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Title: AN ECONOMIC EVALUATION AND BENEFIT-COST ANALYSIS OF NATIONAL FISH HATCHERY OPERATIONS USING LINEAR PROGRAMMING AND CONSUMER'S SURPLUS MODELS AND CONCEPTS

Abstract approved: ______________________
William G. Brown

A significant portion of the U. S. total harvest of Pacific salmon emanates from the major rivers along the Pacific Coast. Among the rivers which are considered to have a rich natural stream habitat for Pacific salmon production is the Columbia River. However, since World War II, due to expansion in the use of the Columbia River for water projects, especially dams for power and other uses, valuable stocks of Pacific salmon and steelhead trout have been depleted as a result of the destruction of spawning grounds. In an attempt to overcome the above problem and enhance the production of salmon and steelhead in the Columbia River Basin, a number of public programs have been instituted. Among the programs considered was the construction of hatcheries for artificial propagation of fish in order to

compensate for the loss of salmon production due to the deterioration of the natural stream.

However, development and maintenance of hatcheries involve a substantial amount of public investment. Given the magnitude of resources involved, a systematic study of the fish hatcheries operation 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. Hence, the primary objective of this thesis has been to investigate the various possible alternative conditions that could direct the operation of hatchery at minimum cost.

The total cost allocated for fish food buying represents over one-third of the total expenditure for any given hatchery. Therefore, since the cost of fish food account as one of the major variable costs in any hatchery operation, special interest was given to see if any possible saving could be attained by means of least cost rations. In Chapter III using linear programming it was shown that the cost of fish food could be substantially reduced.

Furthermore, in Chapter IV using linear programming analysis, various alternative conditions that could maximize the benefit gained from hatchery operation were examined. For purposes of this study the Little White Salmon and Willard National Fish Hatchery were selected. At least from the standpoint of these two hatcheries, it was observed that reduction of expenditure by decreasing funds available for fish food is contrary to cost-minimization objectives.

Using the data from the marking study and the estimated price of both the commercial and sport-caught fish, total benefits for a given hatchery were calculated. Then, the total benefits estimated by the above method were compared against the total cost to come up with the benefit to cost ratios for the hatcheries under consideration. The estimated benefit to cost ratios for the two hatcheries considered in this study (Little White and Willard) 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 the rearing ponds. Especially for the Willard Hatchery, an increase in economic benefits of about $1 million was predicted with an increase 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 in rearing ponds.

Extending the analysis further, in Chapter V, the concept of consumer's surplus was used to test the validity of the benefit-cost ratio estimated by the use of linear programming analysis. Using the concept of consumer's surplus 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 3.385 to 4.268. It should be noted that the values and benefit-cost ratios estimated by the consumer's surplus are quite conservative. Nevertheless, the benefit-cost ratio computed by the consumer's surplus method are quite favorable indicating a high return per dollar expended at the Willard and Little White hatcheries.

An Economic Evaluation and Benefit-Cost Analysis of National Fish Hatchery Operations Using Linear Programming and Consumer's Surplus Models and Concepts

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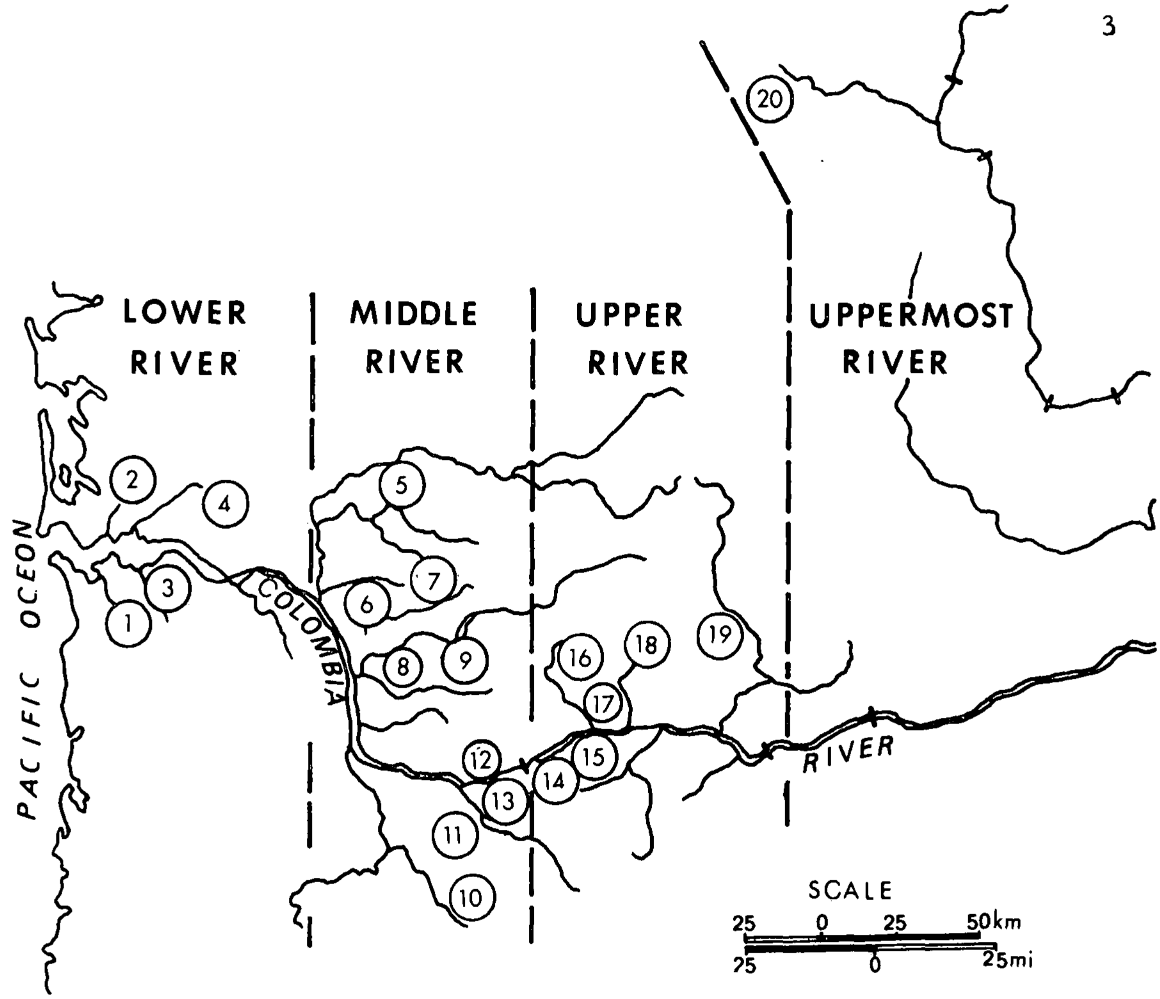
AN ECONOMIC EVALUATION AND BENEFIT-COST ANALYSIS OF NATIONAL FISH HATCHERY OPERATIONS USING LINEAR PROGRAMMING AND CONSUMER'S SURPLUS MODELS AND CONCEPTS

I INTRODUCTION

The harvest of Pacific salmon species is historically and economically important to the United States. For example, according to the International North Pacific Fisheries Commission Statistical Yearbook, approximately 768.5 million pounds of salmon were landed from the North Pacific Ocean and its adjacent areas by Canada, Japan and the U.S.A. during 1971 fiscal year. Of these the United States landed 334.1 million pounds which is approximately 43.5 percent of the total. A significant portion of the U.S. total harvest of Pacific salmon emanates from the major rivers along the Pacific Coast. Among the rivers which are considered to have rich natural stream habitat for Pacific salmon production is the Columbia River.

However, since World War II, due to an expansion in the use of the Columbia River for water use projects, especially dams, valuable stocks of Pacific salmon and steelhead trout have been depleted through the loss and deterioration of natural stream habitat. To overcome this problem and enhance the production of salmon and steelhead the Federal government (in conjunction with the fish management agencies of the states of Oregon, Washington, and Idaho) began financing the Columbia River development program in 1949. The Columbia River Program Office of the National Marine Fisheries Service (NMFS), Portland, Oregon, administers the program. The major objectives of the program have been to improve the stream environment and production of fish in hatcheries to compensate the loss of salmon production due to the deterioration of the natural stream. At present there are 22 salmon and steelhead hatcheries on the lower Columbia River and its tributaries (see the map on the next page).

Of course, development and maintenance of artificial facilities (hatcheries) involves economic costs which could have been avoided if the natural stream of the river were left undisturbed. These costs include: costs for capital outlays, operations, maintenance and food. Like any other investment decisions, these costs have to be assessed carefully and compared against the benefit accrued from the fish production in the hatcheries. In the past, a preliminary study of benefit/cost ratio of hatchery produced Coho and Chinook salmon was estimated by Roy J. Wahle, Robert R. Vreeland, and Robert H. Lander using the data obtained from marking study (21). This study showed a favorable benefit/cost ratio for all hatcheries taken together. One of the objectives of



1. Kloskonine
2. Grays River
3. Big Creek
4. Elokomin
5. Toutle
6. Lower Kalama
7. Kalama Falls
8. Lewis River
9. Speelyoi
10. Eagle Creek
11. Sandy
12. Washougal
13. Bonneville
14. Cascade
15. Oxbow
16. Carson
17. Little White Salmon
18. Willard
19. Klickitat
20. Leavenworth

Figure 1. Location and grouping by river section of Columbia River hatcheries participating in this study.

this thesis includes exploring the validity of this benefit-cost analysis by means of linear programming method and consumer's surplus analysis.

Objectives

The primary objectives of this thesis are: (1) to develop programmed rations which will equal or exceed the nutritional requirements of the fish at minimum cost, (2) to construct linear programming models which will allow us to evaluate the maximum possible returns for each hatchery operation under a given set of conditions, (3) and to investigate the sensitivity of the benefit/cost ratio for a given condition as some of the assumptions or constraints are relaxed.

Brief Discussion on Linear Programming Analysis

Economists are usually interested in maximizing output or utility for a given budget and/or determining the cost minimizing inputs mix for specified output levels with a given technology. Linear programming is often employed to solve this type of problem where an objective is specified with given constraints.

Linear programming originated primarily during World War II as a method for specifying routes that would minimize travel distance for the limited shipping facilities. Since then it has been refined greatly, and its significance as a useful analytical tool has been widely accepted. Among the many users of linear programming are agricultural economists. They use linear programming to specify the optimum organization of resources and enterprises on farms, to specify cost minimizing methods of processing products such as fertilizer or mixed feed, etc.

For illustrative purposes, the general linear programming problem can be written as follows:

Maximize or minimize the linear function,

$$F = P_1Q_1 + P_2Q_2 + \text{------} P_nQ_n$$

Subject to

$$\begin{array}{ccccc} a_{11}Q_1 & + a_{12}Q_2 & + \text{------} & a_{1n}Q_n \lesseqgtr & C \\ \cdot & \cdot & & \cdot & \cdot \\ \cdot & \cdot & & \cdot & \cdot \\ \cdot & \cdot & & \cdot & \cdot \\ a_{m1}Q_1 & + a_{m2}Q_2 & + \text{------} & a_{mn}Q_n \lesseqgtr & C_m \end{array}$$

where

the Q's represent the main variables of the model, and

$$Q_1, Q_2, \ldots\ldots Q_n \geq 0$$

and the a_{ij}'s, C_i's, and p_j's are the known constants.

This is the standard form for a linear programming problem. It consists of three parts: (1) The objective function (e.g., profits or costs) whose value is to be maximized or minimized, (2) the structural constraints, (3) the nonnegativity condition on the variables.

The construction of linear programming model entails four basic assumptions. These assumptions are: linearity, additivity and independence, divisibility, and finiteness.

Linearity: The mathematical interpretation of "linearity" is, simply, no term may comprise more than one variable and that variable must appear in the first degree, and this is exactly the case for linear programming method. The expression (equation) to be maximized or minimized and the inequalities involve only the variables multiplied by constants and added together. From this, we should note that this linear model employs an assumption of competitively determined (or otherwise fixed) input prices and constant returns to scale in production. By the same argument it also disregards all economies and diseconomies of scale.

The inability of linear programming to deal with equations of nonlinear form threatens a certain inflexibility and makes it appear unsuitable for use in real world problems which frequently display nonlinear relationships. Although the linearity condition is an impediment, such problems are amenable to linear programming.

For example, if we have a production function which demonstrates decreasing returns to scale, such a function can be incorporated into the linear programming model by a family of straight line curves as shown in Figure 2.

However, this method of approximation involves some degree of imprecision because the series of straight lines deviate from the true curve. The extent of imprecision depends on the number of straight lines, and hence the number of distinct activities or hypotheses, that are used to portray the curve. Thus, in many cases the assumption of linearity does not per se restrict the use of linear programming.

The Independence and Additivity Assumption: This assumption states that the total amount of resources used by several enterprises must be equal to the sum of the resources used by each individual enterprise. It may also be interpreted the magnitude of a variable in the system is independent of the magnitude of any other variable. The sense in which the variables are independent of one another is that we are not able in linear equation to write a term within which one variable modifies another, that is, a term comprising two or more variables. Terms which comprise more than one variable, such as αXY, βX^2 and αX^β, are not first degree terms and have no place in a linear equation.

Divisibility: Under this assumption, inputs and outputs can be utilized in quantities which are fractional units. That is, the outputs and the inputs of a system are deemed to be infinitely

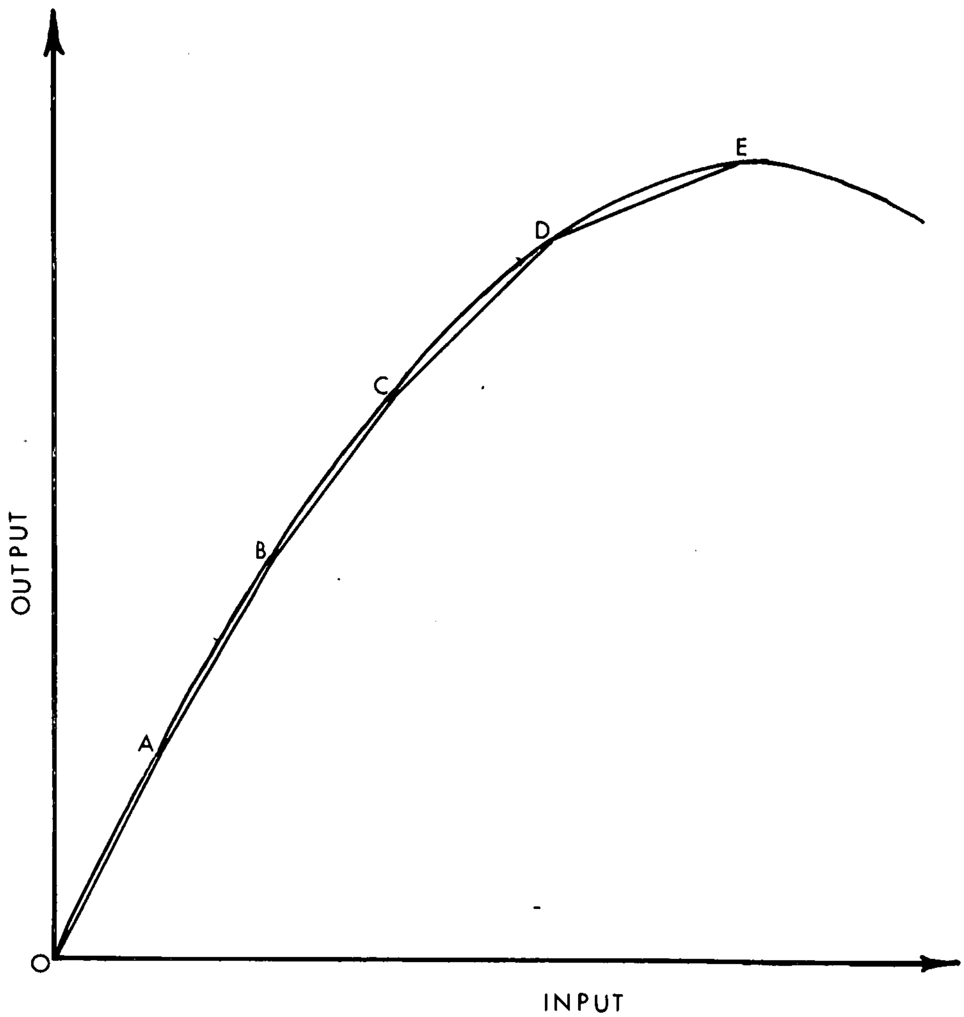


Figure 2. A method of approximating continuous production function into linear programming model.

divisible. For example, an optimum solution of a programming problem may indicate a production of 1, 706.4 fish under a given condition. This is obviously not true, a fraction of an animal is not a feasible output. Thus, we may be forced to approximate the result to 1, 706.0 fish. This rounding off 1, 706.4 fish to 1, 706, offends the divisibility assumption and in some cases could possibly lead to an infeasible solution or to a sub-optimal plan. But, in a more general case the divisibility assumption is not serious enough to have strong impact on the final solution. Moreover, integer programming can be used to overcome such a problem.

Finiteness: It is assumed that there is a limit to the number of alternative activities and to the resource restrictions which need to be considered. Of course this assumption is not uniquely attributed to linear programming problems. Any programming model which attempts to find an optimum solution to a given problem must have a limited number of alternatives and resource restrictions. If such a case does not prevail, it would be impossible to come up with a unique solution. Hence, this assumption is not an important limitation on the use of linear programming.

One final comment regarding linear programming techniques is that this system assumes that resource supplies, input-output coefficients, and prices are known with certainty. Of course, these constants are subject to change, especially the price coefficients may fluctuate when market forces alter the relative price coefficients under consideration. Thus, when a change of price or any one of the constraints occur, we must consider the changes and attempt to derive a new solution.

In this study, the linear programming method is used: (1) to specify the least-cost combination of ingredients for fish diet or ration which must meet specified nutritional requirements, (2) to find the optimum production of salmon smolts for a given capacity of rearing pond space and fish food. None of the above assumptions concerning linear programming are seriously restrictive or limiting for the purpose of the study.

II. REVIEW OF LITERATURE ON FISH FOOD REQUIREMENTS

The theme of this chapter is to review and outline some of the studies that have been done to determine the major nutrient requirements of fish.

Brief Discussion on the Nutrient Requirements of Fish

In recent years fish culture has expanded rapidly as a result of increased use of fish for human food and as feed for animals. This trend has increased the demand for information on the nutrient requirements of fish. In recognition of this fact, several studies have been conducted to spell out the major environmental and dietary components for the maximum attainable fish growth. Among these are the following:

Water temperature. The metabolic rate of fish is altered with a change in water temperature. Thus, environmental temperature is one of the causes of fluctuating food, oxygen, and subsequent energy requirements of fish. Temperature can be regulated in a few modern hatcheries in such a way that it is consistent with maximum fish growth. Under these circumstances, knowledge of the standard environmental temperature (SET) for the various species of fish under consideration is the only relevant information needed.

Several studies have been done to trace the relationship of fish growth and water temperatures for a number of species, Gardner, J. A. (1926), Clausen, R. G. (1933), Fry, E. J. and J. S. Hart (1948), Graham, J. M. (1949), Gibson, E. S. (1954), etc.

Other variables that cause fluctuating food, oxygen, and energy requirements of fish include the species, age, body size, activity, dissolved oxygen or carbon dioxide concentration in the water, seasonal fluctuations, and feeding frequencies. All the above factors, separately or together, influence the growth of hatchery fish. Thus, it is extremely important that the managers of each hatchery should be aware of these variables and their influence on fish growth so that they can constantly manipulate the variables in question for the attainment of maximum growth of fish.

Dietary Components of Fish Food

As stated earlier, one of the objectives of this thesis is to develop a linear programming model that will develop a ration which is consistent with maximum growth of fish in a hatchery environment. Before the formulation of the actual model, it is important at this stage to enumerate the various dietary components of fish food.

As for any other living entity, food is the source of energy for fish and the sole driving force for growth. On the other hand, fish utilize dietary components differently than warm blooded animals. Many fish derive major amounts of energy from proteins and fats rather than from carbohydrates. This is because carbohydrates are not easily digestible by fish. In addition, inclusion of a modest amount of vitamins in the ration will enhance the growth of fish by protecting them from certain diseases.

Thus, an optimal diet for fish should contain protein, amino acids, fats, vitamins, and, in some cases, easily digestible carbohydrates. The most extensive study concerning nutritional requirements of fish food was done by the pioneer work of John Halver, from whom most of my literature is cited.

1. Gross Protein Requirements. Protein requirements of fish diets vary widely, ranging from 30-50 percent of the ration. The variations in the protein requirements are attributed to changes in temperature, water quality, fish size and species. In this particular study the protein requirement has a lower limit of 36.4 percent. This lower limit requirement of protein was inferred from experimental results of the Oregon Fish Commission.

2. Amino Acids Requirements. Usually, the amino acid requirement is expressed as a percentage of the dietary portion. The amino acids are grouped in two classes. (a) Indispensable amino acids; this group of amino acids includes arginine, histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine,

tryptophane and valine. These amino acids are essential for optimal growth of fish. Thus, any fish diet devoid of these amino acids may deter growth substantially. (b) Dispensable amino acids; these include alanine, aspartic acid, cystine, glutamic acid, tyrosine, etc. But, some of the above nonessential amino acids exert sparing effects on requirements for indispensable amino acids. For example, if cystine is included in the ration, it reduces the requirement of methionine and in the same manner, tyrosine reduces the requirement for phenylalanine.

Finally, maximum growth will not be realized unless the appropriate ratio of these amino acid requirements are met. Additionally, we must keep in mind the fact that the quantitative needs for amino acids and protein vary with changes in temperature, water quality, fish size, and species.

3. Lipid Requirements. Dietary fats constitute an important energy source for many widely known fish species. The required fat content of fish food may range from 2 percent to as high as 20 percent, again depending on the type of species, fish size, and temperature. Important factors to be considered when lipid is included in a diet are digestibility, lipid level, and essential fatty acids. Failure to consider these factors may have an antagonistic effect on the health of fish. Generally, liquid fats are used by fish since most fish do not efficiently utilize hard, high-melting-point

fats. In this study the fat requirement has a lower limit of 11.8 percent as suggested by Mr. John Westgate, nutritionist, at the Oregon Fish Commission.

4. Carbohydrates. Carbohydrates are a major source of energy to man and many domestic animals. But, fish are perhaps the most inefficient users of carbohydrates because natural diets are not rich in digestible carbohydrate. On the other hand, sources of dietary nutrients containing high level of carbohydrate are usually the least expensive. Thus, if more carbohydrates could be used without being detrimental to the fish, the cost of rearing fish would be substantially reduced. Yet, in this study, carbohydrates are not considered at all because the use of carbohydrates as a diet for fish is still in the experimental stage.

5. Vitamins. Vitamins are essential for health and maximum growth of fish reared in artificial environment. The specific role of several vitamins in fish metabolism has been studied and for many years vitamins have been used as one of the essential components of fish rations. In this study two percent of vitamin supplement was added to the ration. Again, this percentage figure was obtained from the experimental results of the Oregon Fish Commission.

In conclusion, rations for biological support of fish must contain a full complement of proteins, fats, as well as nonenergy components like vitamins and minerals. In addition, the above major components of fish rations should be utilized in a ratio that will yield the highest possible conversion to fish growth and continue to maintain health in the fish.

III LEAST COST ANALYSIS OF FISH FOOD

The goal of this chapter is to develop linear programming models that will formulate least cost rations that are consistent with a maximum growth of fish in a hatchery environment.

Formulation of the Linear Programming Model for Least Cost Ration

Solving problems by linear programming involves recognition of the problem as a linear programming problem, actual formulation of the mathematical model, and the estimation of parameters used in the model.

The problem at hand is to formulate rations which will equal or exceed the minimum nutritional requirements of the fish at least cost. Linear programming is widely utilized to solve this kind of problem. Generally, linear programming is a valuable tool to use when (a) the objectives of the problem can be easily quantified, (b) there exists a wide range of alternative solutions to a given problem, (c) and certain constraints exist.

The problem confronting the writer of this thesis is, in part, to choose the least cost ingredients that will meet the minimum requirements of proteins, fats, and amino acids in fish ration. There are eleven ingredients under consideration. In the model to be presented shortly, each ingredient is represented by the letter X_j, j=1, 2, 3, . . . , 11. They are treated as the main variables of the model. In addition, the model has 18 constraints, of which 13 represent the various amino acid constraints and the rest of them are for protein, fat, vitamins, and weight.

Definition of the Variables Used in the Model

In the following equations the X_j's denote pounds of wetfish meal, herring meal, cottonseed meal, wheat germ, whey (MNC), crab meal, distillers solubles, kelp meal, oil, vitalpak, and wheat middlings used in the rations.

The coefficient of each variable denotes the amount of amino acids, fat or protein that can be satisfied when a pound of any one of the variables are considered. For example, in (E-2) of the model, a pound of wetfish satisfies .00929 pound of the requirement of arginine.

The variables in the objective function have the same meaning as for the rest of the equations except that the coefficients of the variables denote the estimated cost of the ingredients per pound.

The nutrient coefficients for each variable were obtained from the Oregon Fish Commission. The reliability of the result of this study depends on the accuracy of the estimates of these coefficients.

Descriptions of the General Linear Programming Model

No. of equation	Description of equation	Equation
1	Weight constraints	$X_1 + X_2 + X_3 + X_4 + X_5 + X_6 + X_7 + X_8 + X_9 + X_{10} + X_{11} = 100$
2	Arginine "	$-.00929X_1 + .0422X_2 + .0512X_3 + .0183X_4 + .0059X_5 + .0165X_6 + .0105X_7 + .0034X_{10} + .009X_{11} \geq 2.184$
3	Cystine "	$.00172X_1 + .0084X_2 + .008X_3 + .0048X_4 + .0057X_5 + .004X_6 + .0046X_7 + .0007X_{10} + .0019X_{11} \geq .473$
4	Histidine "	$.00282X_1 + .0153X_2 + .0126X_3 + .0065X_4 + .0033X_5 + .005X_6 + .007X_7 + .0015X_{10} + .004X_{11} \geq .655$
5	Isoleucine "	$.00501X_1 + .0324X_2 + .0149X_3 + .0087X_4 + .0107X_5 + .0119X_6 + .015X_7 + .003X_{10} + .0079X_{11} \geq .800$
6	Leucine "	$.00902X_1 + .0535X_2 + .027X_3 + .0155X_4 + .0173X_5 + .0159X_6 + .0211X_7 + .0045X_{10} + .0119X_{11} \geq 1.4196$
7	Max. Leucine "	$.00902X_1 + .0535X_2 + .024X_3 + .0155X_4 + .0173X_5 + .0159X_6 + .0211X_7 + .0045X_{10} + .0119X_{11} \leq 2.41$
8	Lysine "	$.0121X_1 + .058X_2 + .0194X_3 + .0151X_4 + .0149X_5 + .014X_6 + .009X_7 + .0026X_{10} + .007X_{11} \geq 1.82$
9	Methionine "	$.00344X_1 + .0214X_2 + .0059X_3 + .0052X_4 + .0057X_5 + .0052X_6 + .0055X_7 + .0007X_{10} + .0018X_{11} \geq .728$
10	Phy. & Tyrosine "	$.00742X_1 + .0523X_2 + .0379X_3 + .0167X_4 + .0148X_5 + .0238X_6 + .022X_7 + .0041X_{10} + .0109X_{11} \geq 2.2204$
11	Threonine "	$.0057X_1 + .0296X_2 + .0146X_3 + .0096X_4 + .0086X_5 + .001X_6 + .001X_7 + .0022X_{10} + .0059X_{11} \geq .8008$
12	Tryptophan "	$.00135X_1 + 0083X_2 + .0054X_3 + .0029X_4 + .0036X_5 + .0032X_6 + .0023X_7 + .0007X_{10} + .0019X_{11} \geq .182$
13	Valine "	$.00633X_1 + .0386X_2 + .021X_3 + .0115X_4 + .0094X_5 + .0149X_6 + .015X_7 + .003X_{10} + .0079X_{11} \geq 1.1648$
14	Max. Valine "	$.00633X_1 + .0386X_2 + .021X_3 + .0115X_4 + .0094X_5 + .0149X_6 + .015X_7 + .003X_{10} + .0079X_{11} \leq 2.595$
15	Protein "	$.15X_1 + .72X_2 + .5X_3 + .239X_4 + .167X_5 + .25X_6 + .294X_7 + .065X_{10} + .174X_{11} \geq 36.4$
16	Fat "	$.06X_1 + .095X_2 + .03X_3 + .086X_4 + .01X_5 + .02X_6 + .093X_7 + .022X_8 + X_9 + .018X_{10} + .048X_{11} \geq 11.8$
17	X_{10}=Kelpmeal "	$X_{10} = 2$
18	X_8=Vitalpak	$X_8 = 2$
19	Objective function	$TC = .055X_1 + .254X_2 + .082X_3 + .148X_4 + 12X_5 + .06X_6 + .1X_7 + .12X_8 + .23X_9 + 1.2X_{10} + .065X_{11}$

Once the problem is set up in the above form and the variables defined, the rest of the analysis mainly deals with constructing various models by adding or dropping constraints that are not considered in the above general model.

Model I

In this model, the main interest is to obtain the least cost feasible solution without considering any upper or lower constraints on the quantities of any of the ingredients.

Under this situation the optimal solution that will satisfy all the nutritional requirements imply a cost of $13.48 for a hundred pounds of the fish food. The variables considered in this solution are:

Value of the Objective Function .... Min. $13.48

Variables in solution	X_j's	Amount
Herring meal	X_2	15.6 pounds
Cotton seeds	X_3	27.6 "
Crab meal	X_6	44.3 "
Kelp meal	X_8	2.0 "
Oil	X_9	8.5 "
Vitalpak	X_{10}	2.0 "
Total		100.0 "

The objective function that minimizes the dollar value of this particular model can then be written as

$$*(E\text{-}20) \quad 13.48 = .254X_2 + .082X_3 + .06X_6 + .12X_8 + 23X_9 + 1.2X_{10}.$$

If the interest lies only in minimizing the dollar value of the ingredients under consideration, this solution would have been the ultimate answer of the problem. But, in many instances one has to consider other factors, such as the overall quality and availability of the ingredients in question. For example, in model I, 44.3 percent of the ration consists of crab meal, and crab meal has high concentration of ash and chitin nitrogen which may have a detrimental effect on fish growth. Thus, this condition would, in all likelihood, make model I solution rather unattractive because of probable poor fish growth and survival, even though it still represents the cheapest mix.

Model II

Model II is constructed with the aim to correct some of the drawbacks of model I described above. In other words, in model II nonprice factors have been considered, such as the quality and availability of the ingredients. In constructing model II the following additional constraints were made, as suggested by Mr. John Westgate, nutritionist, at the Oregon Fish Commission.

Wetfish	$= X_1$	= 30 lb.
Cotton seed	$= X_3$	$\leq$ 18 "
Crab meal	$= X_6$	= 10 "

However, consideration of the above additional constraints is not without cost. For instance, the result from the computer print-out in model I indicates an increase in the cost of the ration amounting to .00725 cents for each pound of wetfish included. (This shadow price is "local", subject to change as levels of the ingredients change.) In the same manner, any reduction in the amount of cotton seed or crab meal from the level shown in model I entails a further boost in the cost of the ration.) In any case, under model II the optimum feasible solution indicates a cost of $14.85 for each hundred pounds of fish food. This result is indeed more expensive than model I; however, the ration considered under the present model has a significantly lower chitin nitrogen, ash, and fiber content which are characteristic of better quality food.

The variables in the solution include

Objective function .... Min. $14.85

Variables in solution	X_j's	Amount	Reduced cost
Wetfish meal	X_1	30.0 lb.	+ .015464
Herring meal	X_2	25.2 "	0
Cotton seeds	X_3	18.0 "	- .05831
Crab meal	X_6	10.0 "	- .005159
Distiller	X_7	6.6 "	0
Kelp meal	X_8	2.0 "	-----
Oil	X_9	6.2 "	0
Vitalpak	X_{10}	2.0	-----
Total		100.0 lb.	

The objective function that minimizes the cost under the given constraints can be expressed as

$$*(E-21) \quad \$14.85 = .055X_1 + .254X_2 + .082X_3 + .06X_6 + .1X_7 + .12X_8 + .23X_9 + 1.2X_{10}.$$

NOTE: The figures under the column heading "reduced cost" show the decrement if the sign in front of the figure is negative, or increment if the sign is positive, for considering an additional pound of the ingredients in question. For example, in this model we limited crab meal only to ten pounds. However, we could have saved .005159 cents per pound if we relaxed the upper limit of crab meal to anything above ten pounds and less than 44.3 pounds. In contrast to this, if we decide to increase wetfish meal above 30 pounds, cost of the ration will increase by .015464 cents for each additional pound considered. (Again, these "shadow prices" are local subject to change as levels of the ingredients change.)

Model III

Model III is constructed to compare the preceding two models with the typical fish ration actually used in the current fiscal year by the Oregon Fish Commission. This ration consists of

Variables	X_j's	Amount
Wetfish	X_1	30.0 lb.
Herring meal	X_2	28.0 "
Cotton seed meal	X_3	15.0 "
Wheat germ	X_4	4.0 "
Whey	X_5	4.0 "
Crab meal	X_6	4.0 "
Distillers solubles	X_7	4.0 "
Kelp meal	X_8	2.0 "
Oil	X_9	6.0 "
Vitalpak	X_{10}	2.0 "
Total		100.0 lb.

After imposing these additional constraints on the general L. P. model, the optimal solution for model III is $15.85 per hundred pounds of fish food. This solution is more expensive than either of the first two models. In addition, the ration under model III does not satisfy the phenylalanine requirement. Phenylalanine belongs to the class of indispensable amino acids and failure to meet this requirement could significantly deter the optimal growth of fish.

Concluding Notes: This chapter has been devoted to developing a programmed ration consistent with requirements for maximum fish growth at a minimum cost. Accordingly, three alternative models under various assumptions were critically examined. The criterion used to assess the final result of each of the three models considered were, (a) the least cost diet, and (b) the nutritional value of the diet.

The ration under model I represents the least cost mix. It shows a saving of approximately 15 percent when compared with the cost of the present food ration in use. Although the ration under model I represents the least cost mix, the quality of the ration was inadequate because of the presence of high concentration of ash and chitin nitrogen.

The ration being presently used, model III, is the most expensive of all. In addition, the ration considered under model III is not consistent with requirements for maximum fish growth because of its failure to fulfill the phenylalanine requirements.

Therefore, it appears that the most preferred ration is obtained using model II because of the following reasons: (1) its cost is approximately seven percent less than model III which is the ration in use at present. (2) The nutritional value of the ration considered under model II appears to be superior to either one of the other two models. It satisfies all the constraints; and it has a much lower concentration of ash and chitin nitrogen. However, the actual value of the model II ration for fish feeding can not be relied upon with full certainty until the conclusion of experiments by the Oregon Fish Commission, where the model II is being fed and compared with standard rations, such as the model III ration is obtained.

IV MAXIMIZATION OF FISH PRODUCTION AND ECONOMIC BENEFITS UNDER ALTERNATIVE RESOURCE LEVELS

In Chapter III, the discussion was centered around developing programmed rations which will meet the nutritional requirements of the fish at the minimum cost. Since the cost of fish food is one of the major variable costs, any saving that can be realized from fish food is an important issue in any hatchery operation. Thus, finding ways to minimize fish food cost will undoubtedly contribute to the economic benefit of any given hatchery.

However, minimization of fish food cost is only one of the many possible ways of increasing the economic benefits accruing from hatchery operation. In fact, there are other important factors in hatchery management that will lead to further reduction of operational cost and, therefore, increase the economic benefits of that particular enterprise. The major thrust of this chapter will be to investigate those additional factors that contribute to the economic returns of hatchery operation.

The primary objectives of this chapter are, (1) to construct linear programming models which will permit us to evaluate the maximum possible returns for any hatchery operation under a given condition, and (2) to investigate the sensitivity of the benefit-cost ratio for a given condition as we relax some of the assumptions of the model. Part of this chapter was published in Oregon Agricultural Experiment Station Special Report 428, December 1974. However, more detail analysis is given in this chapter and the appendix than was presented in Special Report 428.

Problem Description

There are 22 hatcheries within the Columbia River system. Operation and maintenance of these 22 salmon and steelhead hatcheries funded by the National Marine Fisheries Service within the Columbia River system involves annual expenditure 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. 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

The General Linear Programming Model

No. of equation	Description of equation	Description of the linear programming model	
1	December	$22.5X_1 + 0X_2 + 7.1X_3$	$\leq$ 75, 752 cu. ft.
2	January	$22.7X_1 + 1.53X_2 + 7.1X_3$	$\leq$ 75, 752 "
3	February	$29.126X_1 + 3.153X_2 + 17.2X_3$	$\leq$ 75, 752 "
4	March	$30.6914X_1 + 3.153X_2 + 18.5876X_3$	$\leq$ 75, 752 "
5	April	$32.6924X_1 + 5.0612168X_2 + 18.5876X_3$	$\leq$ 75, 752 "
6	May	$8.8X_1 + 5.061268X_2 + 4.3X_3$	$\leq$ 75, 752 "
7	June	$12.7X_1 + 0X_2 + 4.3X_3$	$\leq$ 75. 752 "
8	July	$18.0X_1 + 0X_2 + 4.3X_3$	$\leq$ 75, 752 "
9	August	$18.0X_1 + 0X_2 + 7.1X_3$	$\leq$ 75, 752 "
10	September	$20.6X_1 + 0X_2 + 7.1X_3$	$\leq$ 75, 752 "
11	October	$20.6X_1 + 0X_2 + 7.1X_3$	$\leq$ 75, 752 "
12	November	$20.6X_1 + 0X_2 + 7.1X_3$	$\leq$ 75, 752 "
13	Food	$118.667X_1 + 11.6356X_2 + 56.768X_3 - 1.0X_5$	$\leq$236, 040 lbs.
14	W. December	$4.9X_4$	$\leq$ 67, 167 cu. ft.
15	W. January	$4.9X_4$	$\leq$ 67, 167 "
16	W. February	$4.9X_4$	$\leq$ 67, 167 "
17	W. March	$12.194X_4$	$\leq$ 67, 167 "
18	W. April	$12.991683X_4$	$\leq$ 67, 167 "
19	W. May	$12.991683X_4$	$\leq$ 67, 167 "
20	W. June	$4.9X_4$	$\leq$ 67, 167 "
21	W. July	$4.9X_4$	$\leq$ 67, 167 "
22	W. August	$4.9X_4$	$\leq$ 67, 167 "
23	W. September	$4.9X_4$	$\leq$ 67, 167 "
24	W. October	$4.9X_4$	$\leq$ 67, 167 "
25	W. November	$4.9X_4$	$\leq$ 67, 167 "
26	W. Food	$67.5336X_4 - 1.0X_6$	$\leq$210, 195 "
27	Objective function	$TR = 68.17X_1 + 10.0X_2 + 38.76X_3 + 45.45X_4$	

Little White Salmon included spring Chinook, fall Chinook, and Coho. For Willard, only the Coho activity was included because the water during the winter is too cold for good Chinook growth.

Description of the LP Model

In the above equations, X_1 denotes the release of 1,000 spring Chinook at 14.67 per pound from the Little White Salmon 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 22 per pound from the Willard Hatchery.

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 $1,000 \div 14.67 = 68.17$ pounds of fish. Following the same procedure the coefficients for the objective function of X_2, X_3, and X_4 are estimated. X_5 and X_6 in the model denote purchase of additional fish food for Little White and Willard, respectively. (Except for E-29, the value of X_5 and X_6 have zero values since purchase of additional fish food is not allowed.)

Maximization of Production for Fiscal Year 1973 Condition

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. (The above data pertaining total fish food consumption was obtained from the annual report of Willard and Little White Salmon Hatcheries). Substituting these quantities into the LP model, maximum pounds of fish for release can 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. In terms of pounds, this production would represent about 158, 000 pounds of fish released from Little White Salmon, and about 141, 470 pounds from Willard. This production represents a maximum for the assumed available capacity of the rearing facilities.

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 Varying Fish Food Levels

In this section, the interest lies in investigating the behavior of total fish production as we vary the food constraints below and above the current production levels. Note that we are not varying the loading rate or the space constraints.

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 expenditure for fish food, since fish food represents more than one-half the nonlabor expenditures in Table 1, and these nonlabor expenditures are often the only variable expenses, given the Civil Service employment arrangement of the fish hatcheries.

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

Cost items	Willard	Little White
Personnel salaries b/	$ 75, 719	$ 86, 589
Fringe benefits and overhead c/	25, 727	31, 287
Nonlabor 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. Perhaps this is one debatable item in Table 1. This rate 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 less than 8 percent.

Using the costs of Table 1 and the results of the linear programming analysis the average costs were computed at various assumed levels of fish food.

Table 2. Predicted Average Total Cost Per Pound and Maximum Pounds of Fish Produced at Various Fish Food Levels

Percent of fiscal year 1973 fish food levels	Maximum lbs. of fish produced for the assumed level of fish food	Predicted average total cost per pound
20	68, 864. 0	$5. 00
40	137, 728. 0	2. 63
50	172, 161. 0	2. 15
60	206, 593. 0	1. 83
100	299, 424. 0	1. 38
120	358, 857. 0	1. 20
130	388, 570. 0	1. 13

From Table 2 above, the average total cost curve in Figure 3 was constructed. Thus, as it is evident from the shape of the total cost curve of Figure 3, a reduction in fish food will decrease production. 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. Thus, the average total

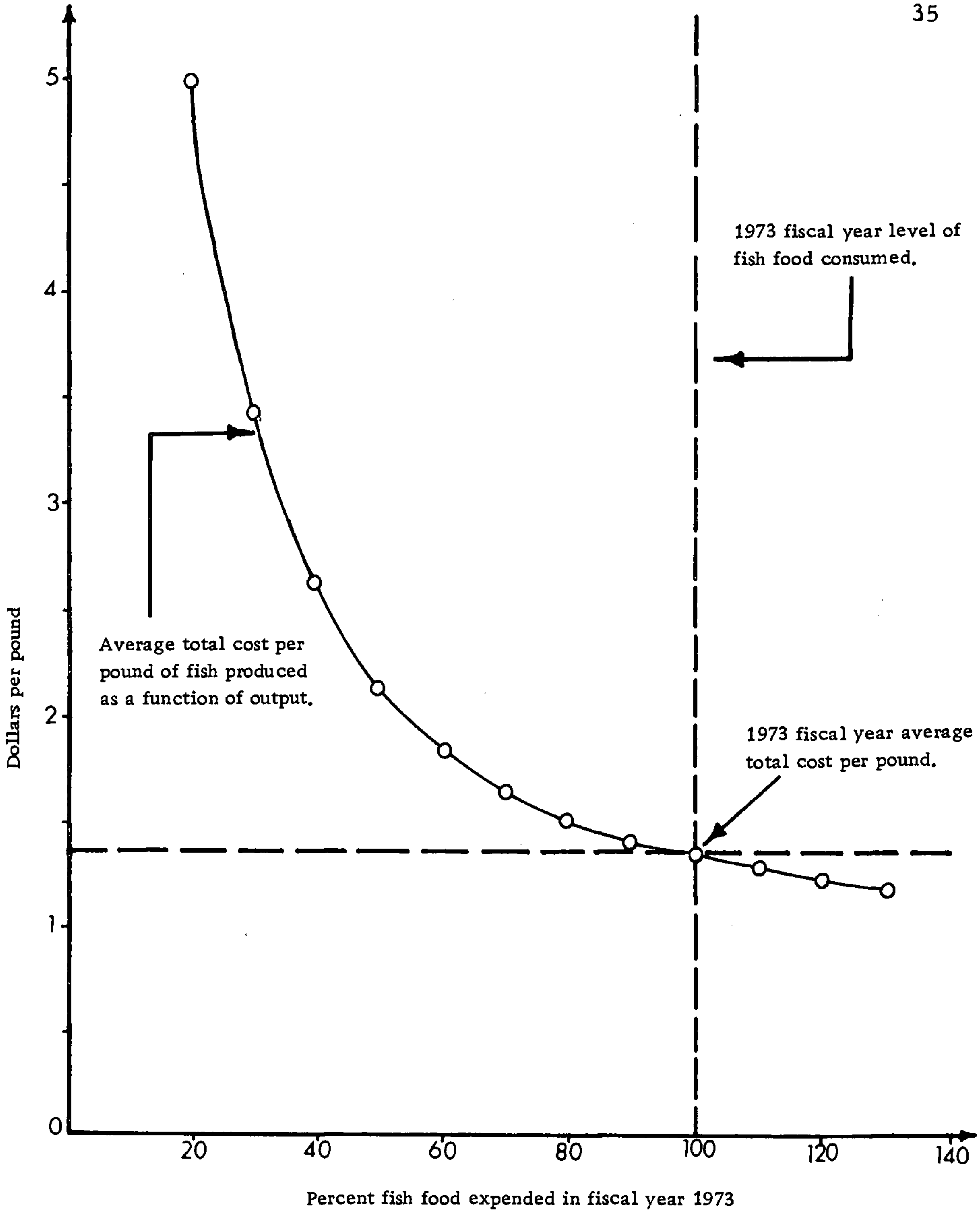


Figure 3. Average total cost in dollars per pound of fish produced at the Little White Salmon and Willard National Fish Hatcheries.

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. Table 2 above presents the results of similar computation for various assumed levels of fish food.

Thus, given the preceding average cost figures, it is apparent that reducing expenditure by decreasing funds available for fish food would be an inefficient way to reduce costs, since a 50 percent reduction in fish food would reduce cost by only 10 percent (42, 392 ÷ 412, 491 ≐ 0. 103) whereas total production would be reduced by about 43 percent, (299, 424 - 172, 161) ÷ 299, 424 ≐ 0. 43. The preceding figures, and the average total cost curve in Figure 3 imply 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

In the linear programming model above, food was the limiting factor. In this section we will allow fish food constraints above the present level. Since space is not a limiting factor, production could be further increased allowing average total costs to decline even more. Yet, the crowding effect of rearing space should be considered carefully. If the rearing space is too crowded, 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 overly crowded 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 shown in Figure 3.

So far, the discussion has been geared to demonstrate how production could be optimized at the existing level of fish food and rearing space capacity. Also, the change in the level of production and average costs is shown as we vary the food constraints above and below the current level of utilizations. However, 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.

Marking Studies

For many years there has been a growing concern among hatchery managers and researchers to develop a method of estimating total contributions of the fish released from the Columbia River Basin to the sport and commercial fisheries. In order to meet this demand a marking experiment was initiated in 1962.

The marking experiment was designed with an objective to estimate the total contribution to the sports and commercial fisheries from the Columbia River hatcheries. This experiment consisted of removing the adipose fin and a portion of the right or left maxillary bone from about 10 percent of each hatchery's production and then sampling for this mark in the commercial and sport fisheries at the time of catch or recovery.

The first marking experiment was undertaken in 1962 by the Columbia Fisheries Program Office to estimate the contribution of hatchery-reared fall Chinook salmon to the fisheries. At that time, the experiment was confined to 12 hatcheries that propagated about 90 percent of all Chinook salmon artificially reared in the Columbia River. This experiment was applied to four consecutive broods of fall Chinook salmon, each lasting a year. Following this, a similar experiment was extended to estimate the contribution of Coho salmon smolts of the 1965 and 1966 broods. There were 20 hatcheries participating in this study. The data collections from these two experiments were completed in 1969 since the life cycle of both Chinook and Coho salmon generally lasts from three to five years. Currently, the Columbia Fisheries Program Office is running a marking study of spring Chinook.

Estimating Procedure

To begin with, the Columbia River was divided into four sections; Lower, Middle, Upper, and Uppermost river. Each section of the river was assigned a unique fin clip or mark each year. This was done to show the variation in the contribution of hatcheries from the various river sections (see Figure 1).

From each hatchery, a sample of about 10 percent of the fish reared were marked. After the marking procedure was completed, the fish were released into the river. This was the first phase of the marking procedure. With its completion, it provides us the total number of marked to unmarked fish at the time of release.

The second phase dealt with the estimation of the total catches from the samples of marked fish caught at different regions. (The region where catches were examined for marked salmon of Columbia River extends from California to Alaska.) Under this procedure, the catch of total hatchery fish for each ocean sport and commercial fishery, and the Columbia River fisheries, was estimated for each year and brood by dividing the estimated catch of fish having a specific mark by the expected marked/unmarked ratio. This later estimate was then adjusted for the relative survival of marked fish. (This adjustment was considered necessary because the mortality rate of marked fish is slightly higher than unmarked fish.) The relative survival of marked fish was estimated by comparing marked/unmarked ratios at release and return (ratio at return ÷ ratio at release). Finally, total catch of hatchery fish was estimated by dividing the catch of fish having a specific mark by the ratio of the relative survival of the marked fish times the marked/unmarked ratio at the time of release.

Once total catches of hatchery fish were estimated by the above method, it remained only to estimate the average weight and unit value of fish caught to calculate their total economic value.

At this stage, a simple numerical example may be helpful to clarify the above method of estimation. Suppose an estimated 3, 241 of 1961-brood Ad-Rm marks of fall Chinook salmon were caught in 1964 in the Washington Ocean Commercial Fishery. The marked/unmarked ratio for this particular brood was 0. 1193, $\frac{\text{marked released}}{(\text{marked + unmarked released})}$, for all hatcheries where Ad-Rm were released, and the survival of marked fish was estimated to be 70 percent that of unmarked fish. Therefore, the estimated catch of unmarked fish would be 3, 241/(0. 1193 x 0. 7) = 38, 814.

Then, total catch would be (3, 241 + 38, 814) = 42, 055 fish. If we seek to express this result in terms of pounds of fish caught, we multiply 42, 055 by 8.45 since the average weight of three years old fall Chinook of 1961 brood is estimated to be 8.45 pounds. The result would be then 42, 055 x 8.45 = 355, 364.75 pounds.

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

Based upon the reports from 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. 324 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 (1972). 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 (1.324) ≐ \$107. More detail calculations of these estimates are given in the appendix.

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 potential value would not be much less if 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 x 13.5 lbs = \$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.

Using the same method of estimation 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) = \$295.00 for the value of the sport catch, giving \$221.06 + \$295.00 = \$516.05 per 1,000 Coho released. (See appendix for details of the calculations of these estimates.) 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 it was 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 ÷ 25.8) (516.05) = \$454.00 per 1,000 fish released. Similarly, the value of Coho from Willard was computed to be (22.7 ÷ 22) (516.05) = \$532.50.

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) (\$107.00) = \$730.00 per 1,000 spring Chinook released. The reliability of this assumption can not be assessed until results from the marking study of spring Chinook become available.

Value and Benefit-Cost Ratios with Fiscal Year 1973 levels of Fish Food

Since the interest is to maximize the dollar value of production, the objective function (E-27) of the previous linear programming model is changed. If dollar value of fish harvested is to be maximized, then the expected value of the commercial and sport catch for each species must be estimated, as explained earlier. Assuming the value of a sport-caught Coho or Chinook was $20, then the new objective (total revenue) function to be maximized by LP was:

$$\text{(E-28)} \quad TR = \$730X_1 + \$107X_2 + \$454X_3 + \$532X_4 - \$0.19X_5 - \$0.19X_6.$$

In this equation X_5 and X_6 denote purchase of additional fish food for Little White and Willard, respectively. The coefficients for X_5 and X_6 are the average price of fish food per pound.

Thus, using the previous LP model with the change in the objective function as specified above, and assuming a fiscal 1973 level of fish food, a maximum of economic benefit would result from releasing about 4, 075, 405 Coho from Little White Salmon Hatchery and about 3, 112, 451 Coho from Willard Hatchery. Total value from Little White Salmon Hatchery 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. (Note that X_5 and X_6 have zero values since purchase of additional fish food is not allowed in the above model.)

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

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

using the fiscal year 1973 costs presented earlier in Table 1.

The benefit-cost ratio for the Willard Hatchery is

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

The above benefit-cost ratio could be criticized, as much as the sport values are estimated 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, 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, production can be increased substantially with smaller increase in cost for the additional fish food required. This was shown by the decreasing cost curve of Figure 3. Good results are being obtained at the Willard Hatchery with heavier concentration of Coho salmon in the rearing ponds. Thus, from the viewpoint of Willard Hatchery the crowding effect due to increased production is not restrictive. Hence, if it is assumed that crowding does not over-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 for 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. This is because the rearing pond space, rather than fish food, was limiting for Coho at Little White. 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

$$\text{B-C ratio} = \frac{\$532.5\ (5,170)}{\$197,581 + \$27,401} \doteq \frac{\$2,753,025}{\$223,982} \doteq 12.29.$$

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.

$$\text{B-C ratio} = \frac{\$2,753,025 - 1,657,380}{\$26,401} \doteq 41.5$$

The three preceding 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.

Qualifications Concerning the Preceding Benefit-Cost Analysis

The first question concerning the preceding analysis pertains to the estimates of value assumed. Substantially more of the fall Chinook are harvested in the British Columbia commercial fishery, about 34 percent, 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).

The second 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 the 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 Weight

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. In order to see how sensitive the linear programming solution was to the assumptions that the sport-caught fish have values proportional to the fish weights, a change in the objective function of the LP program was introduced. Using $16.44 for the value of sport-caught Coho and $34.25 for sport-caught Chinook, the new LP objective function was:

$$\text{(E-29)} \quad TR = \$856.37X_1 + \$125.63X_2 + \$407.85X_3 + 478.30X_4 - \$0.19X_5 - \$0.19X_6.$$

The coefficients of the above equation are markedly different from equation (E-28) because of the assumed change in the sport value of Coho and Chinook.

Values and Benefit-Cost Ratio with Fiscal Year 1973 Levels of Fish Food Assuming that the Sport-Caught Fish Have Values Proportional to the Fish Weight

As shown in (E-29) when the value of sport-caught Coho and Chinook is changed to \$16.44 and \$34.25, respectively, the linear programming "price" for the Little White Salmon Coho dropped from \$454.00 to \$407.85, the "price" for Little White Salmon fall Chinook increased from \$107.00 to \$125.63 per 1,000 released, and the price for spring Chinook increased from \$730.00 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:

$$\text{B-C ratio} = \frac{\$856.37(1,422.47) + \$125.63\ (5,778.8)}{\$214.910} = \frac{\$1,944,151}{\$214,910}$$

$$= 9.05$$

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. Moreover, a slight increase in the benefit-cost ratio is realized, from 8.61 to 9.05.

For the Willard Hatchery, only Coho were considered because the water is too cold for satisfactory growth of Chinook salmon as mentioned earlier. 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

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

(NOTE: The linear programming solution, i.e., the maximum numbers fish for release from Willard is not changed. It is still 3,112,451. The reduction in the benefit-cost ratio for Willard is purely due to the reduction of the sport value for Coho from $20 to $16.44.)

Values and Benefit-Cost Ratios with Increased Fish Food Assuming that the Sport-Caught Fish Have Values Proportional to the Fish Weight

As is evident from the earlier analysis, increased expenditures for fish food increases economic benefits much more than costs. Assuming that the sport-caught fish have values proportional to the fish weight, and allowing fish food buying activity in the LP model, the optimum solution for the Little White Salmon Hatchery indicated 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. (NOTE: Spring Chinook appeared in this solution because fish food was not limiting.) Although net economic benefits were increased by about $32, 759 ($1, 984, 306 - 1, 944, 151), the B-C ratio decreased slightly from 9. 05 to 8. 93 as shown below.

$$\text{B-C ratio} = \frac{\$856.37\ (2,317.113)}{\$214,910 + \$8,396} = \frac{\$1,984,306}{\$222,306} = 8.93$$

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

$$\text{B-C ratio} = \frac{\$478.3\ (5,170)}{\$197,581 + \$26,401} = \frac{\$2,472,811}{\$223.982} = 11.04$$

Again, the benefit-cost ratio of Willard Hatchery decreased from 12. 29 to 11. 04 purely due to the reduction in the price of sport-caught Coho from $20 to $16. 44.

However, for the Willard Hatchery, a substantial increase in the benefit-cost ratio, from 7. 53 to 11. 04, results from the increased production that is realized by allowing fish food buying activity in LP model.

V AN ALTERNATIVE APPROACH OF ESTIMATING THE ADDED BENEFITS TO THE PUBLIC AS A RESULT OF THE PROPOSED INCREASE IN THE HATCHERY PRODUCTION OF SALMON SMOLTS

In the preceding analysis, using the production information obtained from the Little White Salmon and the Willard National Fish Hatcheries, it was shown that increases in the production of salmon smolts by providing the additional fish food required for the new level of production would boost the benefit to cost ratios realized from the two hatcheries. This is because the additional benefit gained from the increased production of salmon is greater than the cost for the additional fish food required to meet the new level of production. That is to say, if

ΔQ = The additional production of salmon smolts

P_q = Per unit value of salmon

P_r = Per unit cost of fish food

ΔR = The required increase in fish food to feed the additional production of salmon smolts,

then the above statements can be summed up in the following manner

$$\Delta Q \cdot P_q > P_r \cdot \Delta R.$$

Hence, other things remaining constant, it will pay to increase production of salmon until $\Delta Q \cdot P_q = P_r \cdot \Delta R$, that is; until the value from the increased production of salmon equals to the cost of the additional food required.

In the above illustration P_q was estimated by the formula,

$$P_q = P_c \cdot (F_c) + \$20 \, (F_s).$$

Where:

P_c = Commercial price per pound of a given species of salmon

F_c = Pounds of commercially-caught salmon

F_s = The number of sport-caught salmon

\$20 = Estimated average value of a sport-caught salmon.

As is evident from the above algebraic expression, in estimating the per unit value of salmon (P_q), it was assumed that a sport-caught salmon has a value of \$20. But, \$20 per sport-caught salmon is an estimate of the average value, and the marginal value could be considerably less. If such a case prevails, then, the estimation of P_q using the above formula may be upward biased. Furthermore, P_c was based upon the average commercial price, and therefore tends toward the gross value of the commercially caught salmon. Therefore, the earlier price assumptions may exaggerate the benefits gained from increased production of salmon by increasing fish food. Due to this apparent weakness associated in the estimation of the per unit value of salmon (P_q), the concept of "Consumer-Surplus" is employed as an alternative method to estimate the benefit from the increased hatchery fish production. As will be shown later, the benefit estimated by using the concept of consumer surplus is downward biased.

The Concept of Consumer's Surplus

The concept of consumer's surplus occupies a controversial but important place in economic theory. This concept has been applied to a wide variety of problems, especially in the field of resource economics for estimating values of public goods, etc.

Consumer's surplus is commonly defined as the difference between the maximum amount that the consumer would pay and the amount that he actually pays. This definition suggests, except in an extreme case, that the consumer derives a surplus utility from being able to buy a commodity at a particular price. Traditionally, consumer's surplus is measured by the triangle-like area below the demand curve and the price line. However, to justify the use of the triangle as economic measures of the true surplus, a restrictive assumption has to be made. This assumption is that the marginal utility of money has to be constant. This assumption, if accepted, would allow (a) money to be used as an acceptable cardinal index of utility, (b) the income-effect due to price change to be approximately zero or that the consumer's demand schedules are unaffected by changes in his real income.

Thus, in cases where the assumption of constant marginal utility of money does not provoke any serious problem, the area below the demand curve would provide an acceptable measure of the total utility from the commodity and the triangle-like area below the demand curve and the price line would approximate the true surplus. With the aid of Figure 4, the concept of consumer's surplus can be easily demonstrated. (NOTE: Figure 4 assumes perfectly elastic supply curve.)

In Figure 4, when the consumer buys LO pounds of fish at ON price for each pound of fish, the consumer's total expenditure can be depicted by the area OLMN (OL · ON). But, the consumer derives total utility, expressed in money, equivalent to the area OLMR from consuming OL pounds of fish. Therefore, the triangular area NMR (OLMR - OLMN) is the surplus utility the consumer gained from being able to buy OL pounds of fish at ON price per pound. Also, as the price of fish decreases the consumer's surplus will increase.

In this study the concept of consumers' surplus is used to show the increase in community welfare due to an increase in quantity of fish produced in the Willard National Fish Hatchery. To illustrate the effect of increased hatchery salmon production on the consumers' surplus, a demand curve for fresh and frozen salmon was estimated. This procedure assumed that most of the

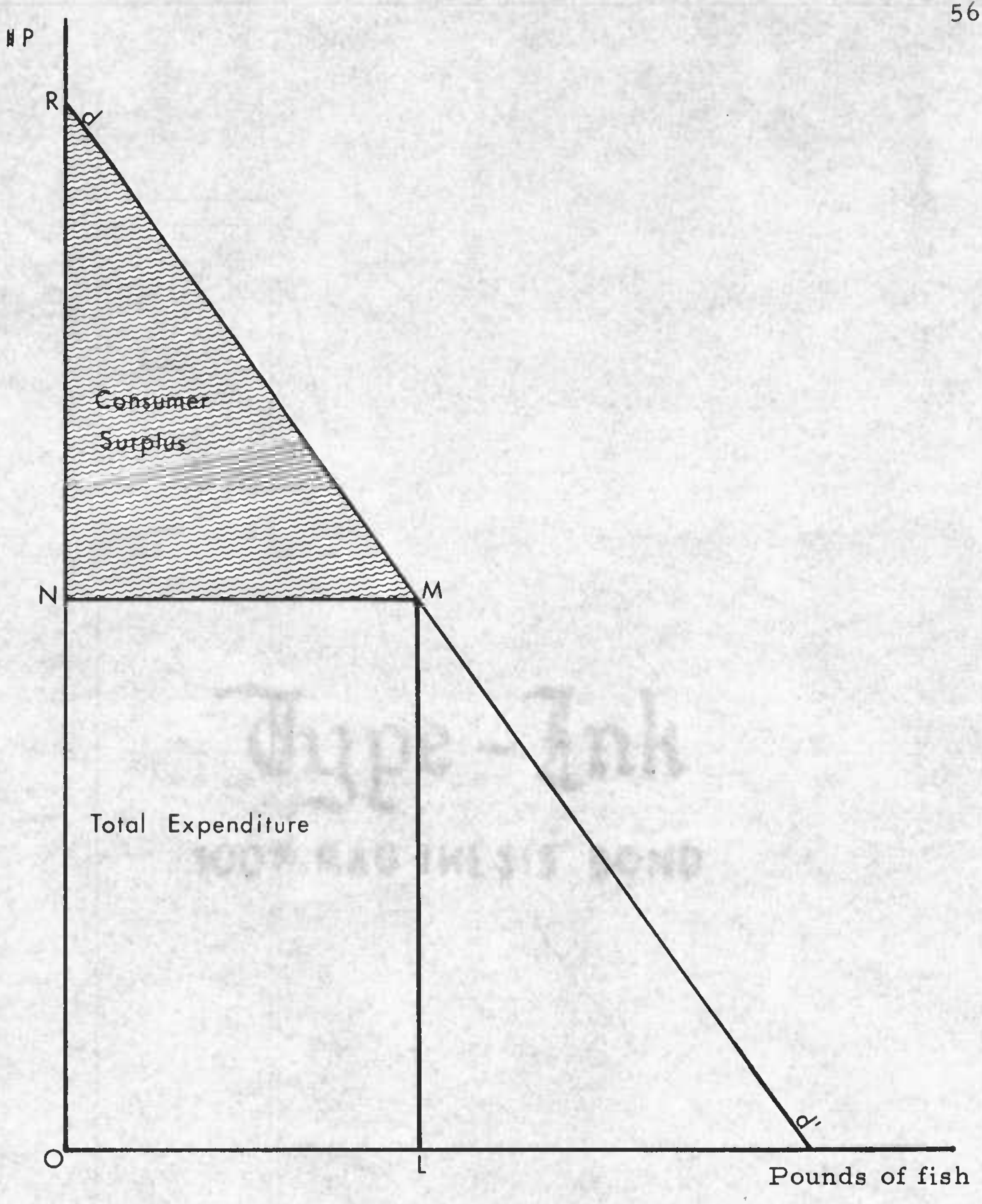


Figure 4. Diagrammatic illustration of consumer surplus.

hatchery produced salmon reaches the final consumer in the form of fresh or frozen instead of canned. As explained earlier, the use of a demand curve to measure consumer surplus enforces the assumption of constant marginal utility of money which is restrictive. But, according to some economists, it may be a reasonable approximation for commodities, like fish, on which the consumer spends only a small amount of his income.

Demand Analysis for Fresh and Frozen Salmon

There may exist a number of factors that possibly affect the quantity of salmon demanded by the consumers each year in U.S. The most obvious of these factors could be income, price of salmon, the price of other fish products, total landing of salmon in a given year, stocks of salmon products from the previous year, etc. However, for the purpose of this study only income and the price of salmon are considered to be the most significant variables that determine the quantity of salmon demanded. Then, the demand function for fresh and frozen salmon can be formulated in the following algebraic form:

$$Q/N = F(P, Y/N).$$

Where:

Q/N = Per capita salmon consumption in pounds

P = Real ex-vessel price of salmon in cents per pound deflated by CPI where 1967=100

Y/N = Real per capita income deflated by CPI where 1967=100

N = United States population.

Using the above variables and time series data from 1947-71 (see appendix for the basic data), a demand equation for fresh and frozen salmon is fitted as shown below.

$$\text{(30)} \quad \text{Log}(Q/N) = -1.1943 \; -1.6155\text{Log}(P) + .76082\text{Log}(Y/N).$$
$$\qquad\qquad\qquad\qquad (-3.3167) \qquad\qquad (1.79)$$

Log denotes logarithm to the base ten. The numbers in the brackets are the t-value for the coefficients of the price and income variables. The coefficients of price and per capita income have the expected signs and are statistically significant (one-tailed test) at the 95 percent probability level. The R^2 statistic for the demand equation is .61. The demand curve in Figure 5 is plotted using the demand equation above at 1973 per capita income level.

Estimation of Values and Benefit-Cost Ratios Using the Concept of Consumer's Surplus

In 1973, the real ex-vessel price of salmon (salmon price deflated by CPI where 1967=100) was 20.71 cents per pound. At this price level, using the demand equation constructed above, the

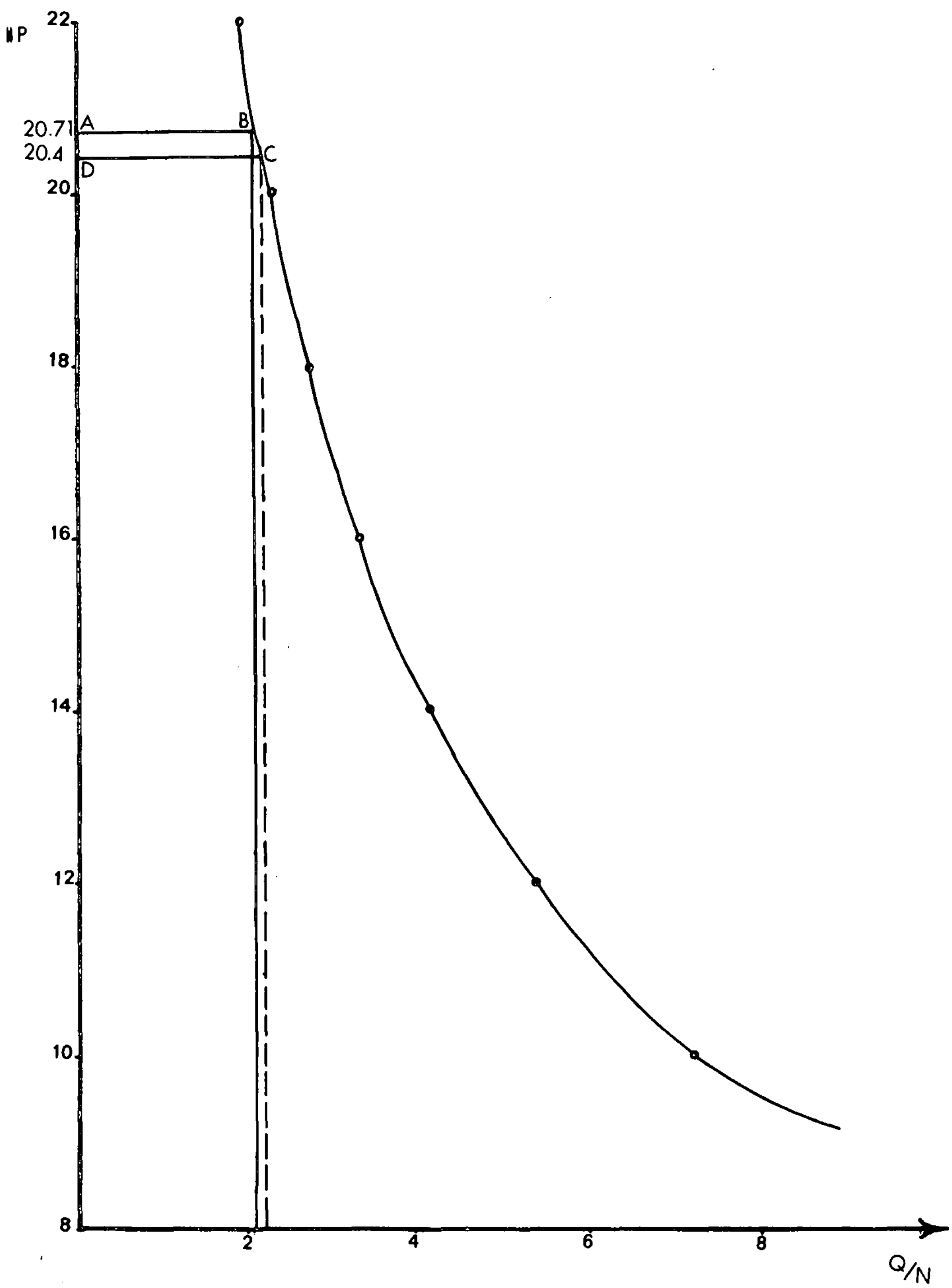


Figure 5. Demand curve for fresh and frozen salmon.

per capita consumption of salmon was predicted to be .224 pounds of salmon.. This result is also shown in Figure 5. Taking 1973 as the relevant period for the analysis, the effect of the proposed increase production of Coho salmon at Willard National Hatchery on the relationship of quantity demanded of salmon and its market price is examined in the following manner. As shown in Chapter IV, if 138, 954 additional pounds of fish food is provided to Willard Hatchery, production would be increased from 3, 112, 451 Coho to a new level of 5, 170, 000 Coho. This is a net increase of 2, 057, 549 Coho. In addition, using the information gained from the marking study, it was estimated that for every 1, 000 Coho released from the Willard Hatchery, 337.3225 pounds of Coho would be recovered in commercial and sport catches. Of this total 241.3 pounds would be caught by the commercial fishermen and 96, 0225 pounds by the sport anglers. For the purpose of this analysis, both commercial and sport caught Coho are assumed to have the same value.

Hence, utilizing the above estimates, the total increase in the production of Coho salmon from Willard National Hatchery in terms of pounds would be

$$\frac{337.3225 \cdot 2,057,549}{1,000} = 694,058 \text{ pounds of Coho,}$$

or in terms of per capita consumption,

$$\frac{694,058}{209,800,000} = .00331 \text{ pounds}$$

since the population of U.S. in 1973 was 209, 800, 000.

To show the impact of increased production of Coho salmon on the community welfare, .00331 pounds of salmon was added to .224 pounds of salmon which was the predicted level of per capita consumption in 1973. The new level of per capita salmon consumption would be .224 + .00331 = .22731 pounds of salmon. This new level of salmon consumption is then imposed on the demand equation and the price associated with such a level of per capita salmon consumption was estimated by

$$\text{Log}(.22731) = -1.1943 - 1.6155\text{Log}(P) + .76082\text{Log}(3233),$$

where real per capita income in 1973 was \$3, 233.

Under this given condition, the predicted price is found to be 20.409 cents per pound. This result implies if price had fallen enough to permit all increased production to be consumed during 1973, then the consumer's surplus would have been,

$$\frac{209,800,000\ (.22731)\ (.301)}{100} = \$143,545.8,$$

where .301 cents (20.71 - 20.409) is the expected fall in price. The above estimate corresponds to the dollar value of the consumer surplus which is the area of the trapizoid ABCD in Figure 5. However, the increase production of Coho to the new optimal level requires an additional food cost of \$26, 400. Therefore, the net benefit from Willard Hatchery due to increased production is

\$143, 545.8 - 26, 400 = \$117, 145.8, and the benefit to cost ratio from the incremental purchase of fish food would be

$$\frac{\$143,545.8}{26,400} = 5.44.$$

Although the above benefit to cost ratio is favorable, it is far below the one estimated using the linear programming analysis. This apparent conflict between the two methods of estimates poses some doubt as to the validity of the various estimates we have calculated, and the rest of this chapter is devoted in an effort to reconcile this difference.

A. To begin with, in the preceding analysis price of salmon and per capita income are expressed in real terms. This entails that the estimate of the dollar value of the consumer's surplus is also in <u>real</u> terms. But the same benefit estimated using the linear programming shows the result in current dollars. Therefore, if a fair comparison is to be made the estimated value of the consumer surplus should be expressed in gross terms. This can be done by multiplying the value of the consumer surplus by the 1973 CPI.

$$\$143,545.8 \cdot (1.33) = \$190,915.9,$$

and the benefit to cost ratio for the incremental purchase of fish food would increase to

$$\frac{\$190,915.9}{26,400} = 7.23.$$

B. So far in this chapter, the analysis was done by assuming both commercial and sport caught Coho to have equal value, and the commercial value of Coho was considered to be a representative estimate for both types of fisheries. However, this underestimates the dollar value of the consumers' welfare gain from the increased production of Coho at Willard Hatchery. This is because sport caught Coho are likely to have a higher value since sport anglers spent more time and effort to catch the fish. Any adjustment factor to correct this bias would increase the dollar value of the consumer's surplus estimated earlier.

C. In the preceding analysis, the average ex-vessel price of salmon was used to estimate the dollar value of the consumer's surplus associated with increased production of Coho at Willard Hatchery. However, in the analysis using linear programming, the ex-vessel price of Coho was used to estimate values associated with Coho production; and the ex-vessel price of Coho is found to be much higher than the average real ex-vessel price of salmon. For example, in 1973, while the real ex-vessel price of salmon was 20.71 cents per pound, the ex-vessel price of Coho salmon was 91.6 cents per pound or in real terms (91.6 ÷ 1.33) = 68.87 cents per pound. This indicates that the ex-vessel price of Coho was $\frac{68.8}{20.71}$ = 3.325 times above the average ex-vessel price of salmon.

Therefore, unless some adjustment factors are considered, the dollar value of the consumer's surplus calculated in this chapter would undoubtedly underestimate the actual welfare gain from the increase production of Coho at Willard National Hatchery. One way of reconciling the above problem could be to simply multiply the estimate of the consumer's surplus calculated earlier by 3.325, assuming the ex-vessel price of Coho is 3.325 times higher than the average ex-vessel value of salmon. The estimate of the consumer's surplus after such an adjustment would be

$$\$143,634.4 \cdot 3.325 = \$477,594.35,$$

and the benefit to cost ratio for the incremental production of Coho would be

$$\frac{\$477,594.35}{26,400} = 18.1$$

The above estimate for the consumer's surplus is in constant dollar. When converted to the current dollar value, the estimate of the consumer's surplus and the B-C ratio due to the increased production of Coho at Willard would be

$$\$477,594.35 \cdot 1.33^{*} = \$635,200.48$$

where 1.33 is the CPI for 1973 (1967=100).

$$\text{B-C ratio} = \frac{\$635,200.48}{26,400} = 24.06$$

The above values and B-C ratios for the incremental production of Coho at Willard National Hatchery are very high. However, these estimates are still below the value estimated using linear programming analysis. (In Chapter IV, using LP analysis the incremental value due to increased production of Coho was estimated to be $1, 095, 645, and the B-C ratio associated with this value was 41.5). Why does such a difference exist?

D. To answer the above question adequately one has to probe the theoretical differences between the concept of linear programming and consumer's surplus. One difference between these two methods of analysis is that when values are estimated using consumer's surplus, price of the commodity is left to move freely in accordance with demand condition. But, in linear programming analysis price is fixed at a certain level and it does not change with change in quantity. To illustrate the above concept, Figure 6 may be helpful.

Assume P_o and Q_o were the price and quantity demanded of Coho in 1973. Then, the value of the total production of Coho would be $P_o \cdot Q_o$. Now, consider that production of Coho has increased from Q_o to Q_1. If price remains constant at P_o, which linear programming analysis assumes, the total value at the new level of production would be $P_o \cdot Q_1$. Then, the difference of $P_o \cdot Q_1$ - $P_o \cdot Q_o$ is equal to the increase in value due to the change in the production of Coho from Q_o to Q_1 which is equivalent to the area ABQ_1Q_o. However, when the concept of consumer's surplus is

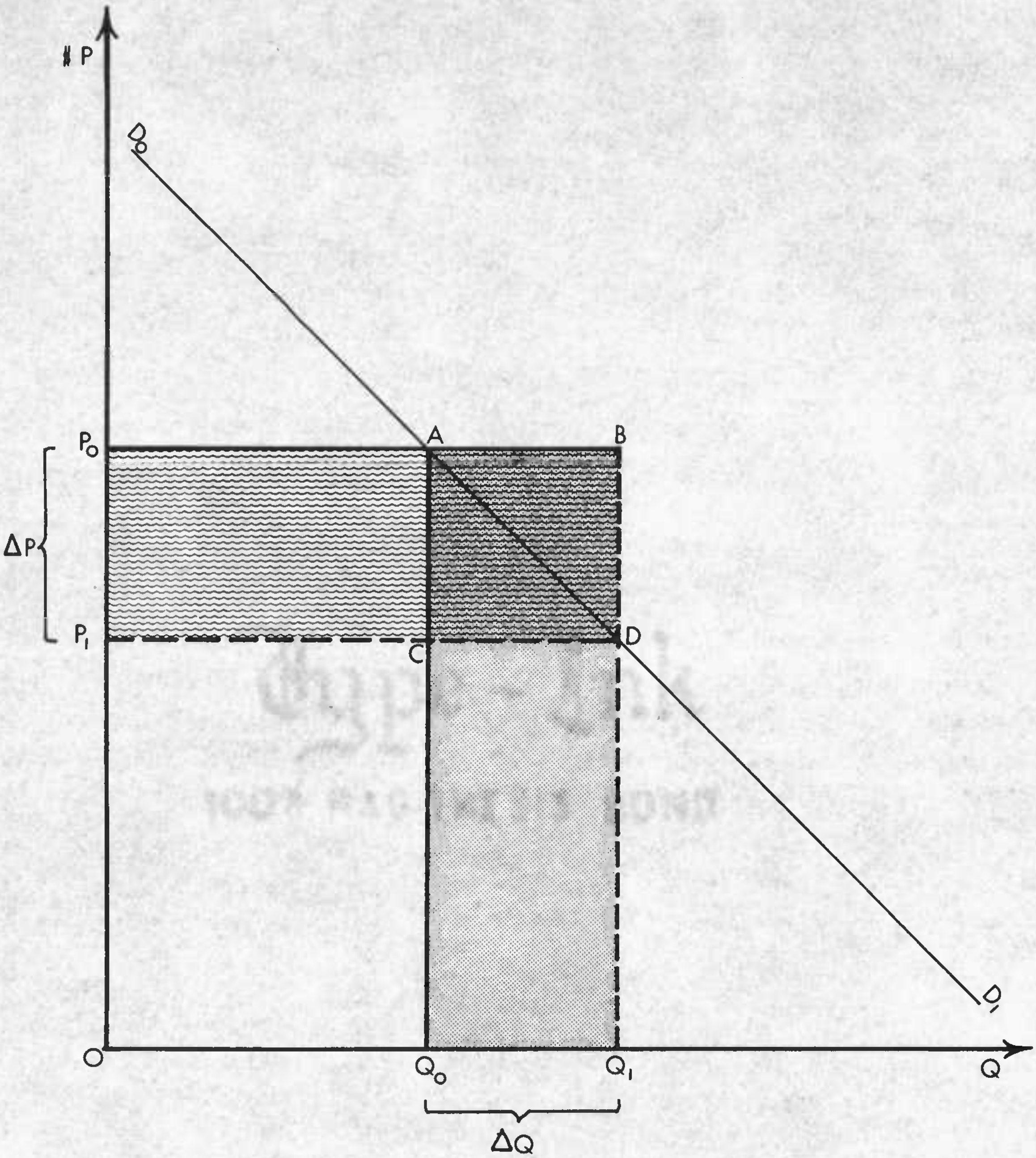


Figure 6. Diagrammatic illustration on the theoretical difference between linear programming and consumer surplus approaches in the estimation of values for the incremental production of Coho.

used, the change in production of Coho from Q_o to Q_1 will have an effect on price. From Figure 6, change in the production of Coho from Q_o to Q_1 will depress price from P_o to P_1. The value of the consumer's surplus associated with the increased production of Coho would be $\Delta P \cdot Q_1$ which is equivalent to the area of P_oP_1DB, and there is no reason to expect this area to be equal to the area ABQ_1Q_o. (Note that under this situation the consumer's surplus estimated so far is over estimated by the area ABD.)

Value and Benefit-Cost Ratio for the Total Operation of Willard Hatchery

As shown in Chapter IV, if 138, 954 additional pounds of fish food were provided to Willard Hatchery a maximum of 5, 170, 000 Coho could be produced for release. In addition, using the information gained from the marking study, it was estimated that for every 1, 000 Coho released from the Willard Hatchery, 337. 3225 pounds of Coho would be recovered in commercial and sport catches.

Thus, using the above estimates, total production of Coho salmon from Willard National Hatchery in terms of pounds would be

$$\frac{337.3225 \cdot 5,170,000}{1,000} = 1,743,957.325 \text{ pounds of Coho}$$

or in terms of per capita consumption,

$$\frac{1,743,957.325}{209,800,000} = .0083125 \text{ pounds of Coho.}$$

This result indicates that .0083125 pounds of the total per capita consumption of 1973 could have been provided by Willard National Hatchery. The per capita consumption for 1973 was predicted, using demand equation (30) to be .224 pounds and the price associated with such a level of per capita consumption was 20.71 cents per pound after being deflated by CPI where 1967=100. Now, the problem would be to investigate the impact on the ex-vessel price of salmon, assuming Willard Hatchery ceased to operate.

To see the impact of Willard Hatchery production of Coho on the community welfare, .0083125 pounds of salmon was subtracted from .224 pounds of salmon. The new level of per capita salmon consumption would be (.224 - .0083125 = .2156875) pounds of salmon. This new level of salmon consumption is then imposed on the demand equation and the price associated with such a level of per capita salmon consumption was estimated to be 21.17 cents per pound. This result implies that if Coho salmon ceased to be released from Willard Hatchery, the real ex-vessel price of salmon would have been increased by .46 cents (21.17 - 20.71). Then, the total welfare gain to the consumers due to Coho production at Willard Hatchery, after considering all the adjustment factors explained earlier, would be

$$\frac{209,800,000 \cdot .46\ (.224)\ (3.325)\ (1.33)}{100} = \$955,992.8,$$

Where:

3.325 is the adjustment factor for the difference in price for the ex-vessel price of Coho and salmon taken as a group

1.33 is the CPI for 1973 at (1967=100).

The total cost for operation at Willard for fiscal year 1973 was $197,581 as shown in Table 1, and there was $26,400 additional expenses for fish food buying. Therefore, the benefit to cost ratio for the total operation of Willard Hatchery would be

$$\frac{\$955,992.8}{\$197,581 + 26,400} = 4.268.$$

Estimation of Values and Benefit-Cost Ratio for the Operation of the Little White Salmon Hatchery

For the Little White Hatchery, as shown in Chapter IV, a maximum of 4,075,405 Coho could be produced for release for the given level of rearing space and fish food. Applying the same procedure as above total production of Coho salmon from Little White Salmon Hatchery in terms of pounds would be

$$\frac{337.3225 \cdot 4,075,405}{1,000} = 1,374,725.8 \text{ pounds of Coho,}$$

or in terms of per capita consumption:

$$\frac{1,374,725.8}{209,800,000} = .00655 \text{ pounds of Coho.}$$

.00655 pounds of Coho salmon was the contribution of Little White to the total per capita consumption of salmon. If this was not available, the real ex-vessel price for salmon would have increased by .35 (21.06 - 20.71). (The same type of procedure as for Willard is used to estimate the effect of salmon production at Little White on the ex-vessel price of salmon.) Then, the total welfare gain to the consumer due to salmon production at Little White Salmon, after considering all the adjustment factors explained earlier, would be

$$\frac{209,800,000\ (.35)\ (.224)\ (3.325)\ (1.33)}{100} = \$727,385.83$$

The total cost for operation at Little White Hatchery as shown in Table 1 is $214,910; therefore, the B-C ratio for the Little White Salmon Hatchery would be

$$\frac{\$727,385.83}{214,910} = 3.385$$

The above values and B-C ratios for the production of salmon at Willard and Little White Hatchery are quite favorable, especially since these estimates are conservative. The above estimates of values and B-C ratios are considered to be conservative because, (1) In constructing the demand equation the ex-vessel price instead of retail price was used. However, if retail price were used, it is quite possible that the consumer's surplus would have been larger.

(2) In this study only the consumer surplus was taken into consideration to estimate the values gained from the production of salmon at Little White and Willard Hatchery. But, the producer, or in this case, the fishermen, also get surplus from the production of salmon at Willard and Little White Hatchery which are not considered in the present analysis. (3) Finally, it was assumed that the sport-caught salmon had only the same value as the commercial which would underestimate the dollar value of the consumer's welfare gain from the production of salmon for the sport fishery. Therefore, the values and benefit-cost ratios estimated by using consumer's surplus are conservative. Nevertheless, the benefit-cost ratios computed by the consumer surplus method are quite favorable, indicating a high return per dollar expended at the Willard and Little White Hatcheries.

VI SUMMARY AND CONCLUSION

Due to expansion in the use of the Columbia River for water projects, especially dams for power and other uses, valuable stocks of Pacific salmon and steelhead trout have been depleted through the loss and deterioration of natural stream habitat. In an attempt to overcome the above problem and enhance the production of salmon and steelhead in the Columbia River Basin, a number of public programs have been instituted. Among the programs considered was the construction of hatcheries for artificial propagation of fish in order to compensate for the loss of salmon production due to the deterioration of the natural stream.

However, development and maintenance of hatcheries involve a substantial amount of public investment. In order to justify continuing public support, the costs associated with hatchery operation should be maintained at a minimum for a given output to avoid misallocation of public resources. Hence, the primary objective of this thesis has been to investigate the various possible alternative conditions that could direct the operation of hatchery at minimum cost.

The total cost allocated for fish food buying represents over one-third of the total expenditure for any given hatchery. In fiscal year 1974, the total cost of fish food for the 22 hatcheries in the Columbia River Basin was approximately $1, 061, 021. (This figure was obtained from the annual report of each hatchery for 1974 fiscal year.) Since the cost of fish food is the major variable cost in any hatchery operation, special interest was given to see if any possible saving could be attained by means of least cost rations. In Chapter III, using linear programming it was shown that the cost of fish food could be substantially reduced. For example, if the ration considered under model II is to be used, assuming the same level of expenditure for fish food as that of 1974, a saving of approximately $70, 000 is possible. In addition, since the ration considered under model II has a higher nutritional quality than the ration in use at the present time, it could enhance the growth of salmon smolts.

Furthermore, in Chapter IV using linear programming analysis, various alternative conditions that could increase the benefit accruing from hatchery operation were examined. For purposes of this study the Little White Salmon and Willard National Fish Hatchery were selected. At least from the standpoint of these two hatcheries, it was observed that reduction of expenditure by decreasing funds available for fish food is contrary to cost-minimization objectives. This is because, as shown in Figure 3, the average total cost per pound of fish produced decreases with an increase in fish production implying increasing returns from fish food expenditure. In this study it was shown that the average cost per pound of fish produced could be lowered by about 18 percent with an increase in production by 30 percent over the usual production levels, assuming the fish are not overly crowded to adversely affect survival after release.

Using the data from the marking study and the estimated price of both the commercial and sport-caught fish, total benefits for a given hatchery were calculated. Then, the total benefits estimated by the above method were compared against the total cost to come up with the benefit to cost ratios for the hatcheries under consideration. The estimated benefit to cost ratios for the two hatcheries considered in this study (Little White and Willard) 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 the rearing ponds. Especially 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 in rearing ponds.

Extending the analysis further, in Chapter V, the concept of consumer's surplus was used to test the validity of the benefit-cost ratio estimated by the use of linear programming analysis. Using the concept of consumer's surplus, 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 3.385 to 4.268. It should be noted that the values and benefit-cost ratios estimated by consumer's surplus are quite conservative (for reasons explained earlier). Nevertheless, the benefit-cost ratios computed by the consumer's surplus method are quite favorable, indicating a high return per dollar expended at the Willard and Little White Hatcheries.

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APPENDIX

Table 3-A. Estimated Number of Marked Fall Chinook of 1961 Brood in Catches

		Ad-Rm				Ad				
Regions	Fisheries	1963	1964	1965	1966	1963	1964	1965	1966	
Alaska	Commercial	-	-	7	-	-	2	23	2	
British Columbia	Commercial	-	4106	1871	235	-	566	370	68	
Washington	Sport	375	1681	416	67	196	224	104	15	
Washington	Commercial	-	3241	455	41	3	397	59	8	
Oregon	Sport	-	72	26	-	-	93	16	-	
Oregon	Commercial	-	324	10	-	-	45	12	-	
California	Sport	-	-	-	-	-	-	-	-	
California	Commercial	-	23	-	6	-	-	4	-	
Subtotal	Sport	375	1753	442	67	196	317	120	15	
Subtotal	Commercial	-	7694	2343	282	3	1010	468	78	
Columbia R. fisheries	Sport	-	7	-	-	-	14	-	-	
	Commercial	72	2151	3544	176	76	297	92	24	
Total	Sport	375	1760	442	67	196	331	120	15	3, 306
	Commercial	72	9845	5887	458	79	1307	560	102	18, 310
										21, 616

Source: (22)

Table 3-B. Estimated Number of Marked Fall Chinook of 1962 Brood in Catches

		Ad-Lm				Ad				
Regions	Fisheries	1964	1965	1966	1967	1964	1965	1966	1967	
Alaska	Commercial	-	-	5	2	-	9	13	-	
British Columbia	Commercial	51	1183	822	48	8	368	254	45	
Washington	Sport	163	540	108	27	35	167	48	-	
	Commercial	8	973	130	4	-	168	28	-	
Oregon	Sport	-	12	-	-	3	21	-	-	
	Commercial	2	25	3	-	-	18	3	-	
California	Sport	-	-	-	-	-	8	-	-	
	Commercial	-	6	-	-	-	67	2	-	
Subtotal	Sport	163	552	108	27	38	196	48	0	
	Commercial	61	2187	960	54	8	630	300	45	
Columbia R. Fisheries	Sport	12	8	-	-	-	-	-	-	
	Commercial	38	1208	606	24	4	18	79	-	
Total	Sport	175	560	108	27	38	196	48	-	1152
	Commercial	99	3395	1566	78	12	648	379	45	6222
										7374

Source: (19)

Table 3-C. Estimated Number of Marked Fall Chinook of 1963 Brood in Catches

		Ad-Rm				Ad				
Regions	Fisheries	1965	1966	1967	1968	1965	1966	1967	1968	
Alaska	Commercial	-	-	9	-	-	19	5	-	
British Columbia	Commercial	55	4483	2246	201	7	434	280	42	
Washington	Sport	1189	2569	451	46	107	288	31	5	
	Commercial	5	3227	464	10	-	178	31	2	
Oregon	Sport	-	193	72	0	0	23	25	-	
	Commercial	4	459	92	3	-	42	15	-	
California	Sport	-	-	-	-	-	7	-	-	
	Commercial	-	12	12	15	-	33	7	-	
Subtotal	Sport	1189	2762	524	46	107	318	56	5	
	Commercial	64	8171	2823	229	7	706	338	44	
Columbia R. fisheries	Sport	-	-	-	-	-	-	-	-	
	Commercial	121	1182	2418	317	3	104	121	29	
Total	Sport	1189	2762	524	46	107	318	56	5	5,007
	Commercial	185	9363	5241	546	10	810	459	73	16,687
										21,694

Source: (2)

Table 3-D. Estimated Number of Marked Fall Chinook of 1964 Brood in Catches

Regions	Fisheries	1966	1967	1968	1969	1966	1967	1968	1969	
Alaska	Commercial	-	-	-	-	-	-	-	-	
British Columbia	Commercial	10	1339	1446	92	6	270	331	7	
Washington	Sport	483	1509	249	-	112	175	126	-	
	Commercial	4	2268	354	3	28	217	76	-	
Oregon	Sport	151	178	21	-	10	48	23	-	
	Commercial	-	436	149	-	-	72	41	-	
California	Sport	-	-	1	-	-	-	-	-	
	Commercial	-	-	-	-	-	10	3	-	
Subtotal	Sport	634	1684	271	-	122	223	149	-	
	Commercial	14	4043	1949	95	34	569	451	-	
Columbia R. fisheries	Sport	-	-	-	-	-	-	-	-	
	Commercial	19	1001	1204	171	9	39	110	27	
Total	Sport	634	1684	271	-	122	223	149	-	3, 083
	Commercial	33	5044	3153	266	43	608	561	34	9, 742
										12, 825

Source: (20)

Table 4. Estimated Numbers, Marked Ratio, and Survival Rate of Fall Chinook Salmon Released From Study Hatcheries for 1961-64 Broods

Brood year	Mark	Marked release	Marked and unmarked release	Marked/unmarked ratio	Survival rate
1961	Ad-Rm	5,446,439	53,653,214	0.1193	0.75
1962	Ad-Lm	5,249,079	52,470,003	0.1163	0.50
1963	Ad-Rm	5,986,464	60,112,063	0.1153	0.39
1964	Ad-Lm	4,638,237	46,778,552	0.1175	0.471

Sources: (2, 19, 20, 21, 22)

Table 5. Estimated Average Weight in Pounds of Fall Chinook by Age, Brood Year and Fisheries

Fisheries	Brood year 1961			Brook year 1962			Brood year 1963			Brood year 1964		
	Year	Age	Weight (lbs)	Year	Age	Weight (lbs)	Year	Age	Weight (lbs)	Year	Age	Weight (lbs)
Commercial (ocean)	1963	2	4.00	1964	2	6.31	1965	2	6.43	1966	2	5.93
	1964	3	8.45	1965	3	10.42	1966	3	8.55	1967	3	9.43
	1965	4	15.29	1966	4	13.90	1967	4	13.49	1968	4.	12.15
	1966	5	18.71	1967	5	22.29	1968	5	21.30	1969	5	20.78
Columbia River commercial	1963	2	6.11	1964	2	7.14	1965	2	6.07	1966	2	5.39
	1964	3	17.98	1965	3	19.78	1966	3	18.29	1967	3	17.50
	1965	4	26.10	1966	4	23.91	1967	4	24.41	1968	4	22.43
	1966	5	28.13	1967	5	28.06	1968	5	27.61	1969	5	27.50

Sources: (2, 19, 20, 21, 22)

Estimation of Total Catches of Fall Chinook for Each of the Four Brood Years Under Consideration

Using the estimating procedure outlined under the marking study, we can estimate the number of marked and unmarked fall Chinook in catches for each of the four brood years. The information needed to calculate the total number of fall Chinook in catches for each brood year are: The total number of marked fish in catches (Tables 3A-3D); the marked to unmarked ratio at release, and relative survival of marked fish for each one of the brood years under consideration (Table 4). Using the information from the table referred to above, total catches of Chinook for each brood year could be estimated in the following way:

1) Estimated number of marked and unmarked fall Chinook (Ad-Rm mark) of 1961 brood in catches,

$$\text{Commercial} = \frac{18,310}{(.75)\,(.1193)} + 18,310 = 222,917.0 \text{ fish}$$

$$\text{Sport} = \frac{3,306}{(.75)(.1193)} + 3,306 = 40,253.0 \text{ fish}$$

Total .... = 263,190.0 fish.

2) Estimated number of marked and unmarked fall Chinook (Ad-Lm mark) of 1962 brood in catches,

Commercial $= \frac{6,222}{(.5)(.1163)} + 6,222 = 113,222.0$ fish

Sport $= \frac{1,152}{(.5)(.1163)} + 1,152 = 20,963.0$ fish

Total .... 134, 185. 0 fish.

3) Estimated number of marked and unmarked fall Chinook (Ad-Rm mark) of 1963 brood in catches

Commercial $= \frac{16,687}{(.39)(.1153)} + 16,687 = 387,756.0$ fish

Sport $= \frac{5,007}{(.39)(.1153)} + 5,007 = 116,148.0$ fish

Total .... = 504, 104. 0 fish.

4) Estimated number of marked and unmarked fall Chinook (Ad-Lm mark) of 1964 brood in catches

Commercial $= \frac{9,742}{(.471)(.1175)} + 9,742 = 185,781.0$ fish

Sport $= \frac{3,083}{(.471)(.1175)} + 3,083 = 58,793.0$ fish.

Value Estimation of Fall Chinook

1) Value estimation of fall Chinook for sport catches: Utilizing the information obtained from the preceding calculations and combining this information with that in Table 4, we can calculate the total average sport catch per 1, 000 fish released as follows:

$$* \quad \frac{\text{Total number of sport catch}}{\text{Total number of fish released}} \times 1,000$$

<u>Brood Year</u>

1961 $= \frac{40,253}{53,653,214} \times 1\ 000 = .75$

1962 $= \frac{20,963}{52,470,003} \times 1,000 = .40$

1963 $= \frac{116.349}{60,112,063} \times 1,000 = 1.94$

1964 $= \frac{58,793}{46,778,552} \times 1,000 = \underline{1.26}$

Total for all brood years .... $= 4.35$.

* Thus, total average sport catch per 1, 000 fish released equals to $4.35 \div 4 = 1.085$.

In earlier years the Little White Hatchery released their fish at 122 fish per pound. However, they now plan to release larger fish, 100 fish per pound. Therefore, an adjustment factor is introduced to account for the larger fish. This is shown as

$$\frac{122}{100} \times 1.085 = 1.324/1,000 \text{ fish released.}$$

* Thus, the estimate for the average number of fall Chinook caught by sport anglers was 1. 324 per 1, 000 fish released.

Going one step further, and assuming the value of the sport catch to be $20 per fish, the dollar value of fall Chinook per 1, 000 fish released is estimated to be

* $1.324 \times \$20 = \$26.48$.

2) Value Estimation of Fall Chinook for Commercial Catches: The average value of commercial catch per 1, 000 fall Chinook smolts released from the Little White Hatchery can be estimated in the same manner as we did for the sport catches above. However, in calculating the commercial value of Chinook we need to express the final result in term of pounds since the available price figures for commercial catch fall Chinook are expressed in terms of dollars per pound.

Thus, to fulfill the above requirement, the data relating to the commercial catches on Tables 3A-3D are multiplied by the corresponding weight figures from Table 5. Out of this computation, the average commercial catch per 1, 000 fall Chinook released was estimated to be 56.66 pounds.

Again, accounting for the variation on the number of fish released per pound from Little White Salmon Hatchery, the adjusted estimate for the average commercial catch per 1, 000 fall Chinook released to be was,

$$\frac{122}{100} \times 56.66 = 69.125 \text{ pounds,}$$

of this total 30.17 were commercially caught from the ocean and 26.49 from the Columbia River commercial fishing.

Estimation of a Weighted Average Commercial Price

Given: Average price of ocean commercial = \$1.30/lb

Average price of Columbia River commercial fishery = \$1.00/lb.

In addition, the total average commercial catch from the ocean was computed to be 30.17 per 1,000 fish released, and 26.49 per 1,000 fish released from the Columbia River commercial fishing.

Once these figures are known, what is left is to compute a simple weighted commercial price as follows

$$* \quad \frac{2,649}{5,666} \times \$1.0 + \frac{3,017}{5,666} \times \$1.30 = \$1.16/\text{lb}$$

Finally, combining all the preceding estimated catches and values, an average value per 1,000 released fall Chinook smolts from the Little White Salmon Hatchery is computed to be

$$* \quad \$1.16\ (69.125) + \$20\ (1.324) = \$107.0.$$

Estimated Catch of 1965 and 1966 Brood Hatchery Coho Salmon

	1965-Brood	1966-Brood[a]
Total sport fish in catches	298, 198	283, 523
Total commercial fish in catches	799, 537	734, 809
Total fish released	22, 932, 496	17, 167, 744

[a] The data of the above chart is extracted from BioEconomic Contribution of Columbia River Hatchery Coho Salmon 1965 and 1966 Broods.

Value Estimation of Coho

Applying the same procedure as before, we can compute the average sport and commercial catch of Coho per 1,000 fish released as follows:

Brood year

1965 Sport catch $= \frac{298,198}{22,932,496} \times 1,000 = 13.003$

1966 Sport catch $= \frac{283,523}{17,167,744} \times 1,000 = 16.51$

Total .... 29.513 fish.

* Therefore, total average sport catch per 1,000 fish released equals to $\frac{29.513}{2} = 14.75.$

Assuming the value of sport catch to be $20 per fish, then, the dollar value of the above result would be

* $20 (14.75) = $295.00 per 1,000 fish released.

Brood year

1965 Commercial catch $= \frac{799,537}{22,932,496} \times 1,000 = 34.86$

1966 Commercial catch $= \frac{734,537}{17,167,744} \times 1,000 = 42.80$

However, in this case we have to change the above results to pounds. The additional information needed to do this is the average weight of the fish for each brood year. This information is obtained from the hatchery study and the respective weight of the fish for the two brood years is 5.89 lbs and 6.48 lbs.

<u>Brood year</u>

1965	34.86 x 5.89 = 205.32 lbs
1966	42.80 x 6.48 = <u>277.34</u> lbs
Total	= 482.66 lbs

* Thus, the average commercial catch per 1,000 Coho released was estimated to be

$$\frac{482.66}{2} = 241.3 \text{ lbs.}$$

Furthermore, the weighted average commercial price of Coho was estimated to be $0.916/lb.

Finally, from the preceding estimated catches and values an average value per 1,000 released Coho smolts was estimated to be

$$\$0.916\ (241.3) + \$20\ (14.75) = \$516.05.$$

Table 6. Data Used to Estimate the Demand Equation 30.

Year	(A) Ex-vessel price of salmon deflated by CPI where 1967=100	(B) Per capita consumption of salmon (in pounds)	(C) Gross U.S. disposable income (bil. $)	(D) U.S. population (in millions)
1947	12.92	.311	169.8	144.4
1948	14.00	.232	189.1	146.6
1949	14.74	.275	188.6	149.1
1950	16.06	.240	206.9	151.7
1951	17.89	.275	226.6	153.8
1952	15.97	.255	238.3	156.5
1953	14.55	.268	252.6	159.3
1954	16.31	.253	257.4	161.7
1955	18.00	.241	275.3	165.1
1956	19.12	.174	293.2	168.4
1957	17.63	.190	308.5	171.1
1958	17.22	.207	318.8	173.9
1959	20.29	.168	337.3	176.8
1960	21.39	.129	350.0	180.6
1961	18.70	.179	364.4	182.7
1962	19.77	.140	385.3	186.4
1963	18.16	.193	404.6	188.6
1964	17.10	.179	438.1	191.6
1965	21.07	.189	473.2	193.7
1966	19.49	.181	511.9	196.1
1967	22.40	.171	546.3	197.7
1968	19.55	.182	591.0	199.0
1969	21.38	.202	634.4	202.0
1970	20.69	.251	691.7	203.6
1971	20.54	.375	746.0	206.1
1972	21.11	-	797.0	208.7
1973	20.71	-	882.6	209.8

Sources: A and B (4, 17)
C (6, 9)
D (5, 6)