon Hatchery has a rearing pond capacity of nearly 76,000 cubic feet; Willard has about 67,200.

MAXIMIZATION OF FISH PRODUCTION FOR GIVEN RESOURCE LEVELS

Based upon the physical and operating characteristics of the Little White Salmon and Willard National Fish Hatcheries, various linear programming models were constructed. After some analysis and communication with the hatchery managers, it was found that rearing pond space and fish food were the two main constraints which would be expected to limit production of salmon smolts.[1/] Consequently, the main body of the linear programming (LP) model could then be simplified to 24 equations dealing with the monthly space requirements for the two hatcheries, and two equations for the fish food requirements. Linear programming activities for Little White Salmon included spring chinook, fall chinook, and coho. For Willard, only the coho activity was included because the winter water is too cold for good chinook growth. Also included in some computer runs of the model were fish food buying and food transfer activities. For information about LP, cf. Heady and Candler [1958]. Additional details about the LP model used in this study are given in the Appendix.

Maximization of Production for Fiscal Year 1973 Conditions

Assuming that the same amount of fish food would be fed as for fiscal year 1973, 236,040 pounds of fish food were assumed for the Little White Salmon Hatchery and 210,195 pounds for Willard. Substituting these quantities into the LP model, maximum pounds of fish for release could be achieved by producing approximately 4,075,405 coho at 25.8 fish per pound at the Little White Salmon Hatchery, and by producing 3,112,451 coho weighing 22 per pound at Willard.[2/] In terms of pounds, this production would represent about 158,000 pounds of fish for release from Little White Salmon, and about 141,470 pounds from Willard. This production represents a maximum for the assumed available fish food and the capacity, under historical loading rates, of the rearing facilities.

1/ Of course, other factors, such as water temperature and quality, also affect fish production of the salmon hatcheries. However, we will assume that water temperature and quality follow the usual seasonal pattern for the specified hatchery. In future studies, the feasibility of various water temperature control alternatives should be investigated.

2/ These weights of fish for release are not necessarily optimal, but are representative of production in recent years.

too cold for satisfactory growth of chinook salmon. Then, of course, the reduction of the assumed sport value of coho from \$20 to \$16.44 would be expected to lower the benefit-cost ratio for the Willard Hatchery to

$$\text{B-C ratio} = \frac{\$478.3(3,112.451)}{\$197,581} \doteq \frac{\$1,488,685}{\$197,581} \doteq 7.53.$$

Values and Benefit-Cost Ratios with Increased Fish Food. - Again, increased expenditures for fish food would be expected to increase economic benefits much more than costs. For the Little White Salmon Hatchery, the optimum solution by linear programming with increased fish food changed from a combination of spring and fall chinook to only spring chinook, with a release of 2,317,113 spring chinook at 14.67 per pound. This production required an additional 38,925 pounds of fish food at \$0.19 per pound. Although net economic benefits were increased about \$32,759, the B-C ratio decreased slightly,

$$\text{B-C ratio} = \frac{\$856.37(2,317.113)}{\$214,910 + \$7,396} \doteq \frac{\$1,984,306}{\$222,306} \doteq 8.93.$$

For the Willard Hatchery, assuming heavier concentrations of coho in the rearing ponds, production could again be increased to an estimated release of about 5,170,000 coho at 22 per pound. The new benefit to cost ratio, assuming 138,954 additional pounds of fish food, would be

$$\text{B-C ratio} = \frac{\$478.3(5,170)}{\$197,581 + \$26,401} \doteq \frac{\$2,472,811}{\$223,982} \doteq 11.04.$$

Thus, for the Willard Hatchery, a substantial increase in the benefit-cost ratio, from 7.53 to 11.04, results from the increased production, assuming that there would be no deleterious effects from increased numbers of coho in the rearing ponds.

SUMMARY AND CONCLUSIONS

Linear programming was helpful in estimating economic benefits from various hatchery management alternatives. The estimated benefit to cost ratios for the Little White Salmon and Willard National Fish Hatcheries under 1973 price and cost conditions were quite favorable, ranging from 7.53 to 12.29, depending upon the method used for computing salmon sport values and concentration of fish in

Another question pertains to the sport value of coho and chinook salmon. It could be argued that a chinook salmon should be worth more than a coho to a sport angler, since a chinook is larger, on the average. To see how sensitive the linear programming solution was to assumptions about sport values, the LP analysis was repeated, but with the assumption that sport value was proportional to the weight of the fish caught.

Estimated Fish Values, Assuming Sport Values are Proportional to Fish Weights

Although the average weights of sport-caught coho and chinook salmon were not known, the average weights of the commercially-caught coho and chinook were reported. These figures indicated an average weight of about 6.51 pounds for coho and 13.51 for fall chinook. Thus, the coho averaged only about 48 percent as heavy as the chinook. Using this fact, along with the estimate that coho made up almost 80 percent of the total sport catch, then a sport value of $16.44 for coho and $34.25 for chinook was computed, based upon the assumption that the overall average of all sport-caught salmon was $20 per fish.

Values and Benefit-Cost Ratios with Fiscal Year 1973 Levels of Fish Food. - Using $16.44 and $34.25 for the value of sport-caught coho and chinook, respectively, the linear programming "price" for Little White Salmon coho dropped from $454 to $407.85, the "price" for Little White Salmon fall chinook increased from $107 to $125.63 per 1,000 released, and the price for spring chinook increased from $730 to $856.37 per 1,000 released. With these new values, the linear programming solution for Little White indicated a maximum net economic benefit from a release of 1,422,470 spring chinook and 5,778,800 fall chinook. The corresponding benefit-cost ratio was

$$\text{B-C ratio} = \frac{\$856.37(1,422.47) + \$125.63(5,778.8)}{\$214,910} \doteq \frac{\$1,944,151}{\$214,910} \doteq 9.05.$$

Thus, a modest change in assumption regarding value of sport-caught salmon was more than enough to switch the solution from all coho to a combination of spring and fall chinook at the Little White Hatchery.

For the Willard Hatchery, only coho were considered because the water is

From the economic point of view, total amount or poundage of fish produced is of little interest in itself. However, the effect of total pounds of production on the average cost per pound does have considerable significance, and is explored in the next section.

Average Fish Costs Per Pound with Fish Food Reduced Below Current Production Levels

In times of budget cutbacks, it sometimes has been necessary to reduce expenditures for fish food, since fish food represents more than one-half the non-labor expenditures in Table 1, and these non-labor expenditures are often the only variable expenses, given the Civil Service employment arrangement of the fish hatcheries. Perhaps one debatable item in Table 1 is the annual capital charge, based on a 30-year amortization schedule and 3.5 percent interest, which may now be somewhat low, even for a social rate of interest. However, even if these estimated annual capital charges were doubled, total costs would be increased by less than 8 percent.

Table 1. Cost Breakdown for the Little White Salmon and Willard National Fish Hatcheries, Fiscal Year 1973 [a]

Cost items	Willard	Little White Salmon
Personnel salaries[b]	$ 75,719	$ 86,589
Fringe benefits and overhead[c]	25,727	31,287
Non-labor expenditures..............	82,651	78,765
Annual capital charge[d]	13,484	18,269
TOTAL.....................	$197,581	$214,910

a/ Figures supplied by the Economic Feasibility Section, Columbia Fisheries Program Office, National Marine Fisheries Service, Portland, Oregon.

b/ Includes regular salaries plus overtime.

c/ Fringe benefits were computed as 15 percent of salaries, and overhead was 22 percent.

d/ Annual capital charge was based on a 30-year amortization plus 3.5 percent interest.

Using the costs of Table 1 and the results of the linear programming analysis for various assumed levels of fish food, the average total cost curve in Figure 1 was constructed. Thus, decreased production from various assumed reductions in fish food was obtained. For example, suppose for budgetary reasons it had been necessary to reduce fish food costs in fiscal year 1973 by 50 percent. Then, from Table 1, total costs for the Little White Salmon and Willard Hatcheries could have been reduced by about $0.19(.5)(236,040 + 210,195) ≐ $42,392. However, from the LP analysis, total fish production would have then been reduced from about 299,424 pounds to only 172,161 pounds.[3/] Thus, the average total cost per pound, at the 50 percent level of fish food, would have been ($412,491 - $42,392) ÷ 172,161 pounds ≐ $2.15 per pound, as compared to the actual 1973 fiscal year average cost of $412,491 ÷ 299,424 pounds ≐ $1.38 per pound. In a similar manner, other average costs were computed at various assumed levels of fish food:

Percent of fiscal year 1973 fish food level	Predicted average total cost per lb.
20	$5.00
40	2.63
60	1.83
80	1.49
100 (1973 production level)	1.38

Given the preceding average cost figures, it is apparent that reducing expenditures by reducing funds available for fish food would be an inefficient way to reduce costs, since a 50 percent reduction in fish food would reduce costs by only about 10 percent (42,392 ÷ 412,491 ≐ 0.103), whereas total production would be reduced by about 43 percent, (299,424 - 172,160) ÷ 299,424 ≐ 0.43. Thus, the preceding figures, and the average total cost curve in Figure 1, imply

[3/] The LP model in the Appendix can solve this problem by maximizing pounds of fish released, objective function (A-8), subject to specified levels of fish food in Equations (A-4) and (A-7), and by deleting fish food buying, X_5 in (A-4) and X_6 in (A-7).

do not stress the fish enough to reduce their survival in the river and ocean later, then the economic benefits could be increased with only a small increase in cost or the purchase of additional fish food.

For the Little White Salmon Hatchery, with the same assumed values for coho and chinook, no increase in production was indicated with increased fish food, because rearing pond space was more limiting for coho than was fish food. However, an increase in production was predicted for the Willard Hatchery with purchase of additional food. According to Bruhn [1970], water and space would be sufficient for a substantial increase in production. Based upon these calculations, the linear programming solution indicated that an additional 138,954 pounds of fish food could be efficiently utilized. An output of 5,170,000 coho for release was indicated. The resulting benefit-cost ratio was computed to be

$$\text{B-C ratio} = \frac{\$532.5(5,170)}{\$197,581 + \$26,401} \doteq \frac{\$2,753,025}{\$223,982} \doteq 12.29.$$

This increased production from increased fish food compares quite favorably to the earlier benefit-cost ratio of 8.39 for the situation without additional food. Even more impressive would be the benefit-cost ratio for the incremental purchase of fish food,

$$\text{B-C ratio} = \frac{\$2,753,025 - \$1,657,380}{\$26,401} \doteq 41.50.$$

The preceding three benefit-cost ratios indicate greatly increased benefits per total dollars expended, assuming that the greater concentration of fish in the rearing ponds would not adversely affect survival after release from the hatchery.

Other questions connected with the preceding analysis pertain to the estimates of value assumed. For one thing, substantially more of the fall chinook are harvested in the British Columbia commercial fishery - about 34 percent, as compared to only 6 percent for coho. The preceding analysis includes the value of fish caught commercially in British Columbia, even though the Canadian harvest does not directly benefit the U.S. (but may indirectly benefit the U.S. via reciprocal fishing agreements).

Similarly, the value of coho from Willard was computed to be (22.7 ÷ 22)(516.05) ≐ $532.5.

Since study results of marked spring chinook were not yet available, the same value per pound of fish released was assumed for spring as for fall chinook. Thus, a value proportional to weight released gave (100 ÷ 14.67)($107) ≐ $730 per 1,000 spring chinook released. The reliability of this assumption cannot be assessed until results from the marking study of spring chinook become available.

Values and Benefit-Cost Ratios with Fiscal Year 1973 Levels of Fish Food. - Given the preceding values for the salmon, and assuming a fiscal year 1973 level of fish food, a maximum of economic benefit would result from releasing about 4,075,405 coho from Little White Salmon and about 3,112,451 coho from Willard. Total value from Little White Salmon would be $454(4,075.405) ≐ $1,850,234. Total value of the Willard Hatchery release would be $532.5(3,112.451) ≐ $1,657,380.

Benefit-cost ratio for the Little White Salmon Hatchery operation would be

$$\text{B-C ratio} = \frac{1,850,234}{\$214,910} \doteq 8.61,$$

using the fiscal year 1973 costs presented earlier in Table 1. For the Willard Hatchery,

$$\text{B-C ratio} = \frac{\$1,657,380}{\$197,581} \doteq 8.39.$$

The above benefit-cost ratios could be criticized, inasmuch as the sport values are estimates of average value, and the commercial values are not too far from gross value rather than net value, since no charge for harvesting has been deducted. However, following the argument of Richards [1968], the potential net value of the commercial harvest could be made approximately equal to the preceding values if society chose to harvest the fish in the most efficient manner. Also, even if the preceding values were reduced by half, benefit-cost ratios greater than four would still be obtained.

Values and Benefit-Cost Ratios with Increased Fish Food. - As indicated earlier, good results are being obtained at the Willard Hatchery with heavier concentrations of coho in the rearing ponds. If it is assumed that the heavier loadings

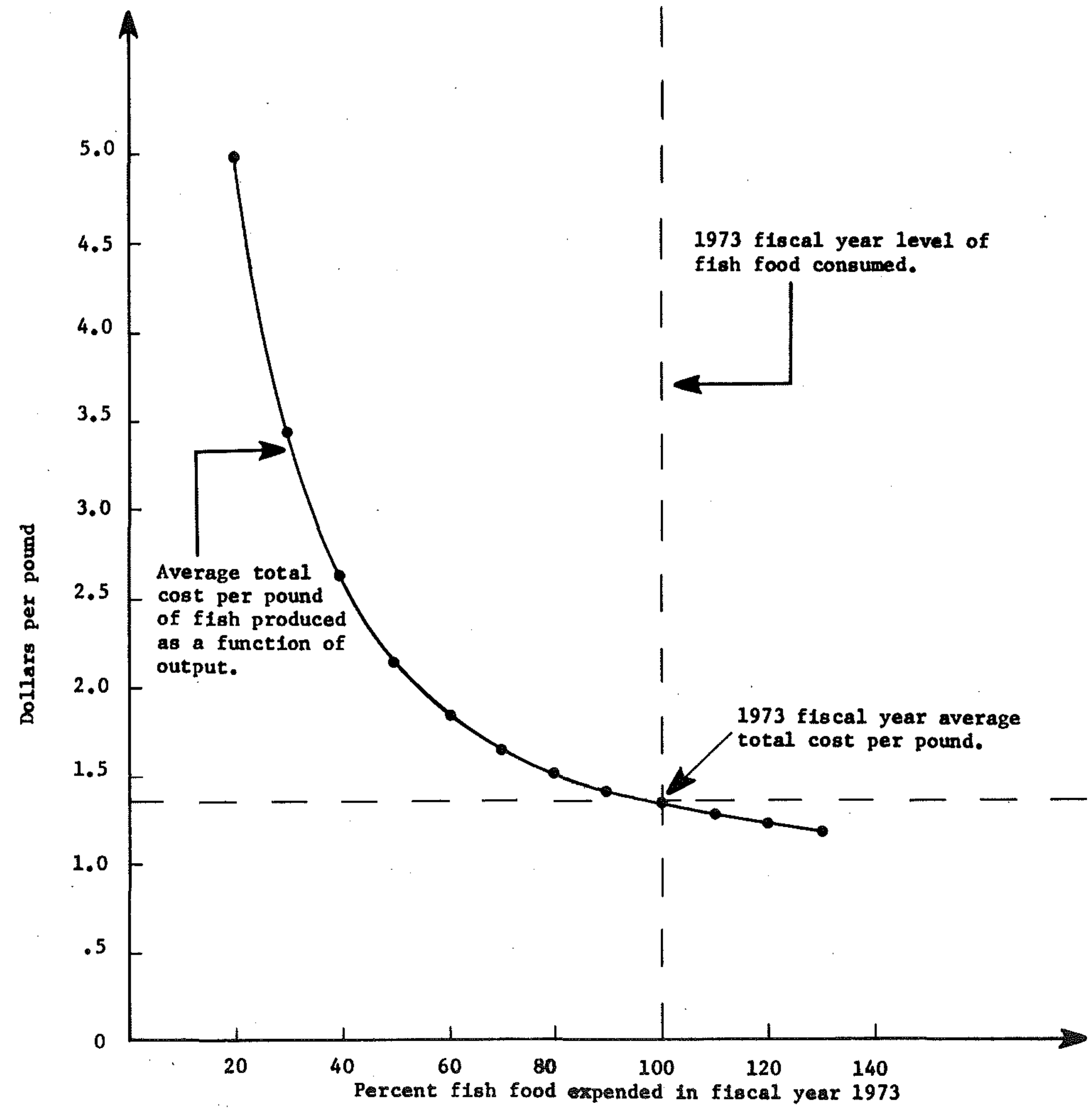

Figure 1. Average total cost in dollars per pound of fish produced at the Little White Salmon and Willard National Fish Hatcheries, combining the costs and outputs of the two hatcheries, and assuming various levels of fish food and output.

increasing returns from fish food expenditures resulting from the fact that Civil Service salaries and related costs and capital charges remain essentially fixed, thereby allowing these costs to be spread over more pounds as production is increased to usual levels.

Average Fish Costs Per Pound with Fish Food Increased Above Past Production Levels

If more fish could be successfully reared per cubic foot of rearing space, then production could be increased even further, allowing average total costs to decline even more.[4/] Of course, if not enough space is allowed the salmonids, the smolts perhaps could appear healthy at time of release but then suffer higher mortality in the river and ocean. However, assuming that the fish are not crowded enough to adversely affect survival after release, then average cost per pound of fish could be lowered from $1.38 to $1.13 per pound by increasing production by 30 percent over the usual production levels, a cost reduction of about 18 percent. This lower range of the average total cost curve is also shown in Figure 1.

While costs of production are an important part of the economics of production, the value of production also needs to be considered. In the next section, to maximize net economic benefits, both costs and returns of various production alternatives are considered simultaneously.

MAXIMIZATION OF ECONOMIC BENEFITS

Before economic benefits can be computed, some measure of value must be assigned to the salmon harvested in the commercial and sport fisheries. Fortunately, studies of marked hatchery coho and fall chinook salmon have been made which provide estimates of the harvest of these fish in the various fisheries, Worlund, Wahle, and Zimmer [1969]; Rose and Arp [1970]; Arp, Rose, and Olhausen [1970]; Wahle, Arp, and Olhausen [1972]; and Wahle, Vreeland, and Lander [1974].

4/ Pond loading capacities at Willard were first calculated by David Bruhn and his staff at Willard National Fish Hatchery, reported by Bruhn [1970]. These heavier loading capacities were actually implemented in the spring of 1974.

Estimated Fish Values, Assuming Equal Sport Value for Coho and Chinook

Based upon the reports of the marking studies for fall chinook salmon, the average commercial catch per 1,000 fall chinook smolts released from the Little White Salmon Hatchery was estimated to be 69.125 pounds. The average number of fall chinook caught by sport anglers was 1.327 per 1,000 released, or about 18 pounds per 1,000 released, assuming a weight of 13.5 pounds per fish. The weighted average commercial price paid for fall chinook in 1973 was computed to be $1.16 per pound, based upon available prices. For the value of the sport catch, a value of $20 per fish was initially assumed, based upon research by Brown, Singh, and Richards [1974]. From the preceding estimated catches and values, an average value per 1,000 released fall chinook smolts from the Little White Salmon Hatchery was computed to be $\$1.16(69.125) + \$20(1.327) \doteq \$107$.

It should be acknowledged that these prices or values are somewhat high, since $1.16 per pound is near the gross commercial value. Similarly, $20 per sport-caught salmon is an estimate of the average value, and the marginal value should be considerably less. For the commercial catch, the <u>potential</u> value would not be much less <u>if</u> society chose to harvest the salmon in the most efficient manner, Richards [1968]. However, the marginal value of sport-caught chinook might well drop to the commercial value, $\$1.16 \times 13.5$ lbs. $\doteq \$15.66$. As indicated by the benefit-cost figures later, such a reduction in sport value for chinook would have only a small effect on benefit estimates for chinook, but would have much more impact on the estimated coho benefits.

In the same way as for chinook, an average value per 1,000 released coho from the above-Bonneville part of the Columbia was computed to be $\$0.916(241.3) = \$221.06$ for the value of the commercial catch, and $\$20(14.75 \text{ fish}) = \$295$ for the value of the sport catch, giving $\$221.06 + \$295 = \$516.05$ per 1,000 coho released. However, the 1971 brood release of coho by the Little White Salmon Hatchery averaged about 25.8 fish per pound, as compared to 22.7 fish per pound for the marking study. To obtain a value, we assumed that the value of fish would be proportional to the weight of fish released, rather than proportional to mere numbers. Therefore, the weight-adjusted value for coho produced at the Little White Salmon Hatchery was computed to be $(22.7 \div 25.8)(516.05) \doteq \$454$ per 1,000 fish released.